



Department of Water Affairs and Forestry

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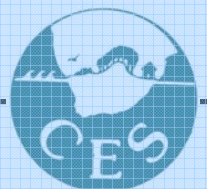


KROMME/SEEKOEI CATCHMENTS RESERVE DETERMINATION STUDY

TECHNICAL COMPONENT

EWR ESTUARY REPORT: KROMME

Coastal & Environmental Services



**KROMME/SEEKOEI CATCHMENTS RESERVE DETERMINATION STUDY
– TECHNICAL COMPONENT**

**EWR ESTUARY REPORT: FINAL
KROMME ESTUARY**

June 2006

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**DEPARTMENT OF WATER AFFAIRS and FORESTRY
DIRECTORATE: RESOURCE DIRECTED MEASURES**

**KROMME/SEEKOEI CATCHMENTS RESERVE DETERMINATION STUDY
– TECHNICAL COMPONENT
EWR ESTUARY REPORT: FINAL
KROMME ESTUARY**

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EXECUTIVE SUMMARY

This technical report forms part of a series on the Kromme Estuary Reserve Determination Study for the Resources Directed Measures Directorate Project Reference No. 26/8/3/10/4. It should be noted that the following other key reports are available in the series:

- Inception Report
- Resource unit report
- Groundwater report
- EWR rivers Report
- Hydrology report
- Monitoring and Ecospecs report
- Socio-economic report
- Main report

Project Team

The core specialist team appointed for this project was as follows (* attended the specialist workshop on 23 and 24 February 2005 in Port Elizabeth):

Lead specialists	Role/Expertise	Contact details
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The following persons formed part of the project team to support capacity building in the application of Ecological Reserve determinations on Estuaries (* attended the specialist workshop on 23 and 24 February 2005 in Port Elizabeth):

Person	Role/ expertise	Contact details
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Other parties present at the Estuarine Specialist Workshop, held in Port Elizabeth on 23 and 24 February 2005 were:

Person	Affiliation/role	Contact details
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Overview of Determination of Ecological Reserve for Estuaries: Process

The preliminary determination of the Ecological Reserve can be conducted on different levels, namely:

- Comprehensive level
- Intermediate level
- Rapid level.

The procedures are discussed in detail in *Resource directed measures for protection of water resource: Methodology for the Determination of the Ecological Water Requirements for Estuaries, Version 2* (DWAF, 2004). A summary of the procedures for the determination of the comprehensive preliminary Ecological Reserve determination for estuaries, in the context of the larger process, are illustrated in the Figures A & B below:

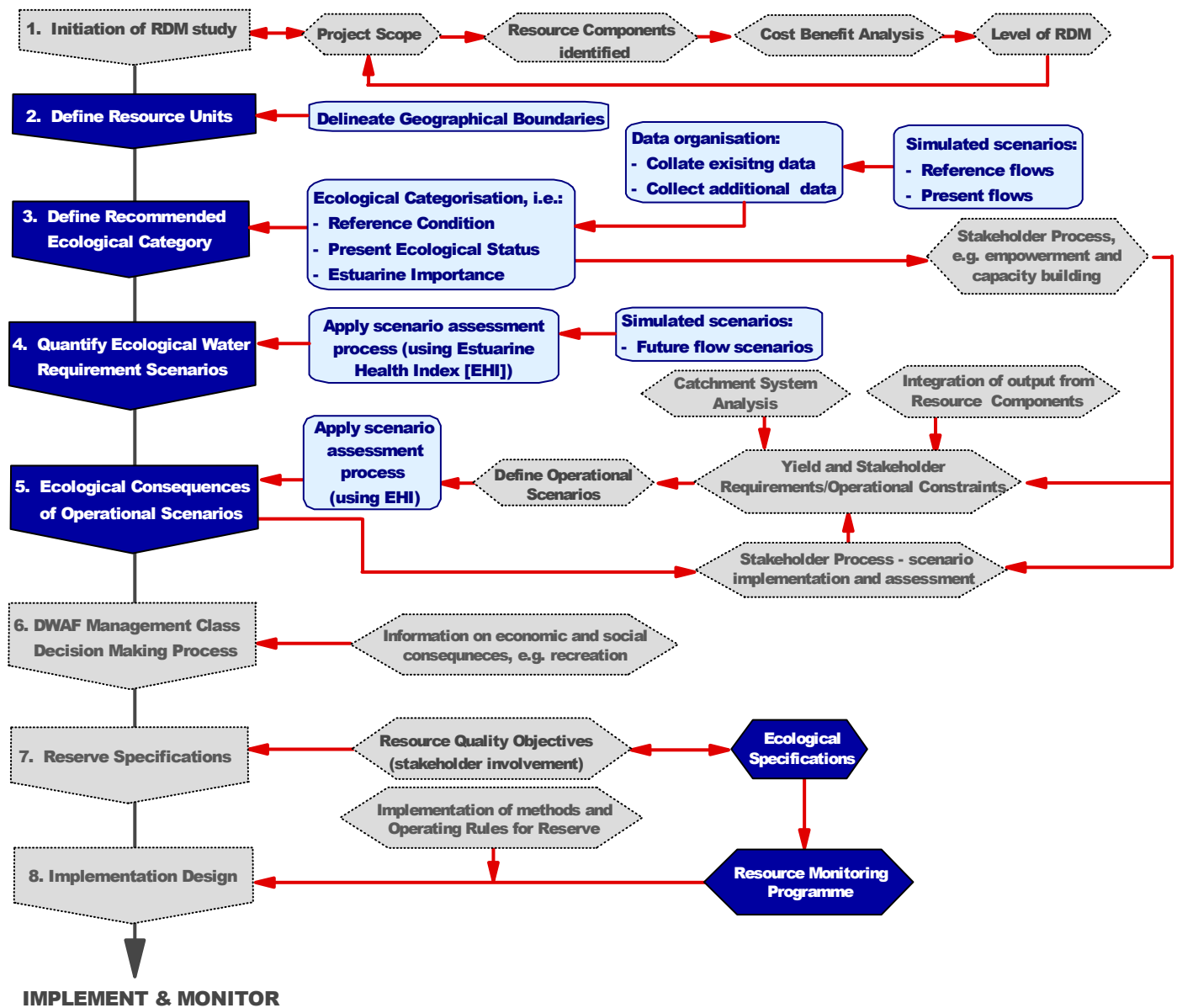


Figure A Procedures for a Comprehensive Ecological Reserve determination on estuaries, in context of the broader RDM process (components not addressed as part of the Ecological Reserve determination process are indicated by non-solid line boxes) (DWAF, 2004).

A summary of the human resources required to conduct a Comprehensive level determination of the preliminary Ecological Reserve for estuaries are illustrated in Figure B.

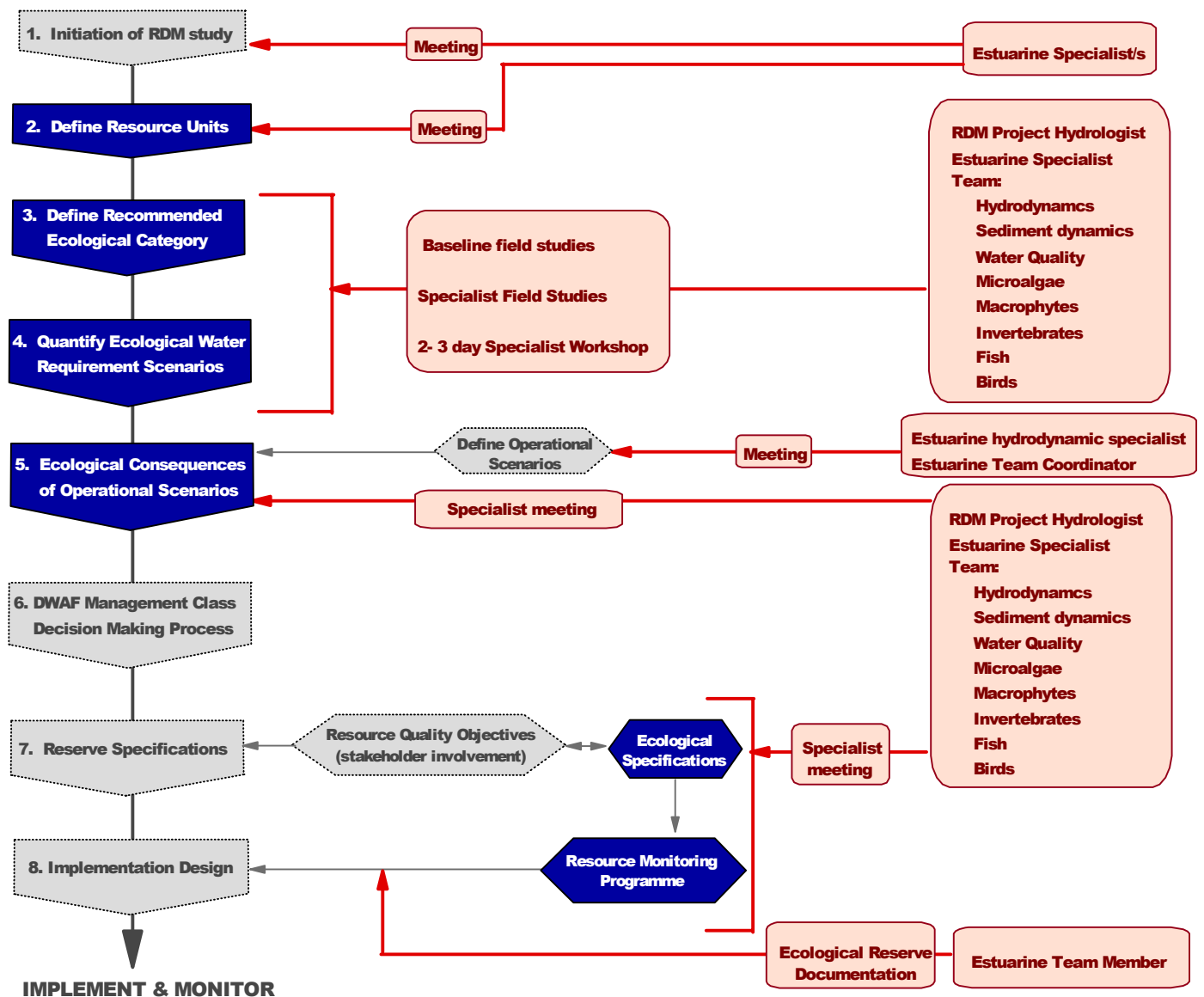


Figure B Indication of human resource requirements for a comprehensive Ecological Reserve determination on estuaries (DWAF, 2004).

Assumptions and Limitations

The following assumptions and limitations must be taken into account:

- The overall confidence in the hydrological data provided to the estuarine team by project hydrologist (Mr A Sparks, Ninham Shand Consulting Engineers, Cape Town) was low as limited accurate runoff data were available.
- The accuracy of predicted Abiotic State for the Kromme Estuary and the distribution of these states under the Reference Conditions, Present State and Future Scenarios depend largely on the accuracy of the simulated runoff data (over the 73-year period) of river inflow at the head of the estuary, provided to the estuarine team by the project hydrologist.

- Water quality data of river inflow at the head of the estuary were provided to the estuarine team by the water quality specialists who reported on the river component. However, the available data was fairly limited for the Kromme Estuary with almost no reliable time series data available for the Geelhoutboom tributary. No data were available for the Reference Condition on either these systems. For the Kromme Estuary, Reference Condition characteristics for inorganic nutrients were therefore estimated by the water quality specialists on the river component using the South African Water Quality Guidelines for Aquatic Ecosystems (DWAf, 1996), the Umgeni Water Quality Index ranges and experience in the Umgeni Water Operational Area (DWAf, 2002).
- As a result of the limited timeframe within which the Ecological Reserve study had to be conducted, and this coinciding with a relatively dry period with limited or no river inflow to the estuary, measured data from this study only represents the marine dominated phase (i.e. Abiotic State 1). The results produced need to be checked and refined once the predictions made around non marine states can be verified. It should be noted that the data collection activities within the RDM process are designed to be completed within a reasonable timeperiod (<18 months) and thus those states which occur on a temporal scale outside of 18 months are generally not sampled.
- For the purposes of the Ecological Reserve determination, it is important to be able to correlate any measured salinity information to specific river inflow patterns. Unfortunately such information was not always captured in previous studies, which made the interpretation of some of the available information difficult. Also, in some of the publications longitudinal salinity patterns were reported as depth averaged values which do not always reflect actual conditions, particularly in the deeper section in the upper estuary, where strong vertical stratification occurs during periods of freshwater inflow. The historical data sets and measurements taken as part of this study were, however, interpreted as best possible to extract the necessary information to support the predictions on the salinity characteristics of the Kromme Estuary under different river inflow scenarios.
- Most of the historical data sets on water quality, were also presented as average data, either depth averaged or averaged over seasons. For the purposes of the Ecological Reserve determination, it is important to be able to link specific water quality characteristics to corresponding salinity regimes (e.g. through plots of salinity versus nutrient concentration), which was not always possible with the manner in which historical data has been processed as part of publications. The data sets were, however, interpreted as best possible to extract the necessary information to support the predictions on water quality characteristics of the Kromme Estuary.

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

Limit	Degree of confidence
Low	If no data were available for the estuary or similar estuaries (i.e. < 40%)
Medium	If limited data were available for the estuary or other similar estuaries (i.e. 40% – 80%)
High	If sufficient data were available for the estuary (i.e. > 80%)

Geographical boundaries

For the purposes of this preliminary work on the Ecological Reserve determination of the Kromme Estuary, the geographical boundaries are defined as follows (Gauss Projection, Clarke 1880 Spheroid):

Downstream boundary: The estuary mouth (34° 08' 30"S 24° 50' 33"E)

Upstream boundary: Kromme Estuary, rocky sill 13.7 km from mouth (34° 06' 44"S 24° 43' 31"E)
Geelhoutboom Tributary (34° 06' 33"S 24° 45' 07"E)

Lateral boundaries: 5 m contour above MSL along the banks.

Present Ecological Status (PES)

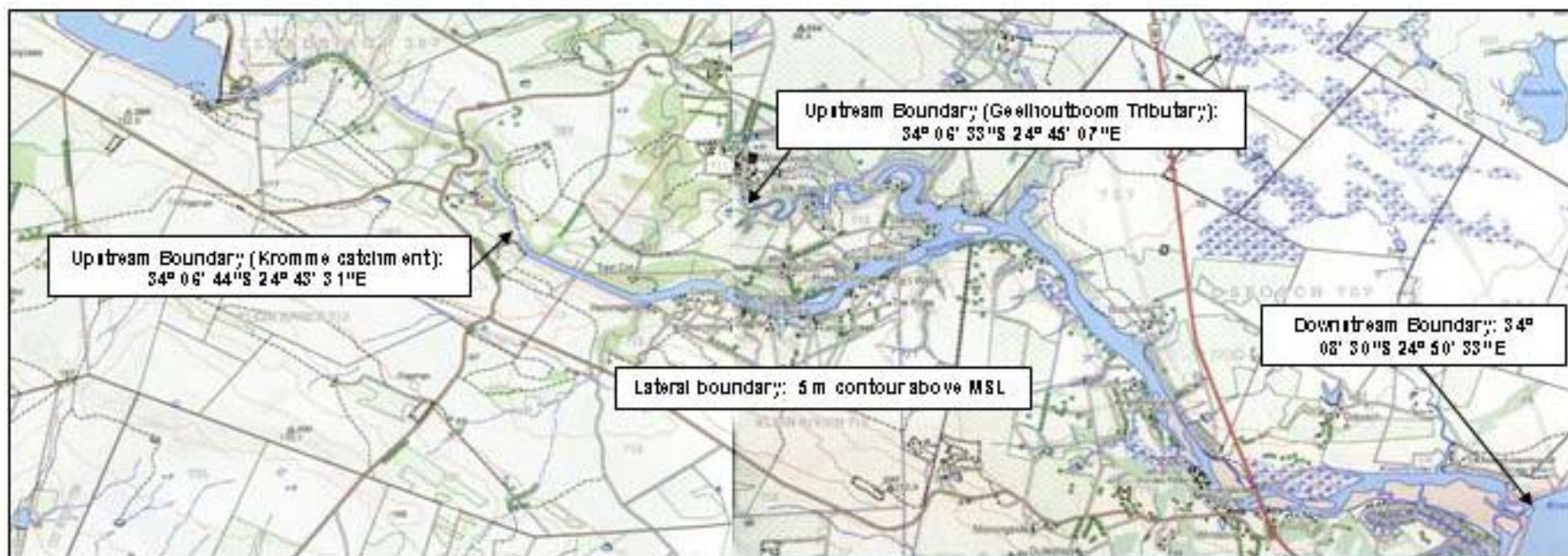
The Estuarine Health Index (EHI) scores allocated to the Kromme Estuary (Present State) were:

Variable	Weight	Score	Weighted score
Hydrology	25	33.7	8
Hydrodynamics and mouth condition	25	100	25
Water quality	25	33.2	8
Physical habitat alteration	25	70	18
Habitat health score			59
Microalgae	20	17	3
Macrophytes	20	50	10
Invertebrates	20	20	4
Fish	20	40	8
Birds	20	70	14
Biotic Health Score			39
Estuarine Health score			49

The EHI score for the Kromme Estuary, based on its Present State, is 49, translating into a Present Ecological Status of D as indicated below:

EHI score	Present Ecological Status	General description
91 – 100	A	Unmodified, natural
76 – 90	B	Largely natural with few modifications
61 – 75	C	Moderately modified
41 – 60	D	Largely modified
21 – 40	E	Highly degraded
0 – 20	F	Extremely degraded

It should however be noted that the habitat health score is far higher (59) than the Biotic health score which is a function of the stable mouth conditions that exist in the estuary. The biotic health of the estuary falls between a largely modified and highly degraded category and thus is in a poor ecological state.



Map of the Kromme Estuary

Importance of Kromme Estuary

The Estuarine Importance scores allocated to the Kromme Estuary were as follows:

Criterion	Score	Weight	Weighted score
Estuary Size	100	15	15
Zonal Rarity Type	90	10	9
Habitat Diversity	20	25	5
Biodiversity Importance	87.5	25	22
Functional Importance	60	25	15
Estuarine Importance Score			66

The Estuarine Importance Score for the Kromme Estuary, based on its Present State, is 66, indicating that the estuary is important, as indicated below:

Importance Score	Description
81 – 100	Highly important
61 – 80	Important
0 – 60	Of low to average importance

Recommended ecological category for Kromme Estuary

The recommended Ecological Reserve Category (ERC) represents the level of protection assigned to an estuary. In turn, it is again used to determine the Ecological Reserve. For estuaries the first step is to determine the 'minimum' ERC of an estuary, based on its Present Ecological Status (PES). The relationship between EHI Score, PES and ERC is set out below:

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

Note: Should the 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).

PES sets the minimum Ecological Reserve Category. The degree to which Ecological Category needs to be elevated higher than PES depends on level of **importance** and level of **protection** or **desired protection** of a particular estuary (see below).

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

* BAS = Best Attainable State

The Kromme Estuary has been targeted as a Desired Protected Area. According to the guidelines for assigning a recommended ERC, the estuary should be classified as a Category A or the Best Attainable State (BAS).

At the specialist workshop (held on 23 and 24 February 2005 in Port Elizabeth) it was concluded that the changes that are currently largely contributing to the Present State of the estuary are related to large dam developments in the catchment (e.g. Impofu Dam). At this stage, it is unlikely that these interferences could be reversed even to get it into a Category B.

In this light the workshop decided that it should be recommended that the Kromme Estuary be improved into the minimum ERC for an 'Important estuary' which is a **Category C**.

Quantification of Ecological Reserve Scenarios

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

Scenario	River		Volume (m ³ /year)
	Kromme	Geelhoutboom	
Reference	Natural Flows	Natural Flows	97 x 10 ⁶
Present	0.4 x 10 ⁶ m ³	Present inflows	35 x 10 ⁶
Scenario 1	5 x 10 ⁶ m ³ released in Nov	Present inflows	38 x 10 ⁶
Scenario 2	10 x 10 ⁶ m ³ released in Oct and Jan	Present inflows	43 x 10 ⁶
Scenario 3	0.4 x 10 ⁶ m ³ (Present inflows)	Inflows as per River Class C/D	35 x 10 ⁶
Scenario 4	5 x 10 ⁶ m ³ released in Nov	Inflows as per River Class C/D	38 x 10 ⁶
Scenario 5	7.5 x 10 ⁶ m ³ released in Oct and Nov	Present inflows	41 x 10 ⁶
Scenario 6	15.5 x 10 ⁶ m ³ released mainly in Oct – Jan	Present inflows	50 x 10 ⁶

The individual EHI scores, as well as the corresponding ERC for the different scenarios are as follows:

Variable	Weight	Present	Runoff scenario					
			1	2	3	4	5	6
Hydrology	25	33.7	38	42	35	44	38	51
Hydrodynamics/mouth condition	25	100	100	100	100	100	100	100
Water quality	25	33.2	41	47	35	42	47	62
Physical habitat alteration	25	70	70	70	70	70	70	70
Habitat Health Score	50	59	62	65	60	64	64	71
Microalgae	20	17	17	17	17	17	17	17
Macrophytes	20	50	52	56	51	54	55	65
Invertebrates	20	20	20	20	20	20	20	57
Fish	20	40	50	55	45	60	65	85
Birds	20	70	75	80	72	77	78	80
Biotic Health Score	50	39	43	46	41	46	47	61
Estuarine Health Index Score		49	53	55	50	55	55	66
Ecological Reserve Category (ERC)		D	D	D	D	D	D	C

Recommended ecological flow requirement for Kromme Estuary

The evaluation of the simulated runoff scenarios was used to derive the recommended Ecological Flow Requirement. The recommended Ecological Flow Requirement is defined as the runoff scenario (or a slight modification thereof) that represents the highest reduction in river inflow that will still protect the aquatic ecosystem of the estuary and keep it in the recommended ERC.

Therefore, **Scenario 6** is selected as the recommended Ecological Flow Requirement (Scenario) for the Kromme Estuary, with a seasonal flow distributions as summarised below:

Kromme: Summary of flow distributions ($15.5 \times 10^6 \text{ m}^3$ mainly in Oct to Jan)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	14.86	26.47	5.53	5.79	3.49	3.90	4.91	29.21	15.89	19.20	25.78	31.75
90%ile	5.62	2.14	1.11	0.80	0.54	0.60	0.69	2.93	3.13	2.63	6.26	12.01
80%ile	2.81	1.42	0.91	0.72	0.37	0.38	0.40	0.63	0.60	0.79	1.54	3.60
70%ile	2.26	1.36	0.86	0.69	0.30	0.33	0.35	0.36	0.47	0.56	0.84	0.97
60%ile	2.08	1.25	0.81	0.68	0.29	0.26	0.30	0.31	0.33	0.42	0.52	0.79
50%ile	2.02	1.19	0.81	0.66	0.26	0.25	0.27	0.27	0.31	0.36	0.42	0.66
40%ile	1.97	1.16	0.79	0.65	0.24	0.25	0.25	0.25	0.28	0.33	0.37	0.57
30%ile	1.93	1.13	0.77	0.63	0.24	0.23	0.24	0.24	0.26	0.28	0.32	0.52
20%ile	1.85	1.09	0.75	0.47	0.24	0.22	0.22	0.22	0.24	0.25	0.29	0.49
10%ile	0.40	0.42	0.33	0.27	0.23	0.08	0.08	0.08	0.12	0.17	0.25	0.34
1%ile	0.06	0.30	0.26	0.24	0.22	0.02	0.03	0.02	0.03	0.04	0.08	0.12

Geelhoutboom: Summary of flow distributions (Present State)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	1.05	1.21	0.34	0.43	0.29	0.32	0.28	1.17	0.90	1.18	1.72	2.09
90%ile	0.37	0.36	0.05	0.00	0.05	0.07	0.08	0.18	0.21	0.18	0.41	0.57
80%ile	0.24	0.11	0.01	0.00	0.00	0.01	0.04	0.07	0.10	0.11	0.17	0.22
70%ile	0.13	0.06	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.07	0.13	0.16
60%ile	0.08	0.03	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.04	0.08	0.09
50%ile	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.05	0.06
40%ile	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.03
30%ile	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02
20%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	River Inflow
State 1: Marine	< 1 m³/s
State 2: Salinity Gradient	1 – 8 m³/s
State 3: Fresh	> 8 m³/s

Hypersaline

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TERMINOLOGY AND ACRONYMS

DWAF	Department of Water Affairs and Forestry
EHI	Estuarine Health Index
ERC	Ecological Reserve Category
MAR	Mean Annual Runoff
MSL	Mean Sea Level
PES	Present Ecological Status
RDM	Resource Directed Measures
REI	River Estuary Interface
RQO	Resource Quality Objectives

1. INTRODUCTION

1.1 Background

This technical report forms part of a series on the Kromme Estuary Reserve Determination Study for the Resources Directed Measures Directorate Project Reference No. 26/8/3/10/4

1.2 Project Team

The core specialist team appointed for this project was as follows (* attended the specialist workshop on 23 and 24 February 2005 in Port Elizabeth):

Lead specialists	Role/Expertise	Contact details
Dr Angus Paterson*	Project coordination	Coastal & Environmental Services a.paterson@cesnet.co.za
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Ms Lara van Niekerk*	Hydrodynamics	CSIR, Stellenbosch, lvnieker@csir.co.za
Mr Roy van Ballegooyen	Hydrodynamics (numerical modelling)	CSIR, Stellenbosch, rvballeg@csir.co.za
Mr Piet Huizinga*	Hydrodynamics (specialist advisor)	Private consultant, p.huizinga@adept.co.za
Prof Gerrit Basson*	Sediment dynamics	University of Stellenbosch, grbasson@sun.ac.za
Dr Janine Adams*	Estuarine vegetation	Nelson Mandela Metropolitan University, janine.adams@nmmu.ac.za
Prof Tris Wooldridge*	Invertebrates	Nelson Mandela Metropolitan University, tris.wooldridge@nmmu.ac.za
Dr Alan Whitfield*	Fish	South African Institute of Aquatic Biodiversity A.Whitfield@ru.ac.za
Dr Jane Turpie*	Birds	Anchor Environmental Consultants jturpie@botzoo.uct.ac.za

The following persons formed part of the project team to support capacity building in the application of Ecological Reserve determinations on Estuaries (* attended the specialist workshop on 23 and 24 February 2005 in Port Elizabeth):

Person	Role/ expertise	Contact details
Ms Julia Beck*	Sediment dynamics	University of Stellenbosch, jsbeck@sun.ac.za
Mr Gavin Snow*	Estuarine vegetation	Nelson Mandela Metropolitan University, gavin.snow@nmmu.ac.za
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Other parties present at the Estuarine Specialist Workshop, held in Port Elizabeth on 23 and 24 February 2005 were:

Person	Affiliation/role	Contact details
Ms Delana Louw	Link to Rivers component, IWR Source-to-Sea	iwre@icon.co.za
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1.3 Overview of Determination of Ecological Reserve for Estuaries: Process

The preliminary determination of the Ecological Reserve can be conducted on different levels, namely:

- Comprehensive level
- Intermediate level
- Rapid level.

The procedures are discussed in detail in *Resource directed measures for protection of water resource: Methodology for the Determination of the Ecological Water Requirements for Estuaries, Version 2* (DWAF, 2004). A summary of the procedures for the determination of the comprehensive preliminary Ecological Reserve determination for estuaries, in the context of the broader RDM process, is illustrated in Figure 1-1.

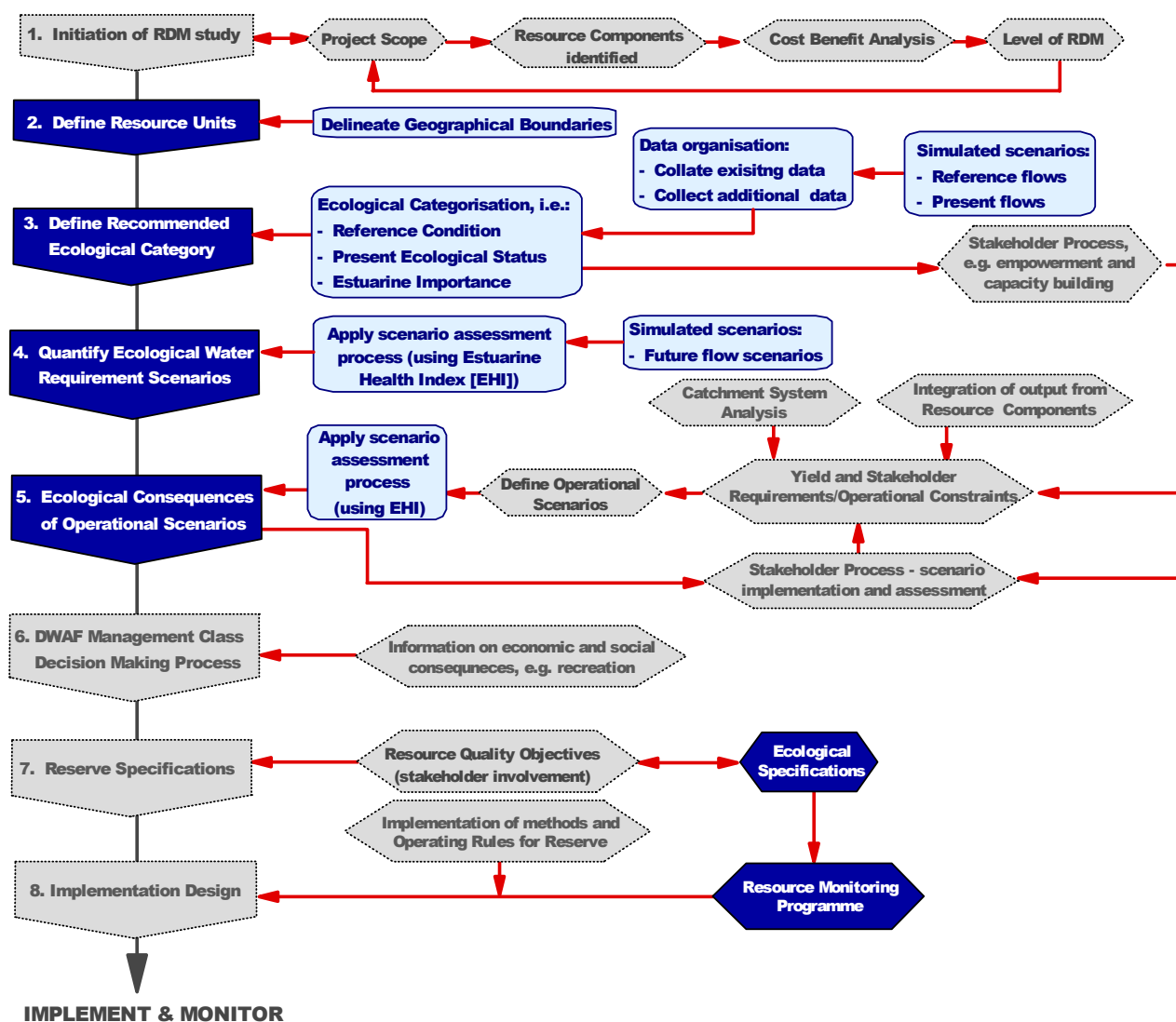


Figure 1-1 Procedures for a Comprehensive Ecological Reserve determination on estuaries, in context of the broader RDM process (components not addressed as part of the Ecological Reserve determination process are indicated by hatched line boxes) (DWAF, 2004).

A summary of the human resources required to conduct a Comprehensive level determination of the preliminary Ecological Reserve for estuaries are illustrated in Figure 1-2.

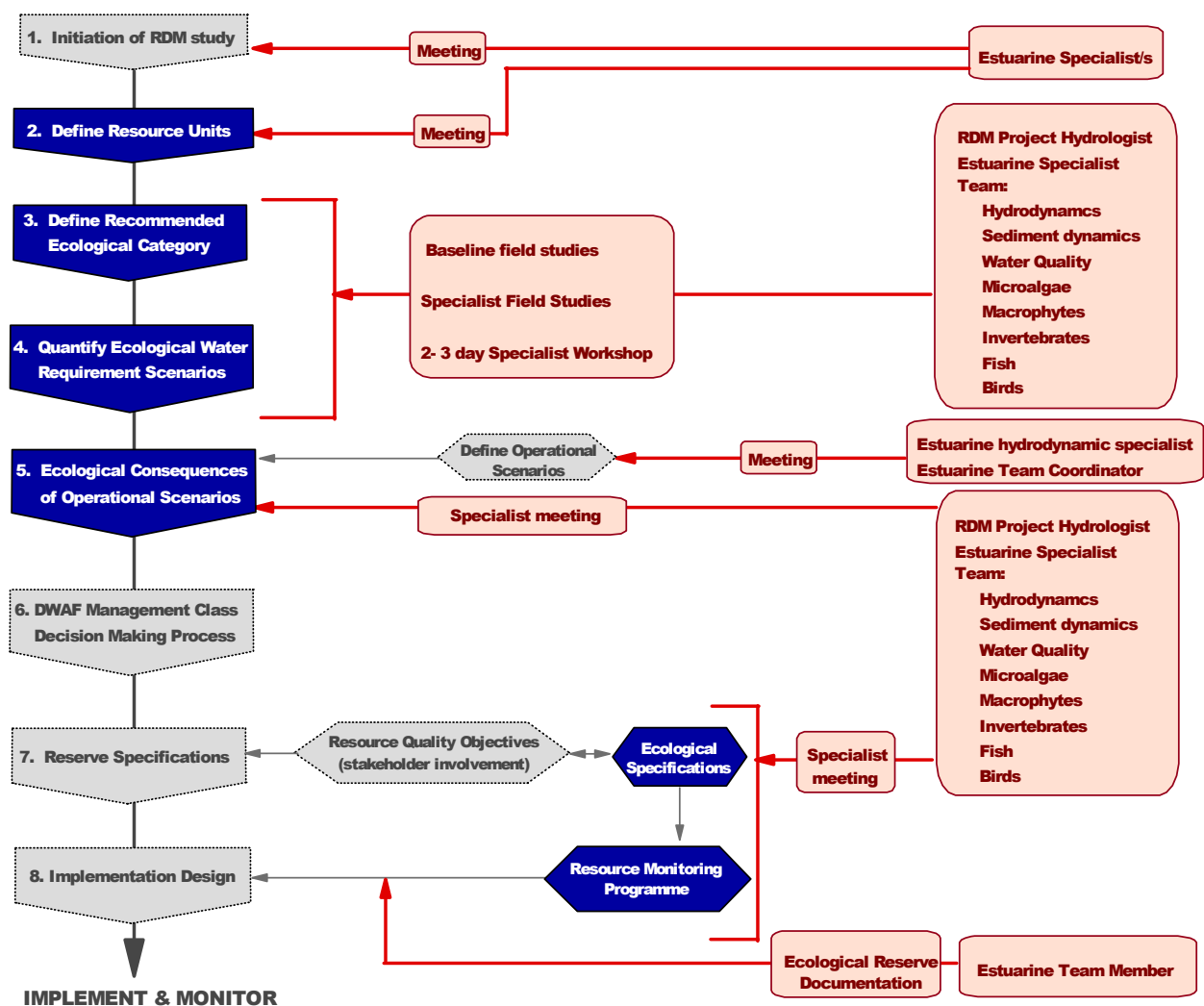


Figure 1-2 Indication of human resource requirements for a comprehensive Ecological Reserve determination on estuaries (DWAF, 2004).

1.4 Assumptions and limitations for this study

The following assumptions and limitations must be taken into account:

- The overall confidence in the hydrological data provided to the estuarine team by project hydrologist (Mr A Sparks, Ninham Shand Consulting Engineers, Cape Town) was low as limited accurate runoff data were available.
- The accuracy of the predicted Abiotic State for the Kromme Estuary and the distribution of these states under the Reference Conditions, Present State and Future Scenarios depend largely on the accuracy of the simulated runoff data (over the 73-year period) of river inflow at the head of the estuary, provided to the estuarine team by the project hydrologist.
- Water quality data of river inflow at the head of the estuary were provided to the estuarine team by the water quality specialists who reported on the river component. However, the available data was fairly limited for the Kromme Estuary with almost no reliable time series data available for the Geelhoutboom tributary. No data were available for the Reference Condition on either of these systems. For the Kromme Estuary, Reference Condition characteristics for inorganic

nutrients were therefore estimated by the water quality specialists on the river component using the South African Water Quality Guidelines for Aquatic Ecosystems (DWAF, 1996), the Umgeni Water Quality Index ranges and experience in the Umgeni Water Operational Area (DWAF, 2002).

- As a result of the limited timeframe within which the Ecological Reserve study had to be conducted, and this coinciding with a relatively dry period with limited or no river inflow to the estuary, measured data from this study only represents the marine dominated phase (i.e. Abiotic State 1).
- For the purposes of the Ecological Reserve determination, it is important to be able to correlate any measured salinity information to specific river inflow patterns. Unfortunately in previous studies such information was not always captured, which made the interpretation of some of the available published information difficult. Also, in some of the publications longitudinal salinity patterns were reported as depth averaged values which do not always reflect actual conditions, particularly in the deeper section in the upper Kromme Estuary, where strong vertical stratification occurs during periods of freshwater inflow. The historical data sets and measurements taken as part of this study were, however, interpreted as best as possible to extract the necessary information to support the predictions on the salinity characteristics of the Kromme Estuary under different river inflow scenarios.
- Most of the historical data sets on water quality were also presented as average data, either depth averaged or averaged over seasons. For the purposes of the Ecological Reserve determination, it is important to be able to link specific water quality characteristics to corresponding salinity regimes (e.g. through plots of salinity versus nutrient concentration), which was not always possible with the manner in which historical data has been processed as part of publications. The data sets were, however, interpreted as best possible to extract the necessary information to support the predictions on water quality characteristics of the Kromme Estuary.
- Criteria for the confidence limits attached to statements in this study are as follows:

Limit	Degree of confidence
Low	If no data were available for the estuary or similar estuaries (i.e. < 40%)
Medium	If limited data were available for the estuary or other similar estuaries (i.e. 40% – 80%)
High	If sufficient data were available for the estuary (i.e. > 80%)

2. DEFINITION OF RESOURCE UNIT

The Kromme River, which is approximately 85 km long, has its origin in the Tsitsikamma Mountains and drains a catchment area of approximately 936 km². The estuary of the Kromme River is a permanently open system, discharging into St Francis Bay on the east coast of South Africa approximately 80 km west of Port Elizabeth (Figure 2-1).

The mean annual precipitation in the Kromme River catchment ranges from 700 mm to 1 200 mm (Reddering and Esterhuyzen, 1983). Pitman *et al.* (1981) gives the mean annual precipitation for the upper catchment of the Kromme as 764 mm and that of the lower catchment as 636 mm. The mean annual runoff (MAR) of the Kromme River is estimated to be $105 \times 10^6 \text{ m}^3$. Little agricultural activity occurs in the catchment and it is largely limited to grazing (Reddering and Esterhuyzen, 1983; Bickerton and Pierce, 1988; Bate and Adams, 2000). Natural vegetation occurs along the upper reaches of the estuary, as well as along the banks of the Geelhoutboom tributary (Bate and Adams, 2000).

River inflow to the Kromme Estuary has been severely impacted by the building of two dams (the Churchill Dam and the Impofu Dam), that between them have a storage capacity of approximately 133% of the estimated MAR of the Kromme Estuary of $100 \times 10^6 \text{ m}^3$ (Bate and Adams, 2000; Scharler and Baird, 2000). The Churchill Dam (built in 1943), situated some 35 km upstream of the head of the estuary, has a storage capacity of $33.3 \times 10^6 \text{ m}^3$ while the Impofu Dam, situated approximately 4 km upstream of the head of the estuary, has a storage capacity of approximately $107 \times 10^6 \text{ m}^3$. The dams in the catchment are considered to attenuate all floods with a return period of less than 1 in 30 years (Bickerton and Pierce, 1988). The magnitude of large floods can also be substantially reduced depending on the volume of water in the dam when these floods occur (See Appendix D for discussion around flood dampening).

Apart from Impofu Dam overflowing during floods, the only freshwater currently supplied to the Kromme Estuary is that allocated to the estuary for ecological purposes (i.e. only floods and controlled releases of freshwater reach the estuary). This allocation is significantly less than the freshwater requirements of the estuary estimated by Jezewski and Roberts (1986) to be approximately $11 \times 10^6 \text{ m}^3$ or approximately 8.9% of the MAR. Of this total $2 \times 10^6 \text{ m}^3$ was to compensate for evaporative losses while approximately $9 \times 10^6 \text{ m}^3$ was set aside for flooding requirements.

A major tributary into the Kromme Estuary is the Geelhoutboom, entering the estuary some 7 km upstream of the mouth. There are a number of other smaller tributaries, with the largest of these being the Sand River. The Sand River drains part of a headland by-pass dune field and joins the estuary approximately 1.3 km upstream of the mouth (Bickerton and Pierce, 1988). Under natural conditions the Geelhoutboom tributary, on average, is estimated to have contributed less than 5% of the freshwater inflow into the estuary throughout the year. Under current conditions this contribution is less than 1% in mid- to late summer but typically between 10 to 30% during the remainder of the year (i.e. the peak contribution is during the early part of the wet season). Under current conditions, during dry years the Geelhoutboom tributary contribution is negligible in terms of freshwater inflow to the Kromme Estuary in the dry summer months but typically 15 to 20% during the remainder of the year. During wet years the freshwater contribution from the Geelhoutboom ranges between 5 to 10% during the rainy season in late winter to early spring to approximately 20% during the dry months in mid to late summer. The contribution from the Sand River is considered to be negligible.

For the purposes of determination of the Ecological Reserve on the Kromme Estuary, the geographical boundaries are defined as follows (Gauss Projection, Clarke 1880 Spheroid):

Downstream boundary: The estuary mouth (34° 08' 30"S 24° 50' 33"E)

Upstream boundary: Kromme Estuary, rocky sill 13.7 km from mouth (34° 06' 44"S 24° 43' 31"E)
Geelhoutboom tributary (34° 06' 33"S 24° 45' 07"E)

Lateral boundaries: 5 m contour above MSL along the banks.

In the lower reaches of the estuary (up to about 5 km from the mouth) channel depths are around 1.5 m, characterised by a sandy bottom substrate. Further upstream, the estuary becomes deeper (3 to 5 m). In the upper reaches current velocities are usually lower than 0.3 m/s, while current velocities of 1 m/s are common near the mouth. Extensive salt marshes cover the banks of the estuary in the middle and lower reaches, while the channel meanders between vegetated cliffs in the upper reaches. A marina has been developed on the west bank near the mouth.

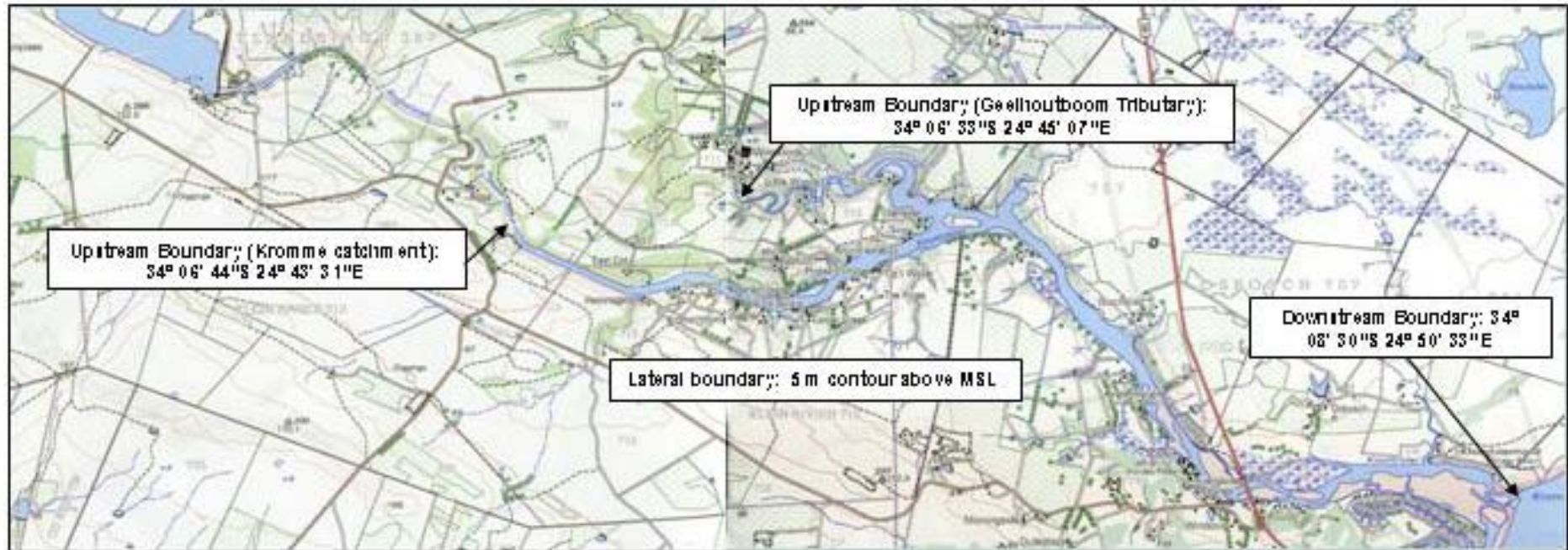


Figure 2-1 Geographical Boundaries of the Kromme Estuary

3. ECOLOGICAL RESERVE CATEGORISATION

3.1 Typical Abiotic States

River inflow into an estuary generally shows strong correlation with certain abiotic parameters, such as state of the mouth and longitudinal salinity distribution patterns. It is usually possible, in the case of a particular estuary, to link or correlate river inflow ranges to typical 'Abiotic States'.

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

- Colour coding was used for the full tables of simulated monthly river flow reaching the estuary for each scenario to highlight the occurrences of the different States for the different flow ranges. The median and 10%ile low flows for each month are summarised at the bottom of each table, as well as the occurrences of the four states for each month for the 73-year period.
- Summary tables of the occurrences of different flows at increments of 10%ile are listed separately to provide a quick comprehensive overview.
- Separate graphs are added to highlight the occurrences of the different States for each scenario for median flows and for 10%ile low flow that reflect drought conditions.

The transition between the different Abiotic States may, however, not be instantaneous, as the resultant salinity distribution patterns (and associated abiotic characteristics) are both dependent on a flow rate, as well as the duration of a particular flow rate or flow range. Nonetheless, to assess ecological consequences of different longterm flow scenarios, estimating the occurrence of different Abiotic States based on the distribution of characteristic flow ranges is considered to be a reasonable assumption.

3.1.1 Kromme Estuary

Based on available data and information, three Abiotic States have been defined for the Kromme Estuary, namely:

	River Inflow
State 1: Marine	< 1 m ³ /s
State 2: Salinity Gradient	1 – 8 m ³ /s
State 3: Fresh	> 8 m ³ /s

The abiotic characteristics associated with each of these Abiotic States are provided below:

ABIOTIC STATE 1: Marine

Typical flow patterns: River flow rates are usually less than 1 m³/s (currently measured flows during this state are often less than 0.2 m³/s, potentially resulting in hypersaline conditions).

Confidence: Medium

State of the mouth: The mouth is permanently open.

Confidence: High

Flood plain inundation patterns: This state does not result in inundation of the flood plain in the lower reaches.

Confidence: High

Amplitude of tidal variation (indicative of exposure of intertidal areas during low tide): Tidal variation could typically range between 0.3 m (neap tide) and 1.5 m (spring tide).

Confidence: High

Retention times of water masses¹: There will be high retention time of the deep water areas upstream of the confluence with the Geelhoutboom tributary. In the lower reaches, strong tidal flushing will result in much shorter residence times, typically one to two tidal cycles at spring tides.

Confidence: Medium

Total volume and/or estimated volume of different salinity ranges: Total volume on average tide is estimated at 3 x 10⁶ m³.

Confidence: Medium

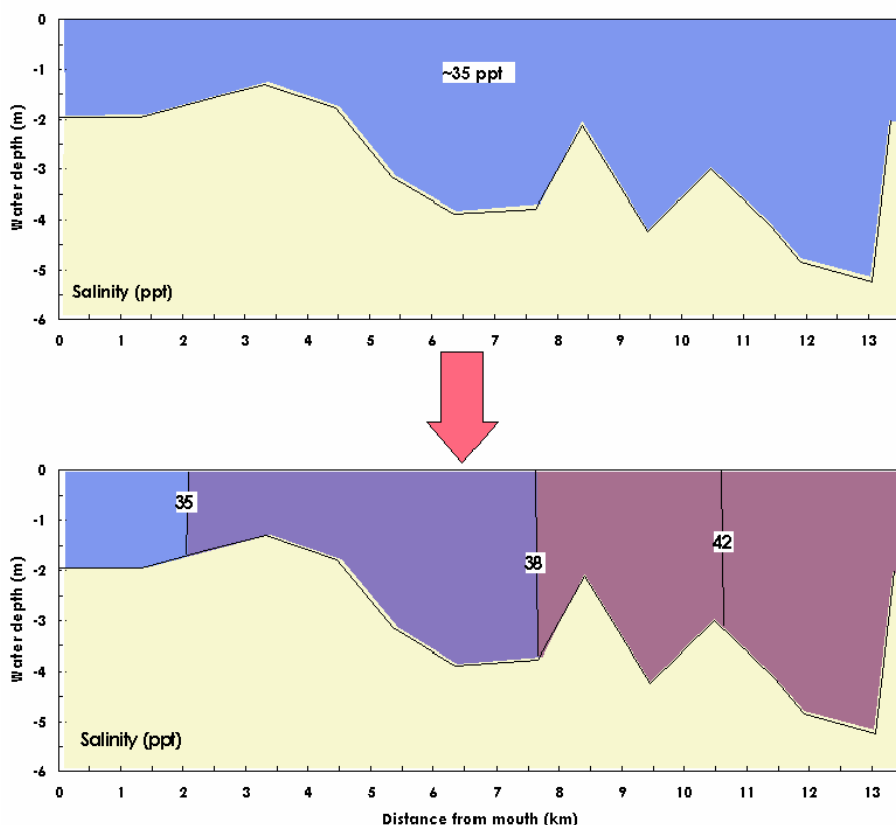
Estimated (maximum) tidal velocities² along the estuary: At the mouth the maximum tidal velocity is approximately 1 m/s, but drops upstream (less than 0.3 m/s).

Confidence: Medium

Salinity distribution in the estuary: During the marine state the estuary becomes a near homogenous water body with salinities close to that of seawater (~ 35 ppt). When river inflow into the estuary decreases to below 0.2 m³/s for more than two consecutive months during summer, hypersaline conditions start to develop in the middle and upper reaches. Salinity in the lower reaches, however, still remains similar to seawater due to tidal flushing.

¹ Retention time is the time it takes for all the water in the estuary to be exchanged.

² Tidal velocities throughout the estuary are discussed in Appendix C Table C2.



Confidence: High

System variables: Levels of system variables in the Kromme Estuary under this state is estimated as follows:

Temperature	Temperatures in the Kromme Estuary is expected to show a strong seasonal pattern, with summer temperatures ranging between 20 and 25 °C and winter temperatures between 13 and 16 °C.
pH	pH values in the Kromme Estuary are expected to remain within the range of seawater (~8).
Turbidity	Turbidity levels are expected to be low in the Kromme Estuary. Secchi disc readings ~ 1 m.
Dissolved oxygen	The Kromme Estuary should generally be well-oxygenated. Concentrations in the deeper water (e.g. in the upper reaches) may drop due to long residence times and organic decay, but levels are not expected to drop below 5 mg/l.

Confidence: Medium

Nutrients: Concentrations in the Kromme Estuary during this state are estimated as follows:

Dissolved Inorganic Nitrogen (DIN)	<50 µg/l, during the initial stages of this state concentrations can be slightly higher, between 100 - 200 µg/l
Dissolved Reactive Phosphate-P (PO₄-P)	<10 µg/l
Dissolved Reactive Silicate (SiO₄-Si)	200-900 µg/l

Confidence: Medium

ABIOTIC STATE 2: Salinity Gradient

Typical flow patterns: Flow rate is usually between 1 and 8 m³/s.

Confidence: Medium

State of the mouth: The mouth is permanently open.

Confidence: High

Flood plain inundation pattern: This state does not result in inundation of the flood plain in the lower reaches.

Confidence: High

Amplitude of tidal variation (indicative of exposure of intertidal areas during low tide): Tidal variation could typically range between 0.3 m (neap tide) and 1.5 m (spring tide).

Confidence: High

Retention time of water masses: Under the higher flow range of this State (4 - 8 m³/s), the retention time of water throughout the estuary is expected to be low, about 1-3 days. However, bottom water in the deeper section of the upper reaches may still be subject to a longer residence time. Should higher inflow rates persist for longer than a few weeks, these bottom waters will also be flushed.

Confidence: Medium

Total volume and/or estimated volume of different salinity ranges: Total volume on average tide is estimated to be 3 x 10⁶ m³.

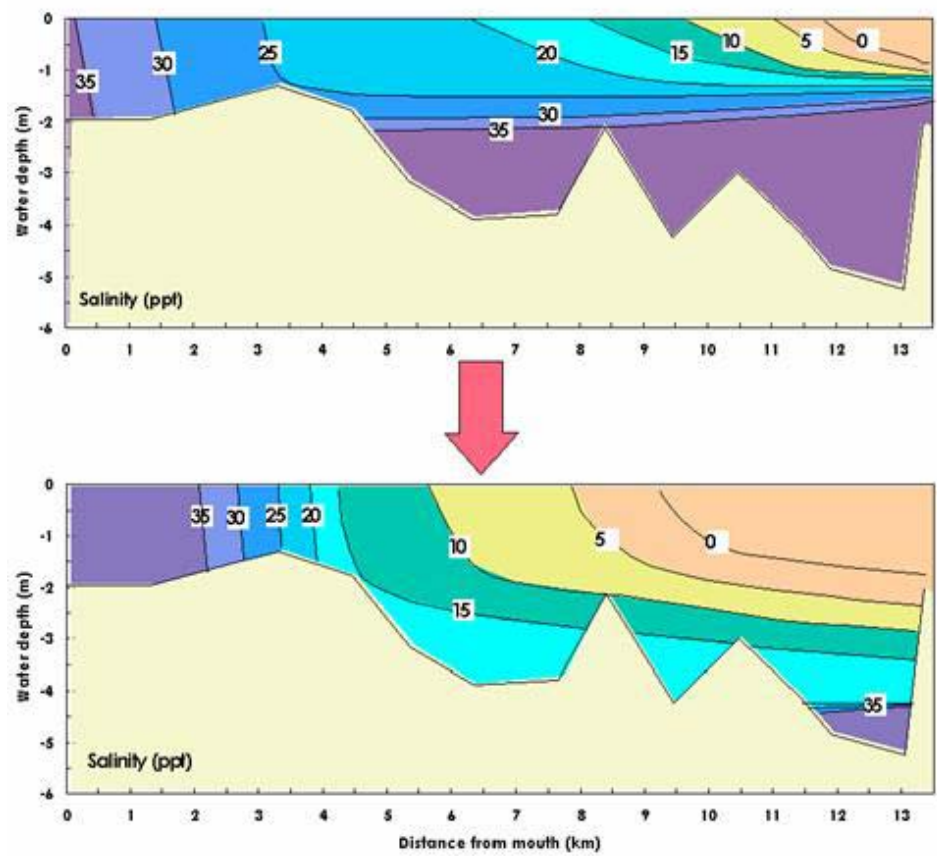
Confidence: Medium

Estimated (maximum) tidal velocity along the estuary: Tidal flow is approximately 1m/s at the mouth during spring tides and is reduced upstream.

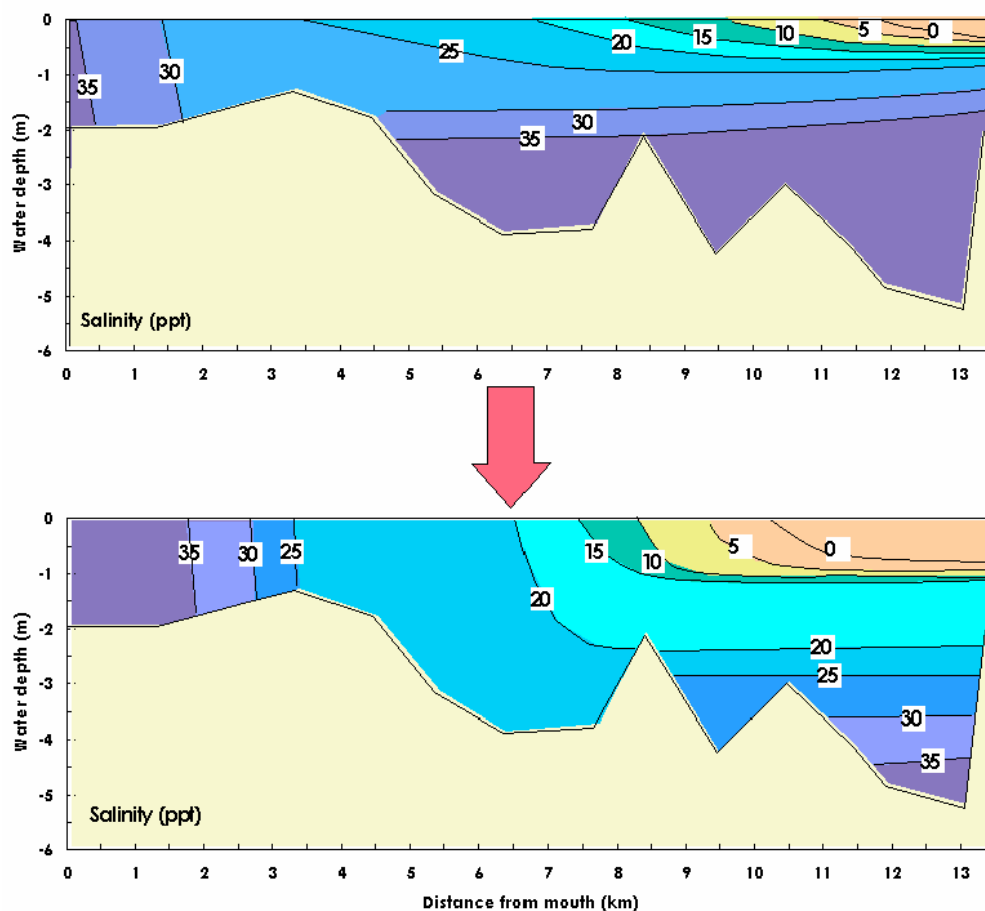
Confidence: Medium

Salinity distribution in the estuary: A salinity gradient exists in the estuary during this State, the extent of which depends on the range and duration of the flow rate. Due to the bathymetry of the estuary, salinity distribution patterns are characterised by strong vertical stratification in the deeper areas of the middle and upper reaches.

Under the higher flow range of this State (4-8 m³/s), strong vertical stratification in the middle and upper reaches will initially maintain a high salinity in deep water. However, if high flows persist, most of the saline waters in the deeper areas will also be removed (through scouring). Due to strong tidal flushing (especially during spring tide), a distinct horizontal salinity gradient will develop in the estuary, concentrated in the lower to middle reaches. The range of salinity distribution patterns under higher flow ranges of State 2 are as follows:



At the lower flow range of this State (1- 3 m³/s), strong vertical stratification in the upper to middle reaches will maintain a high salinity in deep waters. Freshwater conditions are limited largely to the surface waters of the upper to middle reaches. Strong tidal flushing maintains well-mixed saline conditions in the lower to middle reaches of the estuary.



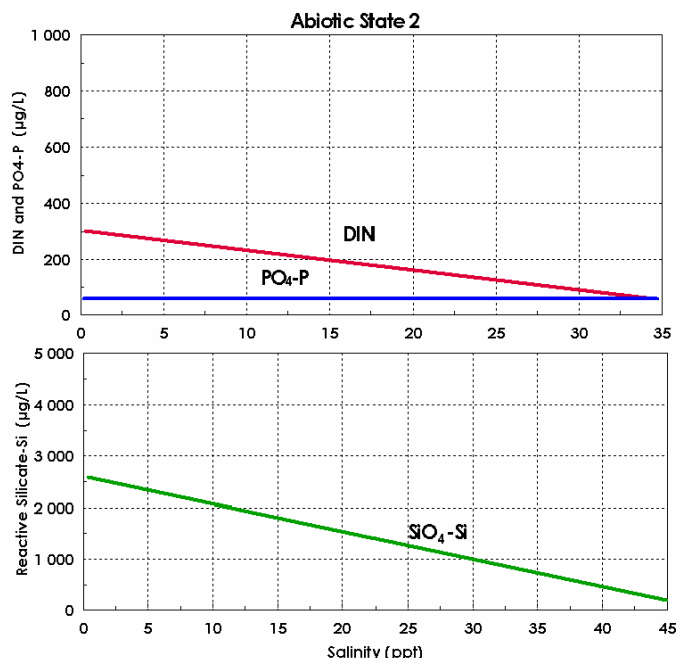
Confidence: High

System variables: Levels of system variables in the Kromme Estuary under this state are estimated as follows:

Temperature	The temperature regime of the Kromme Estuary is expected to show a strong seasonal pattern, with summer temperature ranging between 20 and 25 °C and winter temperature between 13 and 16 °C. Bottom releases from the Impofu Dam during summer months may result in low temperatures in the upper reaches of the estuary (14-18°C) unless the retention time between the dam wall and the head of the estuary is long enough for these waters to warm.
pH	pH values in the Kromme Estuary are expected to remain within the range 7 to 8.5, with the lower ranges being associated with fresher (upper) reaches and the higher range with the more saline (middle and lower) reaches.
Turbidity	Turbidity concentrations in the Kromme Estuary are generally expected to be low. However, during periods of higher freshwater inflow (either from the Geelhoutboom tributary or through releases from the Impofu Dam), turbidity levels can be expected to increase, especially in the upper and middle reaches. Although turbidity data were not available under freshwater inflow conditions, Secchi disc readings reflected a decrease in visibility from about 1 m down to about 0.3 m during periods of significant inflow.
Dissolved oxygen	The Kromme Estuary should generally be well-oxygenated. Concentrations in deeper water (e.g. in the upper reaches) can drop during the dry summer periods, as a result of long residence times and organic material decay, but levels are not expected to drop below 5 mg/l. Results from the Impofu Dam suggest that the water released from the bottom of the dam may result in the flow to the estuary being slightly less oxygenated (4–6 mg/l) than from a surface release (8–10 mg/l), unless sufficient aeration ³ occurs between the dam and the estuary.

Confidence: Medium

Nutrients: The relationship between inorganic nutrient concentration versus salinity is estimated to be as follows during State 2: Salinity Gradient:



To orientate oneself in terms of the spatial distribution of nutrient concentration along the estuary during periods of river inflow, the nutrient versus salinity plots should be compared with corresponding longitudinal salinity profiles.

Confidence: Low/Medium

³ Aeration is likely to occur during the release procedure.

ABIOTIC STATE 3: Fresh

Typical flow patterns: River inflow rates is usually greater than 8 m³/s.

Confidence: Medium

State of the mouth: The mouth is permanently open.

Confidence: High

Flood plain inundation patterns: Inundation of the flood plain in the lower reaches of the Kromme Estuary and Geelhoutboom tributary, particularly during flood events.

Confidence: High

Amplitude of tidal variation (indicative of exposure of intertidal areas during low tide): Tidal variation will typically range between 0.3 m (neap tide) and 1.5 m (spring tide).

Confidence: High

Retention times of the water mass: Under this State the retention time of water will be low, about 1-2 days. In the lower reaches, strong tidal flushing will result in a much shorter residence time, typically one to two tidal cycles.

Confidence: Medium

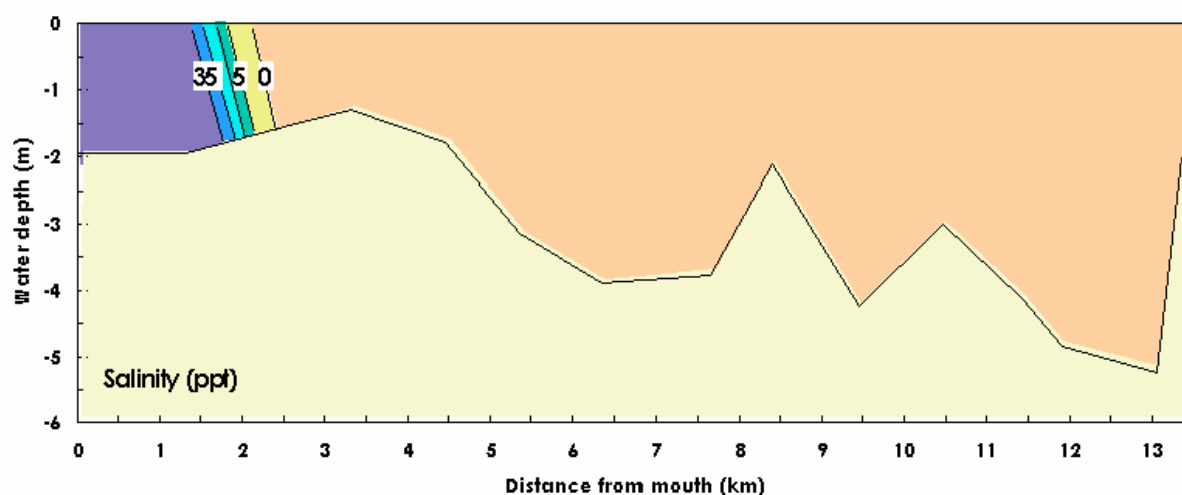
Total volume and/or estimated volume of different salinity ranges: Total volume on average tide is estimated at 3 x 10⁶ m³.

Confidence: Medium

Estimated (maximum) tidal velocity along the estuary: Tidal flow is approximately 1m/s at the mouth during spring tides and reduced upstream.

Confidence: Medium

Salinity distribution in the estuary: The estuary will be dominated by freshwater throughout with a small horizontal salinity gradient near the mouth due to intrusion of saline water, particularly during spring high tide. A typical salinity distribution pattern during State 3 is illustrated as follows:



Confidence: High

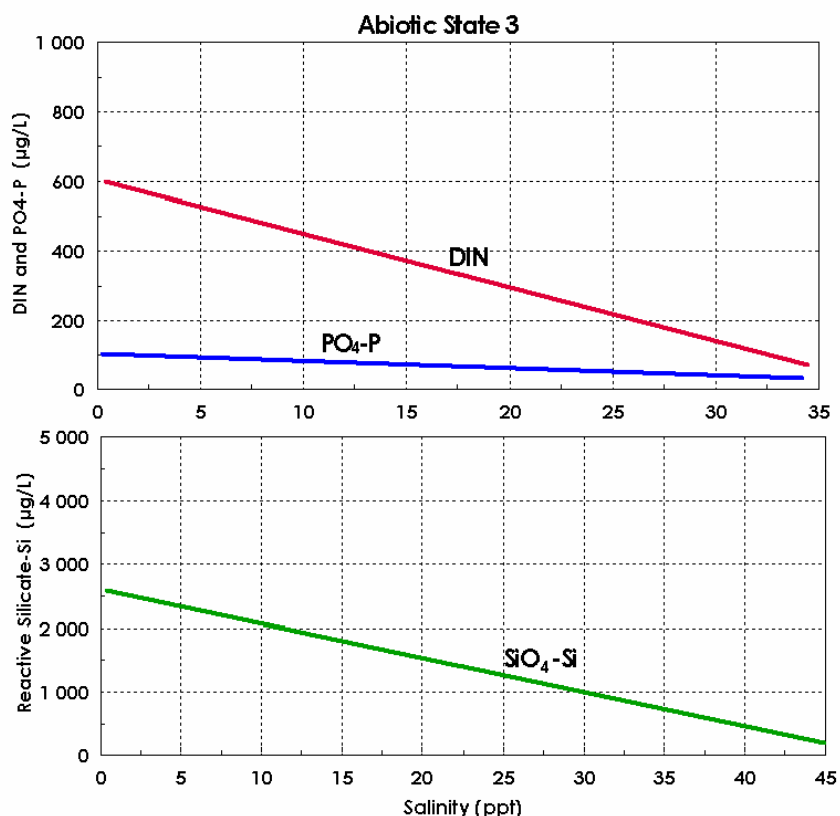
System variables: Levels of system variables in the Kromme Estuary (and Geelhoutboom tributary) under the State 2: Salinity Gradients are estimated as follows:

Temperature	The temperature regime of the Kromme Estuary is expected to show a strong seasonal pattern, with summer temperatures ranging between 20 and 25 °C and winter temperatures between 13 and 16 °C. Bottom water releases from the Impofu Dam during summer months may result in lower temperatures in the upper reaches of the estuary (14-18°C) unless the retention time between the dam and the head of the estuary is long enough for these waters to warm.
pH	pH values in the Kromme Estuary are expected to remain within the range 7 to 8.5, with the lower ranges being associated with fresher (upper) reaches and higher range with more saline (middle and lower) reaches.
Turbidity	Turbidity concentrations in the Kromme Estuary are generally expected to be low. However, during periods of higher freshwater inflow (either from the Geelhoutboom tributary or through releases from the Impofu Dam), turbidity levels can be expected to increase, especially in the upper and middle reaches. Although turbidity data were not available under freshwater inflow conditions, Secchi disc readings reflected a decrease in visibility from about 1 m down to about 0.3 m during periods of significant inflow.
Dissolved oxygen	The Kromme Estuary should generally be well-oxygenated. Concentrations in the deeper water (e.g. in the upper reaches) can drop during the drier summer periods, as a result of long residence times and organic decay, but levels are not expected to drop below 5 mg/l. Results from the Impofu Dam suggest that releases from the bottom waters of the dam may result in inflow to the estuary being slightly less oxygenated (4–6 mg/l) than from a surface release (8–10 mg/l), unless sufficient aeration occurs between the dam and the estuary.

Confidence: Medium

Nutrients:

The relationship between inorganic nutrient concentrations versus salinity is estimated to be as follows during State 3: Fresh:



To orientate oneself in terms of the spatial distribution of nutrients along the estuary during periods of river inflow, the nutrient versus salinity plots should be compared with corresponding longitudinal salinity profiles.

Confidence: Low/Medium

3.1.2 Geelhoutboom Tributary

Based on available data and information, three Abiotic States were derived for the Geelhoutboom tributary, namely:

	River Inflow
State 1: Homogenous water body, similar to middle reaches of Kromme	< 0.08 m ³ /s
State 2: Salinity Gradient	0.08 - 1 m ³ /s
State 3: Fresh	> 1 m ³ /s

The abiotic characteristics associated with each of these Abiotic States are provided below:

ABIOTIC STATE 1: Homogenous water body, similar to middle reaches of Kromme Estuary

Typical flow patterns: River inflow rates usually less than 0.08 m³/s.

Confidence: Medium

Salinity distribution in the estuary: During this state the Geelhoutboom becomes a near-homogenous water body (i.e. no significant salinity gradient). The salinity in the Geelhoutboom is driven by that of the middle reaches of the Kromme Estuary. Salinity can vary, depending on conditions (i.e. the Abiotic State) in the Kromme Estuary. For example when the Kromme is in State 1, salinity in the Geelhoutboom will be around 35ppt, while if the Kromme Estuary is in State 3, the Geelhoutboom will be near fresh.

Confidence: Medium

System variables (Temperature, pH, suspended solids, turbidity and dissolved oxygen): Similar to that of the middle reaches of the Kromme Estuary, which in turn will depend on the Abiotic State in the Kromme at any time.

Confidence: Medium

Nutrients: Similar to that of the middle reaches of the Kromme Estuary, which in turn will depend on the Abiotic State in the Kromme at any time.

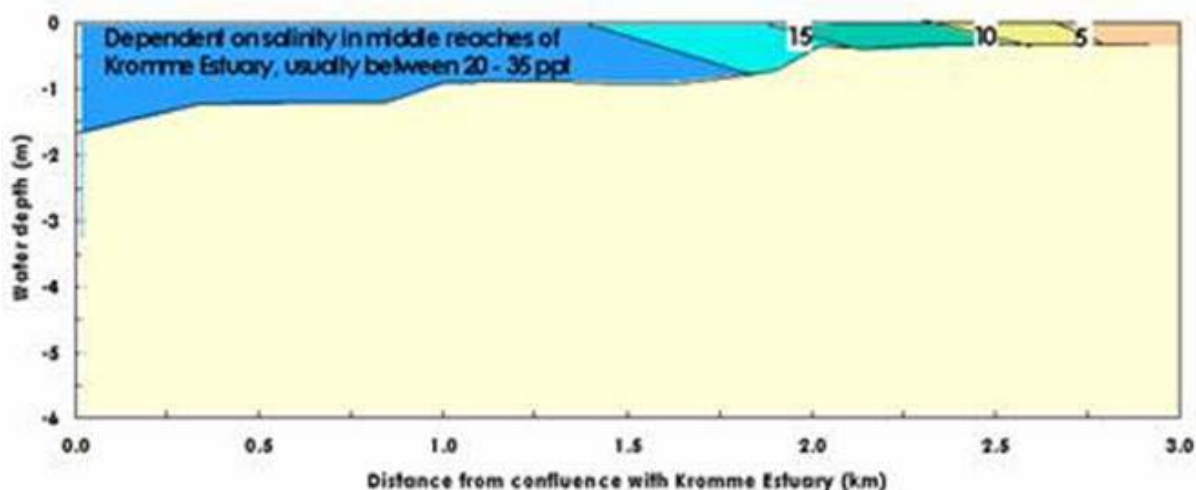
Confidence: Medium

ABIOTIC STATE 2: Salinity Gradient

Typical flow patterns: Flow rates range between 0.08–1.0 m³/s.

Confidence: Medium

Salinity distributions in the estuary: During this state a salinity gradient develops in the Geelhoutboom tributary as illustrated below:



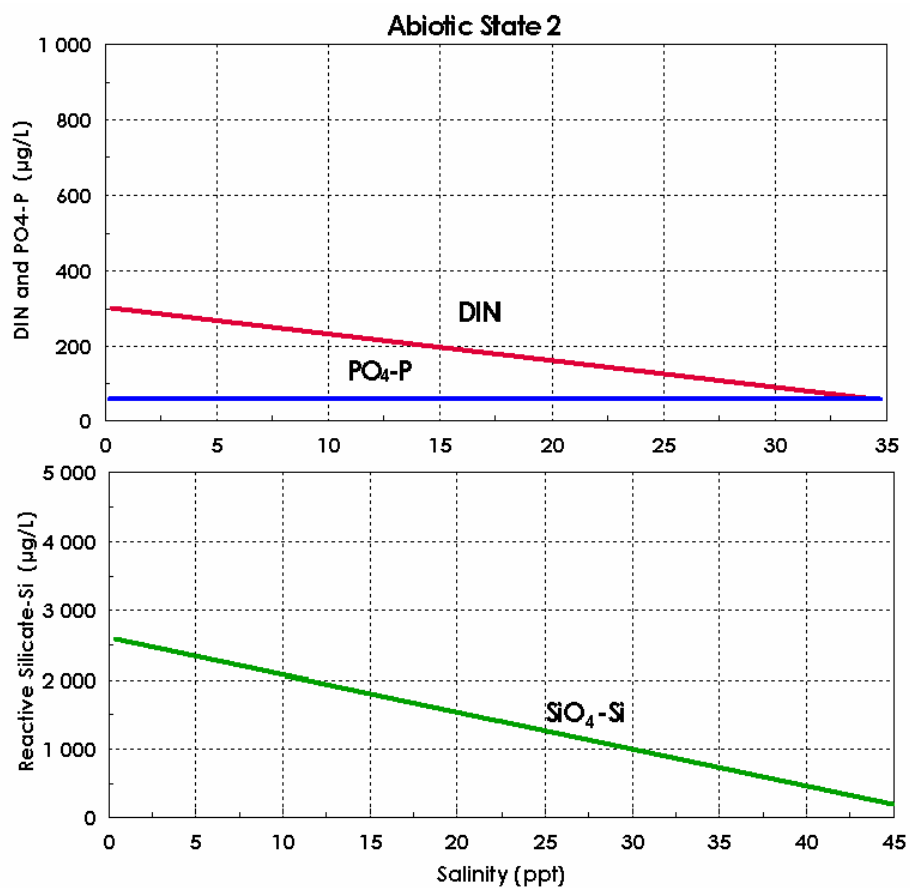
Confidence: Medium

System variables:

Temperature	The temperature regime of the Geelhoutboom tributary is expected to show a strong seasonal pattern, with summer temperatures ranging between 20 and 25 °C and winter temperatures between 13 and 16 °C.
pH	pH values are expected to remain within the range 7 to 8.5, with the lower value being associated with fresher (upper) reaches and higher value with more saline (middle and lower) reaches.
Turbidity	In comparison to the homogenous state higher freshwater inflow is expected to result in increased turbidity levels, especially in the upper and middle reaches. Although turbidity NTU data were not available under freshwater inflow conditions, Secchi disc readings indicate a decrease in visibility from about 1 m down to about 0.3 m during periods of significant inflow (i.e. in the fresher area).
Dissolved oxygen	Should generally be well-oxygenated, being a shallow system.

Confidence: Low

Nutrients: No data were available for the Geelhoutboom tributary in this State, therefore it has been assumed to be similar to that of the Kromme Estuary:



Confidence: Low

ABIOTIC STATE 3: Fresh

Typical flow patterns: River inflow rates usually greater than 1.0 m³/s.

Confidence: Medium

Salinity distribution in the estuary: During this state the Geelhoutboom tributary is largely fresh, with limited or no penetration of saline water at the confluence with the Kromme Estuary. Where estuary water does penetrate at the Kromme confluence, the salinity (and abiotic) characteristics will depend on the State of the Kromme at the time.

Confidence: Medium

System variables:

Temperature	The temperature regime of the Geelhoutboom tributary is expected to show a strong seasonal pattern, with summer temperatures ranging between 20 and 25 °C and winter temperatures between 13 and 16 °C.
pH	pH values in the Geelhoutboom tributary are expected to remain within the range 7 to 8.5, with the lower ranges being associated with fresher (upper) reaches and higher range with more saline (middle and lower) reaches.
Turbidity	High freshwater inflow is expected to result in increased turbidity levels through the Geelhoutboom tributary. Secchi disc readings expected to be < 0.3 m.
Dissolved oxygen	Should generally be well-oxygenated, being a shallow system.

Confidence: Low

Nutrients:

Dissolved Inorganic Nitrogen (DIN)	1700 µg/l
Dissolved Reactive Phosphate-P (PO₄-P)	300 µg/l
Dissolved Reactive Silicate (SiO₄-Si)	2000 - 3000 µg/l

Confidence: Low

3.2 Description of Present State

3.2.1 Abiotic components

The characteristics and functioning of the different abiotic components of the Kromme Estuary are discussed in detail in each of the individual specialist reports provided as appendices to this report, namely:

- Appendix C: Hydrodynamics and Water Quality
- Appendix D: Sediment Dynamics

The main purpose of this report is to use the information provided in the specialist reports to determine, for example, the present ecological status and the implication of future runoff scenarios using the Estuarine Health Index (EHI). To provide the rationale for the scores allocated to different abiotic components, key information derived from the specialist assessments are re-captured in this main report.

i. Seasonal variability in river inflow

Monthly simulated runoff data (73-year period) for the Present State of the Kromme Estuary and Geelhoutboom tributary are provided in Tables 3-1 and 3-2 respectively. A summary of the flow distributions (mean monthly flows in m³/s), derived from the simulated data set, is provided below (hatched months represent flows less than 0.2 m³/s when hypersaline conditions can potentially develop):

Kromme: Summary of flow distributions for Present State

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	13.60	25.85	5.08	4.70	2.48	3.67	4.41	26.39	14.37	16.56	22.96	25.98
90%ile	4.50	1.72	0.56	0.28	0.40	0.45	0.48	1.48	2.66	1.97	2.98	10.39
80%ile	1.79	0.82	0.35	0.23	0.24	0.31	0.25	0.49	0.56	0.44	1.09	3.08
70%ile	0.76	0.48	0.28	0.19	0.18	0.22	0.21	0.22	0.32	0.31	0.43	0.61
60%ile	0.47	0.39	0.23	0.16	0.16	0.17	0.17	0.18	0.21	0.26	0.36	0.41
50%ile	0.36	0.30	0.19	0.15	0.13	0.14	0.14	0.15	0.18	0.22	0.29	0.35
40%ile	0.31	0.27	0.18	0.14	0.11	0.13	0.13	0.14	0.15	0.20	0.25	0.26
30%ile	0.25	0.24	0.17	0.13	0.11	0.12	0.11	0.11	0.13	0.17	0.20	0.22
20%ile	0.22	0.22	0.15	0.12	0.11	0.11	0.10	0.10	0.11	0.13	0.17	0.17
10%ile	0.19	0.19	0.14	0.11	0.10	0.10	0.09	0.09	0.08	0.11	0.14	0.16
1%ile	0.11	0.13	0.11	0.09	0.07	0.03	0.07	0.06	0.06	0.05	0.09	0.10

Geelhoutboom: Summary of flow distributions for Present State

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	1.05	1.21	0.34	0.43	0.29	0.32	0.28	1.17	0.90	1.18	1.72	2.09
90%ile	0.37	0.36	0.05	0.00	0.05	0.07	0.08	0.18	0.21	0.18	0.41	0.57
80%ile	0.24	0.11	0.01	0.00	0.00	0.01	0.04	0.07	0.10	0.11	0.17	0.22
70%ile	0.13	0.06	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.07	0.13	0.16
60%ile	0.08	0.03	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.04	0.08	0.09
50%ile	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.05	0.06
40%ile	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.03
30%ile	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02
20%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 3-1 Monthly simulated runoff data in m³/s (73-year period) for the Present State into the Kromme Estuary

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1927	0.15	0.17	0.13	0.10	0.11	1.08	0.54	0.16	0.13	0.11	0.15	0.26
1928	0.31	0.46	0.24	0.14	0.11	0.10	0.07	0.10	0.11	0.24	0.25	0.46
1929	0.36	0.25	0.15	0.11	0.25	0.22	0.16	0.14	0.18	0.18	0.29	0.31
1930	0.35	0.25	0.14	0.15	0.12	0.12	0.10	0.09	0.08	0.16	0.17	0.51
1931	1.24	0.62	0.77	1.97	0.82	0.23	0.15	0.12	0.13	0.18	0.17	27.14
1932	9.73	1.59	0.35	0.15	0.12	0.13	0.13	2.67	2.45	0.68	19.44	3.63
1933	0.33	0.71	0.24	0.16	0.16	0.19	0.13	0.12	0.11	0.27	0.26	0.20
1934	3.87	0.51	0.18	0.11	0.11	0.11	0.13	24.40	7.66	1.92	4.67	2.21
1935	0.66	1.07	0.30	0.17	0.11	0.12	0.10	0.23	0.18	0.19	0.19	0.17
1936	0.33	1.98	0.50	0.17	0.12	0.14	0.10	0.09	0.13	0.16	0.17	0.22
1937	0.22	0.23	0.19	0.15	0.11	0.09	0.11	0.14	0.13	0.13	0.13	0.17
1938	0.21	0.30	0.18	0.12	0.45	0.41	0.24	0.17	0.14	0.16	0.92	0.63
1939	0.39	0.38	0.34	0.26	0.41	0.44	0.26	0.19	0.28	0.32	0.25	0.35
1940	0.26	0.23	0.14	0.12	0.11	0.11	0.12	0.11	0.31	0.22	0.17	0.17
1941	0.25	0.23	0.45	0.32	0.16	0.12	0.10	0.21	0.21	0.20	0.20	0.17
1942	0.28	0.25	0.18	0.19	0.15	0.12	0.11	0.10	0.81	0.54	0.43	0.60
1943	0.39	0.83	0.49	0.20	0.15	0.23	0.21	31.51	8.77	2.59	1.02	3.11
1944	0.77	0.31	0.17	0.12	0.11	0.09	0.07	9.81	11.44	1.99	1.14	0.41
1945	1.58	0.41	0.18	0.12	0.11	0.38	0.22	0.12	0.10	0.25	0.31	0.28
1946	0.34	0.25	0.14	0.11	0.09	0.20	0.18	0.33	0.43	10.84	1.72	0.39
1947	0.29	0.27	0.17	0.12	0.11	0.14	0.48	0.29	0.17	0.16	0.17	0.22
1948	0.84	0.48	0.19	0.13	0.11	0.10	0.08	0.09	0.07	0.06	0.08	0.09
1949	0.09	1.76	0.72	0.13	0.11	0.09	0.09	0.10	0.08	0.22	0.40	0.37
1950	0.44	1.26	0.57	1.04	0.48	0.17	0.11	0.13	0.17	0.71	0.57	5.83
1951	2.51	0.29	0.17	0.14	0.69	0.32	0.13	0.14	0.15	0.15	0.41	13.59
1952	3.40	0.41	0.23	0.14	0.13	0.11	0.09	0.09	0.11	0.22	0.37	0.71
1953	23.58	8.77	0.32	0.17	0.11	0.48	0.30	1.31	1.05	6.07	18.20	6.38
1954	0.36	0.99	0.18	0.14	5.97	7.56	0.24	0.16	0.16	0.17	0.54	0.42
1955	0.28	5.62	4.39	0.16	0.17	0.20	0.14	1.42	2.71	0.30	0.30	10.85
1956	9.13	15.98	3.36	0.28	0.27	0.24	0.20	0.25	0.33	0.31	0.36	4.54
1957	5.09	0.32	0.17	0.11	0.09	0.16	0.12	0.52	0.36	0.21	0.39	0.36
1958	0.27	0.21	0.15	0.34	0.23	0.15	0.21	0.20	0.17	0.18	0.36	0.33
1959	0.36	0.25	0.19	0.31	0.20	0.12	0.10	0.16	0.18	0.29	0.29	0.31
1960	0.22	0.20	0.14	0.13	0.15	0.65	0.41	0.50	0.39	0.34	0.33	0.26
1961	0.23	0.20	0.13	0.11	0.11	0.25	0.23	0.17	0.13	0.12	1.18	0.69
1962	0.60	0.39	0.19	0.27	0.18	0.96	0.82	0.46	0.32	0.28	0.27	0.23
1963	0.19	0.22	0.28	0.25	0.16	0.15	0.12	0.11	0.57	0.41	0.52	10.84
1964	6.82	0.47	0.23	0.14	0.10	0.14	0.14	0.20	0.20	0.18	0.17	0.16
1965	0.58	2.95	0.29	0.19	0.17	0.13	0.09	0.10	0.09	0.08	0.17	0.19
1966	0.19	0.24	0.17	0.12	0.10	0.10	0.83	0.70	0.45	0.40	0.40	0.54
1967	0.39	0.27	0.17	0.12	0.10	0.11	0.23	0.21	21.89	7.43	2.60	25.52
1968	3.99	0.38	0.20	0.14	0.11	0.12	0.09	0.09	0.11	0.12	0.14	0.17
1969	0.24	0.21	0.13	0.11	0.11	0.10	0.07	0.07	0.06	0.06	0.12	0.13
1970	0.20	0.19	0.44	0.24	0.20	0.18	0.81	0.73	0.55	3.01	32.01	11.56
1971	1.93	1.22	0.21	0.12	0.30	0.19	0.20	0.19	0.18	0.21	0.27	0.21
1972	0.15	0.15	0.11	0.09	0.10	0.15	0.16	0.15	0.12	0.10	0.11	0.12
1973	0.13	0.19	0.14	0.25	0.24	0.83	0.45	0.31	0.31	0.22	1.34	6.04
1974	0.69	0.27	0.15	0.14	0.17	0.27	0.17	0.11	0.11	0.14	0.24	0.37
1975	0.27	0.20	0.15	0.12	0.13	0.32	0.34	0.25	0.22	0.46	0.49	0.36
1976	0.87	0.62	0.26	0.15	0.42	0.25	0.16	6.03	3.96	0.37	0.34	0.62
1977	0.45	0.45	0.28	0.17	0.11	0.14	0.19	0.17	0.23	0.23	0.24	0.23
1978	0.45	0.49	0.29	0.23	0.18	0.14	0.10	0.12	0.15	0.38	15.38	14.19
1979	0.56	0.34	0.19	0.15	0.12	0.09	0.11	0.10	0.12	0.12	0.12	0.17
1980	0.22	0.26	0.20	0.44	0.25	2.15	0.99	10.10	9.62	0.44	14.35	8.56
1981	5.34	0.79	0.25	0.15	0.11	0.12	0.76	0.76	0.18	0.23	0.28	0.26
1982	0.21	0.19	0.12	0.09	0.09	0.09	0.07	0.09	0.11	31.29	12.83	0.44
1983	3.52	0.30	0.18	0.12	0.10	0.14	0.10	0.08	0.08	0.14	0.15	0.14
1984	0.13	0.14	0.14	0.20	0.18	0.13	0.13	0.12	0.18	0.19	0.18	0.14
1985	0.23	0.27	0.21	0.18	0.13	0.11	0.08	0.07	0.08	0.09	0.25	0.22
1986	0.75	0.52	0.23	0.14	0.11	0.11	0.17	0.14	0.38	0.26	0.21	0.52
1987	0.33	0.21	0.14	0.10	0.12	0.03	0.13	0.10	0.22	0.21	0.20	0.19
1988	0.19	0.19	0.10	0.08	0.04	0.02	0.16	0.08	0.10	0.13	0.13	0.17
1989	1.50	2.38	0.72	0.19	0.22	0.18	0.21	0.21	0.64	0.44	0.33	0.31
1990	0.55	0.37	0.18	0.12	0.10	0.09	0.06	0.02	0.05	0.04	0.14	0.10
1991	0.22	0.21	0.16	0.13	1.12	0.46	0.14	0.14	0.17	0.27	1.29	0.76
1992	1.43	1.14	0.36	0.23	0.16	0.12	0.15	0.14	1.47	0.76	0.43	24.38
1993	7.52	0.38	0.34	0.22	0.16	0.15	0.13	0.15	0.15	0.26	3.07	3.03
1994	4.63	0.27	4.63	11.73	0.37	0.36	0.46	1.49	0.56	0.24	0.43	0.23
1995	0.26	0.29	0.37	0.22	0.15	0.14	0.10	0.09	0.07	0.11	0.20	0.23
1996	3.19	51.25	6.25	0.20	0.13	0.13	13.22	4.35	3.15	2.24	1.78	0.35
1997	0.24	0.22	0.14	0.14	0.11	0.30	0.18	0.13	0.11	0.11	0.28	0.26
1998	0.19	0.22	0.19	0.14	0.11	0.11	0.10	0.10	0.08	0.30	0.23	0.16
1999	0.12	0.11	0.14	0.18	0.27	0.43	0.28	0.17	0.13	0.10	0.10	0.12

1 <0.2 1 0.2-1.0 2 1.0-8.0 3 >8.0

Table 3-2 Monthly simulated runoff data in m³/s (73-year period) for the Present State into the Geelhoutboom tributary

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1927	0.00	0.00	0.00	0.00	0.00	0.19	0.11	0.00	0.01	0.00	0.02	0.07
1928	0.06	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.08
1929	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.02	0.05	0.04
1930	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10
1931	0.34	0.07	0.23	0.67	0.16	0.00	0.00	0.00	0.00	0.04	0.00	1.95
1932	0.76	0.25	0.00	0.00	0.00	0.00	0.00	0.08	0.07	0.04	0.57	0.27
1933	0.01	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.00
1934	0.23	0.08	0.00	0.00	0.00	0.00	0.00	0.99	0.55	0.17	0.20	0.19
1935	0.12	0.11	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.03	0.00	0.00
1936	0.05	0.35	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.03
1937	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
1938	0.01	0.02	0.00	0.00	0.05	0.07	0.03	0.01	0.00	0.02	0.26	0.17
1939	0.08	0.05	0.03	0.00	0.05	0.12	0.04	0.03	0.08	0.09	0.01	0.11
1940	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.01	0.00
1941	0.03	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.01	0.00
1942	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.14	0.13	0.19
1943	0.03	0.26	0.08	0.00	0.00	0.00	0.02	1.64	0.69	0.18	0.10	0.23
1944	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.34	0.15	0.15	0.08
1945	0.25	0.00	0.00	0.00	0.00	0.04	0.01	0.00	0.00	0.03	0.05	0.03
1946	0.07	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.08	0.39	0.17	0.09
1947	0.03	0.00	0.00	0.00	0.00	0.00	0.06	0.02	0.02	0.01	0.01	0.03
1948	0.27	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1949	0.00	0.38	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.08	0.06
1950	0.09	0.42	0.08	0.33	0.05	0.00	0.00	0.00	0.01	0.22	0.17	0.28
1951	0.10	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.02	0.01	0.13	0.89
1952	0.33	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.07	0.16
1953	1.82	0.70	0.00	0.00	0.00	0.06	0.04	0.42	0.26	0.23	1.19	0.47
1954	0.03	0.00	0.00	0.00	0.53	0.22	0.00	0.01	0.02	0.04	0.17	0.10
1955	0.02	0.36	0.02	0.00	0.00	0.00	0.00	0.28	0.18	0.07	0.08	0.38
1956	0.72	0.36	0.17	0.00	0.00	0.00	0.02	0.06	0.10	0.08	0.11	0.26
1957	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.06	0.01	0.07	0.06
1958	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.03	0.10	0.06
1959	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.05	0.03	0.07
1960	0.00	0.00	0.00	0.00	0.00	0.09	0.08	0.16	0.10	0.10	0.08	0.02
1961	0.01	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.01	0.31	0.17
1962	0.19	0.03	0.00	0.00	0.00	0.21	0.27	0.14	0.06	0.08	0.06	0.01
1963	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.10	0.17	2.04
1964	0.67	0.09	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.02	0.00	0.00
1965	0.11	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
1966	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.15	0.13	0.12	0.11	0.17
1967	0.05	0.00	0.00	0.00	0.00	0.00	0.01	0.03	1.43	0.61	0.19	1.00
1968	0.36	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
1969	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1970	0.00	0.00	0.04	0.00	0.00	0.00	0.13	0.17	0.18	1.05	2.92	0.93
1971	0.05	0.06	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.04	0.05	0.00
1972	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1973	0.00	0.00	0.00	0.00	0.00	0.13	0.07	0.06	0.08	0.02	0.46	0.60
1974	0.13	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.04	0.07
1975	0.00	0.00	0.00	0.00	0.00	0.02	0.06	0.03	0.03	0.13	0.14	0.06
1976	0.29	0.15	0.00	0.00	0.04	0.00	0.01	0.65	0.33	0.08	0.09	0.20
1977	0.08	0.09	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.03	0.03	0.01
1978	0.13	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	1.26	0.61
1979	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1980	0.02	0.01	0.00	0.02	0.00	0.59	0.30	0.28	0.20	0.10	0.88	0.34
1981	0.32	0.11	0.00	0.00	0.00	0.00	0.12	0.05	0.03	0.07	0.07	0.04
1982	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.50	0.68	0.10
1983	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1984	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00
1985	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02
1986	0.15	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.02	0.03	0.12
1987	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.02	0.02	0.01
1988	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02
1989	0.37	0.81	0.07	0.00	0.00	0.00	0.00	0.03	0.21	0.11	0.08	0.07
1990	0.17	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1991	0.00	0.00	0.00	0.00	0.19	0.02	0.00	0.01	0.02	0.07	0.44	0.20
1992	0.48	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.43	0.21	0.13	2.21
1993	0.74	0.04	0.03	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.23	0.14
1994	0.09	0.00	0.03	0.04	0.05	0.07	0.07	0.09	0.03	0.04	0.05	0.03
1995	0.04	0.02	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03
1996	0.37	2.23	0.60	0.00	0.00	0.00	0.14	0.20	0.17	0.14	0.14	0.05
1997	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.05	0.02
1998	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.02	0.00
1999	0.00	0.00	0.00	0.00	0.00	0.06	0.03	0.00	0.00	0.00	0.00	0.00

1 <0.08 2 0.08-1.0 3 >1.0

ii. Present flood regime

All major floods have been significantly modified. Freshettes and smaller floods have been removed from the Kromme Estuary. Floods attenuated 55% (1:2-year) to 38% (1:20-year). Major floods will also be affected.

Return period (years)	Peak Discharge – Present State (m ³ /s)
2	20
10	185
20	445

Based on 11-year period (1993-2004)

The farm dams present in the Geelhoutboom River mostly reduced freshettes and small floods entering into the system. However, major floods would still pass through from the Geelhoutboom tributary.

Confidence: High

iii. Present sediment processes

The lower reaches of the Kromme Estuary (up to about 4 km from the mouth) are characterised by marine sediments. Due to reduced flooding, marine sediments are slowly moving upstream, at about 3.5 mm per year (based on simulations).

Simulations indicated that the deeper section in the middle and upper reaches (about 8 km long) is very slowly silting up at a rate of 9 mm per year.

The following information was obtained from field measurements reflecting Present State:

- Median sediment size 0.21 mm.
- Sediment is coarser in upper estuary near the head of the estuary in comparison to the mouth. This is most likely due to the finer sediment being flushed away by the releases (See Appendix D Section 3.2.3.)

Presently the Impofu Dam traps most sediment that should have reached the estuary, while farm dams on the Geelhoutboom River trap about 80% of sediment coming from that catchment (in particular the sand fraction).

Confidence: High

iv. Occurrence and duration of different abiotic states under Present State

Estimated occurrence and duration of the different Abiotic States in the Kromme Estuary and Geelhoutboom tributary under the Present State, based on simulated monthly river inflow from the Kromme and Geelhoutboom rivers are indicated Tables 3-1 and 3-2, respectively.

To provide a conceptual overview of the annual distribution of Abiotic States under the Present State for the Kromme Estuary and Geelhoutboom tributary, median monthly flows (representative of seasonal conditions) and 10%ile flows (representative of drought conditions) were used to depict the situation for normal and drought periods (Figure 3-1).

Confidence: Medium

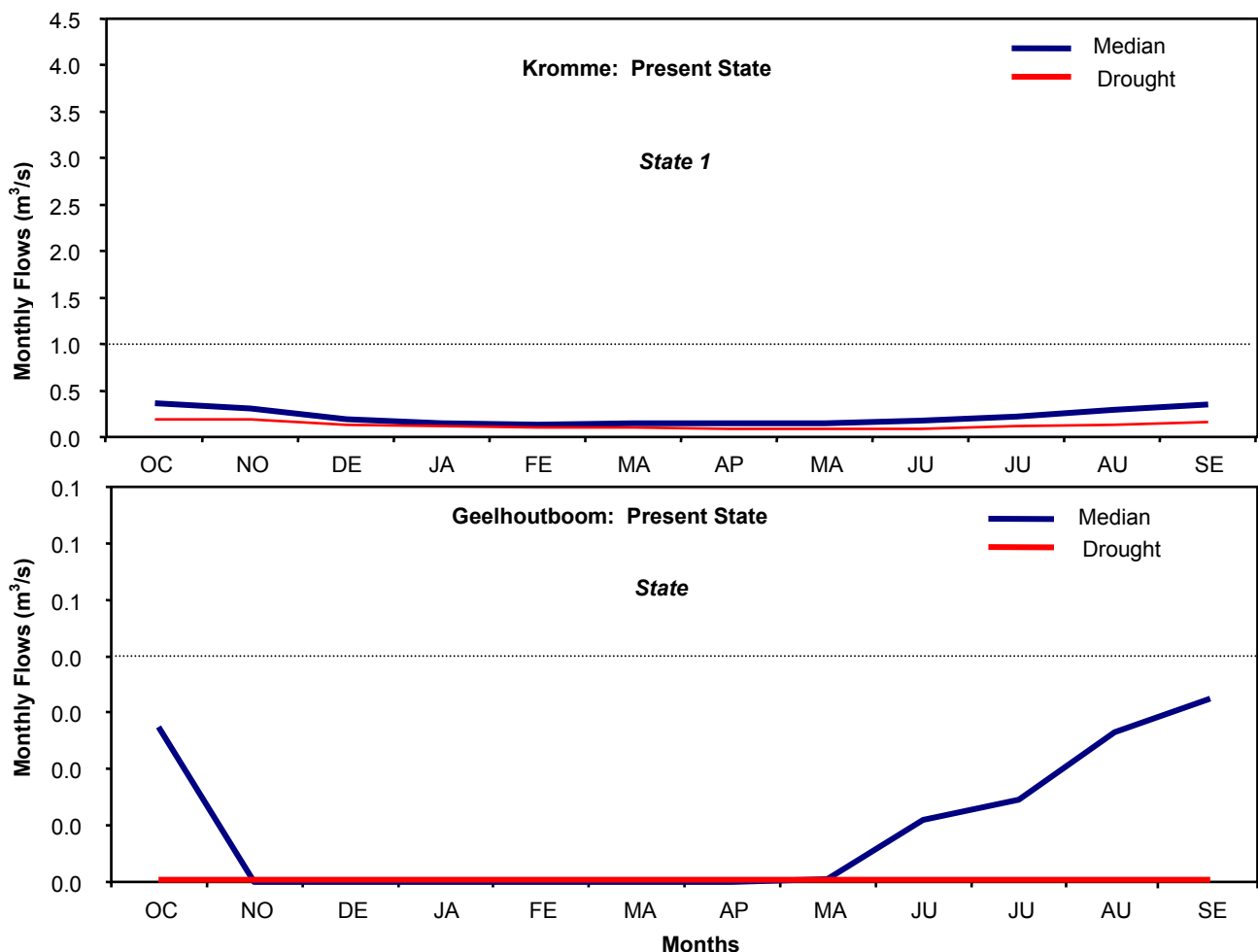


Figure 3-1 Predicted distribution of Abiotic States under the Present State for the Kromme Estuary and Geelhoutboom Tributary, based on median monthly flows (representative of seasonal conditions) and 10%ile flows (representative of drought conditions)

- v. Anthropogenic influences, other than modification of river inflow, presently affecting abiotic characteristics

Structures (e.g. weirs, bridges, mouth stabilisation)
The construction of the road bridge over the lower Kromme Estuary has locally stabilised the dynamic nature of the channel and may be contributing to the silting up of the salt marsh area adjacent to the approaches. The construction of the St Francis Bay Marina has disrupted some of the tidal flows and increased the estuarine area. There are numerous jetties built along the banks of the estuary, which reduce the estuary tidal flow velocities and lower sediment transport. Local scouring near the mouth is due to dredged channels. Possible impacts of dredged material on the estuary will be reflected in changes to the mouth morphology and tidal flow conditions. Jetties may have reduced outside bend scour effects during floods, resulting in a slightly shallower main channel. Confidence: High

Discharges into estuary affecting water quality

Anthropogenic waste inputs that could affect water quality are not expected to be a major issue in the Kromme Estuary. Studies conducted on trace metal distribution patterns in the Kromme Estuary (Watling and Watling, 1982) also concluded that trace metals did not present a hazard due to the absence of urbanisation and industrialisation in the area. Since this study limited industrial development has occurred in the catchment.

Confidence: Medium

3.2.2 Biotic components

The characteristics and functioning of the different biotic components of the Kromme Estuary are discussed in detail in each of the individual specialist reports provided as appendices to this report, namely:

- Appendix E: Microalgae
- Appendix F: Macrophytes
- Appendix G: Invertebrates
- Appendix H: Fish
- Appendix I: Birds

The main purpose of this report is to use the information provided in the specialist reports to determine, for example, the present ecological status and the implication of future runoff scenarios using the Estuarine Health Index (EHI). This report also provides the rationale for the scores allocated to different components, and key information derived from the specialist assessments is re-captured.

i. Description of the Present State of biotic components

Microalgae

Phytoplankton:

Uniform salinity throughout the estuary is expected during no-flow periods. Vertically averaged water column chlorophyll *a* (chl *a*) is expected to range between 1 and 10 µg/l. The lowest concentration is expected near the mouth and at the head of the estuary, with highest values in the middle reaches. There is no significant change in chl *a* concentration expected between winter and summer or in deep water (> 2m). Significant increases in chl *a* are expected in response to nutrient loading (particularly PO₄, NO₃ and NH₄⁺) following freshwater entering the estuary from the Kromme and Geelhoutboom rivers. Highest chl *a* biomass is expected in regions of the estuary with the highest turbidity (generally in the middle reaches near the Kromme/Geelhoutboom confluence). The phytoplankton community composition is as follows: 75-95% flagellates, 2-20% diatoms, 0-5% dinoflagellates, 0-1% cyanophytes, 0-2% chlorophytes (euglenophytes incl.) and <1% coccolithophorids. Zero base flow due to the construction of the dam has resulted in phytoplankton maximum biomass (chl *a*) being reduced from a possible >30 µg/l in the river-estuary interface zone (REI) to the present low levels. It is important to point out that 75-95% of the counts were flagellates, may not be phytoplankton. In fact, because dinoflagellates and chlorophytes were counted separately, it is possible that all or most of the flagellates were heterotrophic and therefore not phytoplankton.

Benthic microalgae:

Subtidal and intertidal chlorophyll *a* are expected to range between 3 and 15 µg/g and 1 and 30 µg/g respectively (this is generally between 10 and 80 mg.m⁻² for benthic microalgae). During extended periods of calm (~1 week), the highest benthic chl *a* is expected to be located near the mouth where it opens to the St Francis Bay canals.

Confidence: High

Macrophytes

Biomass distribution: A large intertidal salt marsh is present on the north bank of the estuary approximately 2 km from the mouth. Small, isolated salt marshes also occur farther upstream on the south bank (4 km from the mouth) and on the north bank about 2 km from the head of the estuary. Salt marshes extend into the middle-upper reaches of the Geelhoutboom tributary. Reedbeds occur upstream of the roadbridge on the south bank of the estuary, and in small streams and tributaries feeding the estuary in the middle-upper reaches. Eelgrass, *Zostera capensis*, occurs throughout the estuary. These beds range from sparse stands on the sand banks in the mouth region to dense stands in the protected creeks of the salt marshes and in the middle and upper reaches of the estuary. Numerous marine macroalgae are found in the estuary particularly in quiet sheltered areas.

Species diversity, richness and rarity: Seven of the nine possible plant community types occur in the Kromme Estuary, with the subtropical swamp forest and mangrove communities being absent. The large intertidal salt marsh areas are important (only 18% of South African estuaries are permanently open with intertidal salt marsh areas) and can thus be considered rare.

Seasonal and inter-annual variability, as well as flood situations and drought conditions: Large floods can uproot the submerged macrophyte *Zostera capensis*, thus influencing the distribution and abundance of this species. Because these floods have been reduced there has been an increase in the biomass and area covered by *Zostera capensis*. 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: High

Invertebrates (including zooplankton, benthic invertebrates and macrocrustaceans)

Zooplankton:

The zooplankton biomass is low throughout the estuary. During the summer months and when the estuary becomes hypersaline, biomass/abundance drops even lower. Because of the homogenous nature of the salinity, zonation of species is very weak. Seasonal differences are slight, with peaks in abundance escalating by orders of magnitude within weeks following a freshwater pulse. On these occasions, stratification of the water column usually develops. Since freshwater pulses occur after heavy local rains, peaks in abundance may occur during any season.

Species diversity, richness and rarity: Overall species diversity tends to be high in the Kromme Estuary, mainly due to the presence of marine associated species. However, diversity of typical estuarine species is low for the same reason. Three species of copepods usually dominate the zooplankton in local estuaries. Of these, *Acartia natalensis* occurs erratically and in relatively low abundance mainly due to the persistently high salinity values. It may even disappear from the plankton in some years. If salinity drops below about 20 ppt during the summer, populations attain high abundance levels. The copepod *Tortanus capensis* is fairly unique to the Kromme Estuary and appears to be a specialist occurring in estuaries where salinity values are persistently high throughout (around 35ppt or higher). In this estuary, evenness is relatively high, with no species dominating the zooplankton compared to the situation in freshwater rich systems.

Seasonal and inter-annual variability, as well as flood situations and drought conditions: Because of the persistently high salinity values, seasonal and interannual variability is low. After floods, recovery of the zooplankton is rapid and individual species attain extremely high levels of abundance for relatively short periods (weeks to months). There was a major decline in the zooplankton standing stock as a consequence of reduced phytoplankton stock after the dam was built. Submerged macrophyte biomass on the other hand increased, leading to changes in the balance between primary producers.

Confidence: High

Benthos (Benthic invertebrates and macrocrustaceans):

Many of the non-burrowing macrobenthic species benefit from the presence of *Zostera capensis* and attain high abundance levels. The isopod *Exosphaeroma hylocoetes*, the molluscs *Lamya capensis*, *Haminea alfredensis* and *Natica genuana* are found only at sites covered with *Zostera*. The greater the biomass of *Zostera*, the higher the biomass of these invertebrates. Other species such as the polychaete worm *Ceratonereis erythraeensis* and the crabs *Cleistostoma edwardsii* and *Hymenosoma orbicul* are also more abundant in vegetated areas. The mudprawn *Upogebia africana* on the other hand is more common in open areas. The shrimp *Palaemon perengueyi* is the most important species contributing to total invertebrate production in the estuary (25%), with abundance levels directly associated with the presence of subtidal *Zostera* beds.

Species diversity, richness and rarity: In terms of habitat, benthic macroinvertebrate production is greatest in *Zostera capensis* beds (35.2%), followed by salt marsh and mud habitats (each 25.2%). Thus 85% of macroinvertebrate production in the Kromme Estuary is associated with non-sandy habitats upstream of the mouth area. Increase in *Zostera capensis* density and coverage after dam construction therefore led to changes in zoobenthic community structure.

Seasonal and inter-annual variability, as well as flood situations and drought conditions: Because of the relative stability of the *Zostera* beds, seasonal and interannual variability will be less compared to years when the estuary is flushed (decrease in *Zostera* biomass). However, interannual variability in recruitment will be the main factor leading to population shifts in abundance.

Confidence: High

Fish

Species diversity, richness and rarity: Fish species diversity in the Kromme Estuary tends to be high, mainly due to the presence of stenohaline marine species that are normally not found in estuaries with a normal salinity gradient. Examples of such species found in the Kromme system include the sand steenbras *Lithognathus mormyrus*, zebra *Diplodus cervinus* and short-tail stingray *Dasyatis brevicaudatus*. Mainly as a result of the additional marine species, diversity indices calculated for the Kromme Estuary are in the upper quartile for permanently open Eastern Cape estuaries.

Biomass distribution and productivity: There is a moderate fish biomass in the Kromme Estuary when compared to other permanently open estuaries in the Eastern Cape. Expansion of the *Zostera* beds has resulted in an increase in the abundance of macrophyte associated fish species but reduced planktonic food availability will have caused a decline in the biomass and productivity of planktivorous species.

Seasonal and inter-annual variability, as well as flood situations and drought conditions: Because of the persistently high salinity values, seasonal and inter-annual variability is likely to be low when compared to systems with pronounced seasonal flows. River floods would have caused a temporary decline in the abundance and diversity of the fish community but the rebound in biomass and productivity would have been rapid once the floodwaters had dissipated. Under drought conditions there would have been reduced fish recruitment and a concomitant decline in fish biomass and productivity.

Confidence: High

Birds

Species diversity, richness and rarity: A total of 64 species have been recorded on the Kromme Estuary over the past ten years, with an average of 34 species recorded on any one count in mid-summer and 32 species in mid-winter. The species richness is similar to that of other large permanently open estuaries in the warm temperate zone. Excluding terns, which can dominate bird numbers in summer, the community has a relatively high degree of evenness, with relatively high numbers of larger waders as well as the small waders that predominate.

Biomass distribution and productivity: The estuary supports an average of 1 400 birds in summer and 700 in winter (excluding terns). In addition, a variable-sized tern roost of up to 13 000 birds occurs at the mouth. Most of the estuary's birds are found in the lower estuary, from the mouth to the intertidal flats just above the bridge. In the lower estuary, bird densities are highest on muddier areas with medium coverage of *Zostera*. Birds are found in fairly low densities along the middle reaches, which are dominated by jetties and very little sandy or muddy intertidal areas. Very few birds occur above the confluence with the Geelhoutboom.

Seasonal and inter-annual variability, as well as flood situations and drought conditions: Summer numbers are much higher than winter numbers and are dominated by migrant waders. In winter resident species dominate and some increase in number. Flood conditions are likely to cause temporary movements of birds, but normal bird numbers and distributions would soon resume.

Confidence: High

ii. Effect of abiotic characteristics and processes, as well as other biotic components on estuarine biota

Mouth condition
Microalgae: Following mouth closure, as a result of reduced river flow, there generally is a shift in the source of nutrients from riverwater to the mineralisation of nutrients from organic matter within the benthos. This shift, combined with a clearer water column, reduces the level of phytoplanktonic dominance and increases microphytobenthic dominance. A permanently open mouth allows for tidal exchange, a process necessary for exposing intertidal areas, creating salinity gradients and maintaining tidal flow. This results in a greater diversity of habitats within the estuary, supporting a more diverse community of microalgae. Confidence: High
Macrophytes: An open mouth is important as it maintains the intertidal plant community types i.e. intertidal salt marsh and <i>Zostera</i> beds. Salt marsh plants occur in distinct zones along a tidal inundation gradient. If the mouth closes the plants found in these zones would die. Confidence: High
Invertebrates: Important species such as the shrimp <i>Palaemon perengueyi</i>, the mudprawn <i>Upogebia africana</i> and salt marsh crabs all require a marine phase of development during their life cycles. Should mouth closure persist (2-3 years), local populations will become extinct. If mouth closure occurs during the breeding season, population abundance levels will decline in relation to the duration of mouth closure. Confidence: High
Fish: Most fish species in this estuary are dependent on an open mouth state for the completion of their life cycles. Prolonged mouth closure (+1 year) would result in a major decline in the abundance of estuarine associated marine taxa due to the absence of recruitment by the larvae and 0+ juveniles of these species. Emigration by adults of these species to the sea to spawn would also be adversely affected. Confidence: High
Birds: The mouth condition has little direct effect, only indirect, through impacts on habitat and food. The main effects are on terns, with an open mouth providing suitable feeding conditions. Confidence: High

Exposure of intertidal areas during low tide
Microalgae: The exposure of intertidal areas provides habitat for intertidal benthic microalgae. The biomass of intertidal microalgae is generally higher than that of subtidal microalgae, providing more food for higher trophic levels. Confidence: High
Macrophytes: Tidal flushing is important for salt marsh nutrient exchanges and for maintaining the zonation and diversity of salt marsh plants. Confidence: High
Invertebrates: If die-back of <i>Zostera</i> occurs, numbers of some intertidal species will decline because of their requirement for plant coverage (habitat). Confidence: High
Fish: If the estuary mouth was to close and intertidal areas were to become continuously inundated, then the availability of littoral habitat for fishes would increase. Confidence: High

Birds:

Tidal exposure is essential for estuarine birds, with the majority of species depending on these habitats for food, and several more using intertidal areas for roosting.

Confidence: High

Sediment processes and characteristics**Microalgae:**

Total suspended solids in riverwater generally stay in suspension as a result of ionic repulsion. Once the riverwater mixes with seawater in the estuarine environment, the high concentration of cations cause the particles to flocculate and settle from the water column. The fine sediment particle size in the middle reaches of the estuary is evidence of this. If there was less river water entering the estuary, then a shift to a more sand dominated system is expected, resulting in a gradual loss of habitat suitable for epipellic microalgae (mud associated).

Confidence: Medium

Macrophytes:

Intertidal salt marsh is associated with high silt content and supratidal salt marsh with high clay content. Because of the lack of flooding in the Kromme Estuary and decreases in sediment disturbances there has been an increase in the area covered by *Zostera* in both the intertidal and sub tidal areas. .

Confidence: High

Invertebrates:

Sediment deposition is an important process influencing species distribution. Extension of the sandbank (3.5 m per annum) in the lower estuary favours sand-dwelling species at the expense of a mud community. Excess deposition of fine material from the Geelhoutboom tributary can smother benthic species.

Confidence: High

Fish:

Increase in flood tide delta in the lower reaches will favour sand associated fish species.

Confidence: High

Birds:

Sediment characteristics affect the food and feeding methods of estuarine birds, with different species being adapted to different conditions. Therefore, a change in characteristics is likely to affect bird community composition.

Confidence: High

Retention times of water masses**Microalgae:**

The development of microalgal biomass is dependent on flow velocity and retention time. A flow of $<0.3 \text{ m}^3/\text{s}$ has an estuarine retention time of 3.5 to 7 weeks. This is ideal for microalgae in an estuary with a well developed REI zone but in the Kromme Estuary, the flow is insufficient to create a longitudinal salinity gradient and hypersaline conditions are common. A temporary increase in flow to $4\text{--}8 \text{ m}^3/\text{s}$ for >4 weeks would be optimal because this would result in scouring of high saline water in the upper reaches, creating a longitudinal salinity gradient (= residence time of ~ 3 days to 3 weeks for the entire estuary).

Confidence: High

Macrophytes:

Retention of the water body will lead to increased salinity due to evaporation. This would adversely affect the intertidal salt marsh since surface sediment salinity would increase. This would decrease seed germination and macrophyte growth.

Confidence: High

Invertebrates:

Long retention time of the water mass will increase salinity in the estuary, leading to population decreases of important estuarine zooplankters. There will also be a shift in community composition of the zooplankton and benthos. In deeper areas, long retention times of water masses can lead to oxygen depletion and physiological stress on benthic animals.

Confidence: High

<u>Fish:</u> Increased retention time of water masses within the estuary will benefit the spawning of certain estuarine species (e.g. <i>Gilchristella aestuaria</i>) but will reduce the supply of olfactory cues to estuarine-associated marine fish larvae in the sea. Confidence: High
<u>Birds:</u> No direct impact Confidence: High

Flow velocity
<u>Microalgae:</u> Microalgal biomass is closely associated with flow velocity and retention time. A flow of $<0.3 \text{ m}^3/\text{s}$ has an estuarine retention time of 3.5 - 7 weeks. This is ideal for microalgae in an estuary with a well developed REI zone but in the Kromme Estuary the flow is insufficient to create a longitudinal salinity gradient and hypersalinites can be encountered. A temporary increase in flow to $4 - 8 \text{ m}^3/\text{s}$ for >4 weeks would be optimal because this would result in scouring of high saline water in the upper reaches creating a longitudinal salinity gradient (= residence time of ~ 3 days to 3 weeks for the entire estuary). Confidence: High
<u>Macrophytes:</u> There has been a decrease in flow velocity because of reduction of freshwater input and this has led to sediment stability, which in turn has led to an increase in colonisation by submerged macrophytes and marine macroalgae. In the lower reaches of the estuary the area covered by reeds, sedges and salt marshes has also increased. Confidence: High
<u>Invertebrates:</u> Strong currents are unfavourable for the estuarine zooplankton. Benthic animals will respond in accordance with changes in sediment particle size distribution. Strong currents lead to coarser sediments that are unfavourable for most species. Confidence: High
<u>Fish:</u> Strong water currents can result in the loss of estuarine fish eggs and larvae to the marine environment. However, sufficiently strong currents in the Kromme Estuary would only occur during river flooding and such conditions are likely to be of relatively short duration. Confidence: High
<u>Birds:</u> This can affect foraging by piscivorous birds, but only at very high velocities. Confidence: High

Volume of water in estuary
<u>Microalgae:</u> An increase in water volume provides more habitat for phytoplankton and, to a lesser extent, benthic microalgae. Confidence: High
<u>Macrophytes:</u> A larger volume of water in the estuary will lead to increased inundation of the intertidal salt marsh. This will lead to die-back of species that are intolerant of long periods of inundation. Confidence: High
<u>Invertebrates:</u> Increased inundation of intertidal areas will lead to increased habitat for some species. Confidence: Medium
<u>Fish:</u> If the mouth were to close and result in increased inundation of intertidal areas, then this would lead to increased habitat for juvenile fishes and the adults of small littoral species. Confidence: High

Birds:

Inundation of intertidal habitats would lead to reduction in bird numbers.

Confidence: High

Salinity**Microalgae:**

Phytoplankton chl a responds positively to nutrients in freshwater (particularly PO₄-P, NO_x-N and NH₄-N). A full salinity range from fresh at the head of the estuary becoming marine at the mouth with a strong vertical gradient is ideal for maximum microalgal biomass and diversity. However, this is typical of an extended flow of 4-8 m³/s, a flow that seldom occurred during the Reference Condition in the Kromme Estuary.

A change in the salinity in the estuary, within reason, is unlikely to have an effect on benthic or phytoplanktonic microalgae biomass. However, a gradient in salinity along the length of the estuary would provide more habitats for a greater diversity of microalgal taxa, with marine species near the mouth and more freshwater species occurring further upstream.

Confidence: High

Macrophytes:

Salinity is uniformly high throughout the Kromme Estuary. These high salinities have increased marine macroalgae colonisation from the sea, and *Zostera capensis* has extended into the upper reaches of the estuary. The abundance of reeds and sedges has probably decreased, particularly in the Geelhoutboom tributary. Because of the high salinity these plants are confined to sites of freshwater seepage in the estuary. High water column salinity and lack of flushing by floods results in salt accumulation in the salt marshes. Bare patches are evident in the salt marshes in the middle / upper reaches of the estuary.

Confidence: High

Invertebrates:

Uniform and persistently high salinity values along the Kromme Estuary have changed community composition and abundance levels. The increase in *Zostera* coverage favours invertebrates such as *Palaemon perengueyi*, but not *Upogebia africana*. Zonation of species is also negatively affected, particularly those species in the water column that are influenced by salinity gradients.

Confidence: High

Fish:

Increased and more uniform salinities within the Kromme Estuary favours marine species and has led to the disappearance of those few freshwater species that may have inhabited the head region of the estuary.

Confidence: High

Birds:

Most estuarine birds tolerate a wide range of salinities, but a few species are typical of more freshwater or marine habitats, and the abundances of these species would be affected by change.

Confidence: High

Other water quality variables**Microalgae:**

The Kromme Estuary is considered to be low in nutrients. Emmerson *et al.* (1982) described the estuary as oligotrophic. An increase in nutrients (particularly PO₄-P, NO_x-N and NH₄-N) will result in a substantial increase in microalgal biomass.

Confidence: High

Macrophytes:

Nutrient enrichment can increase growth and biomass of submerged macrophytes and macroalgae. Despite the agricultural activity in the catchment nutrient input is low because of low freshwater inflow. In the marina seepage from septic tanks and limited tidal flushing could cause a localised increase in macrophyte growth.

Confidence: High

<u>Invertebrates:</u> Animal communities will respond to increases in food availability brought about by any increase in nutrient loading. Confidence: High
<u>Fish:</u> Increased nutrient loading will compensate for the loss of catchment supplies, which would result in a higher fish biomass and productivity. Confidence: High
<u>Birds:</u> Sediment particle size is important in determining species composition and bird densities, with muddy (not silty) habitats being important for foraging. Increased nutrient loading would lead to increased bird biomass due to increased food supplies. Confidence: High

Other biotic components
<u>Microalgae:</u> Microalgae are primary producers and provide an essential food source to higher trophic levels. An increase in microalgal biomass is expected to result in an increase in zooplankton. Grazing can result in variable microalgal biomass values. Confidence: High
<u>Macrophytes:</u> Grazers such as the sea hare <i>Bursatella leachi africana</i> are important in controlling epiphyte growth on the <i>Zostera</i> plants. Confidence: High
<u>Fish:</u> Increased <i>Zostera</i> habitat has benefited macrophyte associated fish species such as the Cape stumpnose <i>Rhabdosargus holubi</i> and Cape moony <i>Monodactylus falciformis</i>. Confidence: High
<u>Birds:</u> The abundance of algae, invertebrates and fish of particular size classes and their availability (e.g. position in the sediment and estuary) are the most important determinants of estuarine bird composition and density, rather than the composition of these groups per se. <i>Zostera</i> cover is beneficial for birds, but only up to a certain density. Availability of roosting habitats (e.g. salt marsh, dunes) is important. Confidence: High

- iii. Anthropogenic influences, other than modification of river inflow, presently directly affecting biotic characteristics

Structures (e.g. weirs, bridges, jetties)
<u>Microalgae:</u> The road bridge and jetties have a minimal effect on microalgae other than increasing epiphyte biomass. Confidence: High
<u>Macrophytes:</u> The largest salt marsh near the mouth has been disturbed by the road bridge and private roads. A large stand of <i>Phragmites</i> (7.2 ha) occurred to the west of Marine Glades, but was demolished during the extension of the canal system. The area covered by salt marsh had decreased by 17 ha due to flood plain development. Confidence: High

Invertebrates:

The road abutment across the lower flood plain has changed plant community composition, leading to changes in intertidal invertebrate communities. Restriction of channel areas by the bridge has probably led to stronger tidal currents locally. This changes sediment characteristics and distribution in the immediate area of the bridge. In the lower estuary the bridge has probably made the sandbank more stable, which favours sand dwelling animals. Weirs along any water course will also inhibit migration patterns of some animals.

Confidence: High

Fish:

Construction of marina canals has increased the availability of aquatic habitat to fishes in the lower reaches of the estuary. These canals would also act as a refuge area for estuarine-associated fishes during river flooding of the estuary.

Confidence: Medium

Birds:

The numerous jetties provide perching and roosting habitat for kingfishers and cormorants. The road bridge interferes with flight paths but without major impact. The marina has provided additional habitat for birds, particularly Water Dikkops.

Confidence: High

Human exploitation (consumptive and non-consumptive)**Microalgae**

Virtually unaffected by the level of human exploitation in the estuary.

Macrophytes:

Zostera capensis is highly susceptible to destruction by bait collectors and boats. Boating activity may stir up bottom sediments that could impact the submerged macrophytes (*Zostera capensis*) reducing both cover and biomass. Boat activity can also cause the erosion of salt marshes. There is some evidence of this in the middle reaches of the estuary.

Confidence: High

Invertebrates:

The rapid increase in human numbers adjacent to the estuary has led to increased bait exploitation and disturbance to the substrate (e.g. trampling of mudbanks). This has probably led to high mortality of newly settled larvae (e.g. mudprawns).

Confidence: High

Fish:

Increased numbers of anglers has led to increased bait exploitation and targeting of recreational fish species. Both these activities have placed additional pressures on over-exploited fish species such as the white steenbras *Lithognathus lithognathus*.

Confidence: Medium

Birds:

Human activity (including boats and dogs) has a major impact on birds during peak holiday periods, disturbing both feeding and roost sites. Speed boating erodes banks, which destroys feeding habitat.

Confidence: High

Flood plain developments**Macrophytes:**

Numerous resort developments have encroached into the flood plain areas. Construction of the roadbridge removed salt marsh and the marina development resulted in the loss of reed and sedge areas.

Confidence: High

Invertebrates:

Developments along the flood plain may alter the configuration or even the infilling of channels feeding in to the estuary. This leads to habitat destruction and decrease of populations in these areas. The extension of the marina canals has also drastically altered habitats in the lower estuary and therefore the species assemblages originally living there.

Confidence: High

Fish:

Construction of the marina canals has provided increased habitat for fishes in the mouth region of the estuary.

Confidence: High

Birds:

Construction of the marina canals has provided increased habitat for birds.

Confidence: High

3.3 Reference Conditions

3.3.1 Abiotic components

i. Seasonal variability in river inflow

Monthly simulated runoff data (73-year period) for the Reference Condition of the Kromme Estuary and Geelhoutboom tributary are provided in Tables 3-3 and 3-4 respectively. A summary of the flow distribution (mean monthly flows in m³/s), derived from the simulated data set, is provided below (hatched months represent flows less than 0.2 m³/s when hypersaline conditions can potentially develop):

Kromme: Summary of flow distribution for Reference Condition

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	20.03	28.03	7.48	10.43	10.87	13.31	16.52	37.33	21.62	27.62	35.63	36.27
90%ile	10.74	8.51	3.58	2.01	3.58	3.66	2.75	9.62	5.59	5.21	12.81	10.21
80%ile	7.19	3.87	2.40	1.19	1.58	2.08	2.04	3.48	4.01	3.61	5.35	5.76
70%ile	4.23	2.89	1.89	1.04	1.04	1.20	1.68	1.78	2.59	3.22	4.33	4.57
60%ile	3.62	2.44	1.37	0.73	0.68	0.93	1.21	1.37	1.88	2.56	3.05	3.39
50%ile	2.83	1.98	1.11	0.59	0.59	0.78	0.95	1.06	1.53	2.11	2.58	2.73
40%ile	2.48	1.79	0.93	0.49	0.43	0.61	0.78	0.81	1.25	1.74	2.00	2.25
30%ile	2.24	1.50	0.84	0.42	0.33	0.48	0.59	0.69	0.86	1.49	1.66	1.87
20%ile	1.59	1.27	0.71	0.38	0.28	0.38	0.44	0.54	0.70	0.98	1.44	1.56
10%ile	1.35	0.95	0.53	0.32	0.25	0.28	0.34	0.39	0.52	0.74	1.05	1.13
1%ile	0.46	0.29	0.31	0.13	0.15	0.16	0.17	0.17	0.24	0.27	0.42	0.61

Geelhoutboom: Summary of flow distribution for Reference Condition

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	1.10	1.20	0.40	0.44	0.53	0.54	0.34	1.36	0.96	1.25	1.71	2.07
90%ile	0.47	0.37	0.17	0.09	0.13	0.17	0.19	0.27	0.26	0.19	0.44	0.58
80%ile	0.28	0.19	0.12	0.07	0.07	0.10	0.08	0.14	0.16	0.14	0.18	0.26
70%ile	0.19	0.14	0.09	0.05	0.05	0.07	0.07	0.07	0.10	0.10	0.15	0.20
60%ile	0.14	0.12	0.07	0.04	0.04	0.04	0.05	0.05	0.07	0.09	0.11	0.14
50%ile	0.12	0.09	0.05	0.03	0.02	0.03	0.04	0.04	0.06	0.08	0.10	0.11
40%ile	0.10	0.08	0.05	0.03	0.02	0.02	0.03	0.04	0.04	0.06	0.08	0.08
30%ile	0.08	0.07	0.04	0.02	0.02	0.02	0.02	0.03	0.04	0.05	0.06	0.07
20%ile	0.07	0.06	0.04	0.02	0.02	0.02	0.02	0.02	0.03	0.04	0.05	0.06
10%ile	0.06	0.05	0.03	0.02	0.01	0.01	0.02	0.01	0.02	0.03	0.04	0.05
1%ile	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.03

Table 3-3 Monthly simulated runoff data in m³/s (73-year period) for the Reference Condition into the Kromme Estuary

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1927	1.07	0.93	0.52	0.25	0.67	7.95	2.81	1.07	0.87	0.81	1.16	2.07
1928	2.35	4.13	1.54	0.52	0.39	0.29	0.31	0.54	0.84	3.38	2.72	3.98
1929	3.03	1.52	0.67	0.32	3.84	1.09	1.18	1.06	1.70	1.70	3.26	3.54
1930	2.95	1.61	0.86	0.93	0.44	0.37	0.43	0.52	0.55	2.58	1.67	9.83
1931	14.03	3.79	5.68	7.28	4.00	1.48	0.90	0.71	1.53	1.46	1.14	33.84
1932	10.35	4.29	1.88	0.54	0.63	0.64	2.35	10.72	4.07	2.66	20.56	5.71
1933	2.67	3.88	1.46	1.57	1.80	1.54	0.93	0.67	0.71	3.39	2.14	1.50
1934	11.73	2.81	0.95	0.32	0.86	0.54	1.11	33.31	8.08	4.04	6.90	4.90
1935	3.66	3.86	1.87	0.74	0.36	0.89	0.99	3.22	1.79	1.91	1.57	1.68
1936	2.72	10.66	2.74	0.73	0.46	1.08	0.65	0.39	1.38	2.31	1.66	2.26
1937	1.85	1.64	1.27	0.72	0.39	0.28	0.45	1.10	1.03	0.89	0.97	1.67
1938	1.79	3.32	1.11	0.42	8.17	3.96	2.09	1.35	0.91	1.82	6.89	4.53
1939	3.04	2.79	4.52	2.07	7.29	3.68	2.05	1.46	3.39	3.30	2.38	2.93
1940	2.22	1.46	0.61	0.64	0.46	0.51	1.27	0.81	4.94	1.95	1.38	1.56
1941	2.56	1.98	3.30	2.18	0.80	0.46	0.52	1.67	1.88	1.71	1.48	1.23
1942	2.15	1.88	1.21	1.15	0.63	0.53	0.63	0.58	11.44	3.37	2.90	4.66
1943	2.77	8.92	3.60	0.99	0.64	1.16	1.15	47.66	9.05	4.70	3.48	5.40
1944	3.61	1.88	0.87	0.40	0.29	0.28	0.30	21.99	12.32	4.12	3.24	2.56
1945	4.45	2.18	0.80	0.38	0.33	2.68	1.24	0.61	0.59	3.83	4.39	3.35
1946	3.71	1.86	0.70	0.33	0.22	1.10	2.51	4.70	5.73	18.33	4.55	2.78
1947	2.31	1.60	0.84	0.40	0.30	0.63	4.71	1.79	1.44	1.43	1.54	2.33
1948	10.33	3.30	1.25	0.83	0.64	0.38	0.37	0.43	0.36	0.31	0.45	0.55
1949	0.40	14.06	3.13	0.46	0.25	0.18	0.31	0.46	0.40	7.33	5.42	3.66
1950	3.87	18.65	3.19	9.11	2.54	0.83	0.44	1.39	2.20	15.17	5.16	7.94
1951	3.69	1.65	0.74	0.56	7.79	1.57	0.68	0.77	1.00	1.00	6.06	21.73
1952	6.24	2.98	1.35	0.52	0.47	0.38	0.35	0.27	1.17	3.13	4.29	6.07
1953	35.12	9.92	2.08	0.73	0.27	2.78	1.68	10.46	4.39	7.61	24.77	7.13
1954	2.60	1.97	0.89	0.46	16.33	3.60	1.21	0.90	0.88	0.95	4.19	2.73
1955	2.29	15.74	2.45	0.61	0.61	0.90	0.66	12.21	3.21	1.71	2.13	10.67
1956	12.53	6.28	4.23	1.43	1.50	1.27	1.38	1.95	2.29	2.11	2.63	5.92
1957	3.72	1.82	0.66	0.25	0.11	0.82	0.54	6.28	2.70	1.72	4.61	2.69
1958	2.38	1.28	0.82	3.05	1.11	0.89	2.02	1.72	1.40	2.14	5.24	3.34
1959	3.25	1.83	1.49	5.67	1.14	0.49	0.86	1.34	1.63	3.70	2.79	4.33
1960	2.34	1.40	0.76	0.44	0.59	7.69	2.33	3.65	2.46	1.96	2.00	1.69
1961	1.50	1.02	0.45	0.28	0.30	1.40	1.51	1.00	0.69	0.80	17.03	3.92
1962	5.03	2.60	1.00	1.26	0.69	10.62	6.99	4.34	2.74	2.38	2.40	1.89
1963	1.35	1.26	2.01	1.46	0.69	0.84	0.74	0.57	8.03	2.63	6.74	30.86
1964	9.12	2.82	1.27	0.50	0.25	2.44	1.75	2.71	2.51	2.12	1.57	1.20
1965	10.84	5.57	2.32	1.19	1.64	0.61	0.46	0.59	0.55	0.70	1.78	2.07
1966	1.64	1.48	0.86	0.34	0.27	0.83	15.38	5.26	3.33	3.27	2.94	4.18
1967	2.83	1.67	0.96	0.42	0.28	0.40	2.04	1.73	42.06	8.49	4.55	24.98
1968	6.19	2.65	1.08	0.48	0.32	0.34	0.34	0.34	1.27	1.10	1.09	2.28
1969	2.93	1.46	0.50	0.32	0.34	0.23	0.18	0.14	0.11	0.16	0.90	1.11
1970	1.77	1.11	6.32	1.14	2.40	1.10	9.54	5.66	4.35	19.40	52.76	12.54
1971	2.68	2.62	1.11	0.39	4.01	1.06	2.28	1.77	1.71	2.24	2.58	1.84
1972	0.87	0.50	0.23	0.12	0.20	0.78	0.89	0.79	0.60	0.41	0.48	0.63
1973	0.68	0.74	0.41	0.96	1.05	6.33	2.38	1.72	1.59	1.14	19.71	10.30
1974	3.90	1.33	0.48	0.34	1.04	2.08	0.97	0.43	0.74	0.97	1.48	2.08
1975	1.38	0.74	0.69	0.38	0.36	1.74	1.68	1.36	1.35	3.34	3.22	2.53
1976	7.44	3.86	2.16	0.71	1.80	1.10	0.83	21.80	5.01	2.44	2.15	3.02
1977	2.29	1.99	1.26	0.59	0.30	0.42	0.95	0.89	1.90	1.82	1.78	1.56
1978	7.64	2.67	2.22	1.19	0.83	0.45	0.39	0.74	1.40	5.34	28.97	9.40
1979	4.22	2.24	0.92	0.50	0.31	0.18	0.40	0.38	0.77	0.73	0.66	1.33
1980	1.36	1.45	1.57	3.02	1.16	20.24	4.25	13.82	3.93	2.56	20.43	5.79
1981	7.52	3.94	1.65	0.70	0.34	0.57	10.75	2.36	1.14	1.70	1.73	1.56
1982	1.23	0.74	0.35	0.13	0.16	0.13	0.23	0.53	0.84	48.77	9.25	3.06
1983	2.50	1.89	0.82	0.33	0.20	0.68	0.40	0.25	0.42	0.79	0.82	0.72
1984	0.48	0.32	0.93	1.03	1.03	0.58	1.80	0.90	1.26	1.51	1.22	0.80
1985	4.24	1.98	1.91	1.19	0.58	0.32	0.23	0.18	0.44	0.53	2.69	1.90
1986	6.82	3.03	1.13	0.46	0.27	0.23	1.44	0.78	2.70	1.74	1.42	4.95
1987	2.26	0.96	0.59	0.28	0.28	0.29	0.79	0.91	2.31	1.76	1.64	1.53
1988	1.58	0.95	0.76	0.38	0.25	0.17	0.91	0.72	0.60	1.32	1.08	1.69
1989	11.01	16.19	3.51	0.95	1.28	0.78	1.22	1.23	5.04	2.68	1.98	1.88
1990	3.57	2.18	0.85	0.32	0.22	0.18	0.14	0.18	0.33	0.34	1.05	0.91
1991	1.58	1.04	0.83	0.47	8.74	2.09	0.62	0.64	0.84	3.19	13.70	4.63
1992	14.16	6.90	2.01	1.04	1.09	0.51	0.74	0.78	13.68	3.87	3.52	42.52
1993	9.74	2.07	2.95	1.04	0.58	0.45	0.52	1.83	1.79	3.95	7.03	4.62
1994	6.45	2.40	6.96	13.81	2.50	2.08	1.78	2.64	1.96	1.54	1.67	1.71
1995	1.45	1.55	3.79	1.24	0.62	0.66	0.51	0.40	0.29	1.20	2.40	2.85
1996	11.44	52.15	8.82	1.07	0.57	0.70	19.45	5.43	4.18	3.48	3.01	2.22
1997	1.61	1.25	0.57	0.38	0.23	6.85	1.11	0.98	0.85	0.86	4.90	2.33
1998	1.44	1.13	0.94	0.57	0.31	0.46	0.44	0.55	0.52	2.88	1.77	1.08
1999	0.51	0.19	0.35	1.77	1.87	3.10	1.79	1.06	0.67	0.46	0.36	0.64

1 <0.2 1 0.2-1.0 2 1.0-8.0 3 >8.0

Table 3-4 Monthly simulated runoff data in m³/s (73-year period) for the Reference Condition into the Geelhoutboom tributary

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1927	0.04	0.04	0.02	0.01	0.01	0.44	0.20	0.05	0.04	0.03	0.04	0.07
1928	0.09	0.14	0.07	0.03	0.02	0.01	0.01	0.02	0.03	0.09	0.09	0.18
1929	0.13	0.07	0.04	0.02	0.08	0.06	0.05	0.04	0.06	0.06	0.10	0.11
1930	0.12	0.08	0.03	0.04	0.02	0.02	0.02	0.02	0.02	0.05	0.05	0.20
1931	0.46	0.22	0.25	0.67	0.29	0.07	0.05	0.03	0.04	0.05	0.05	1.93
1932	0.78	0.26	0.12	0.04	0.02	0.02	0.04	0.20	0.15	0.09	0.56	0.32
1933	0.12	0.15	0.07	0.04	0.04	0.05	0.04	0.03	0.03	0.10	0.09	0.07
1934	0.30	0.17	0.05	0.02	0.02	0.01	0.04	1.23	0.55	0.17	0.20	0.20
1935	0.17	0.16	0.10	0.04	0.02	0.02	0.02	0.08	0.06	0.06	0.06	0.05
1936	0.12	0.39	0.18	0.04	0.02	0.03	0.02	0.01	0.04	0.05	0.05	0.08
1937	0.07	0.07	0.05	0.03	0.02	0.01	0.02	0.04	0.04	0.04	0.04	0.05
1938	0.07	0.09	0.05	0.02	0.17	0.15	0.08	0.05	0.04	0.05	0.33	0.21
1939	0.13	0.11	0.11	0.09	0.13	0.13	0.08	0.05	0.08	0.09	0.08	0.11
1940	0.09	0.07	0.03	0.02	0.02	0.02	0.03	0.02	0.12	0.08	0.05	0.05
1941	0.08	0.07	0.16	0.11	0.04	0.02	0.02	0.07	0.07	0.07	0.06	0.05
1942	0.10	0.07	0.05	0.05	0.03	0.02	0.02	0.02	0.33	0.19	0.13	0.19
1943	0.14	0.26	0.17	0.06	0.03	0.07	0.07	1.68	0.71	0.18	0.15	0.23
1944	0.18	0.10	0.04	0.02	0.02	0.01	0.01	0.44	0.39	0.18	0.15	0.14
1945	0.25	0.14	0.05	0.02	0.01	0.14	0.08	0.03	0.02	0.09	0.11	0.10
1946	0.11	0.07	0.03	0.02	0.01	0.06	0.06	0.12	0.17	0.44	0.25	0.13
1947	0.10	0.08	0.04	0.02	0.02	0.03	0.19	0.10	0.06	0.05	0.05	0.07
1948	0.28	0.16	0.05	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02
1949	0.01	0.71	0.26	0.02	0.01	0.01	0.02	0.02	0.02	0.08	0.16	0.14
1950	0.15	0.41	0.20	0.34	0.17	0.04	0.02	0.04	0.05	0.24	0.18	0.27
1951	0.19	0.09	0.04	0.03	0.27	0.11	0.03	0.04	0.05	0.04	0.12	0.88
1952	0.40	0.13	0.07	0.03	0.02	0.02	0.02	0.01	0.03	0.08	0.14	0.27
1953	1.81	0.75	0.11	0.04	0.02	0.18	0.11	0.45	0.27	0.23	1.18	0.52
1954	0.13	0.08	0.05	0.03	0.70	0.28	0.06	0.04	0.04	0.05	0.17	0.14
1955	0.09	0.36	0.16	0.04	0.04	0.06	0.04	0.41	0.21	0.09	0.09	0.37
1956	0.72	0.39	0.22	0.09	0.09	0.07	0.06	0.07	0.10	0.09	0.11	0.25
1957	0.20	0.11	0.04	0.01	0.01	0.04	0.03	0.21	0.14	0.07	0.14	0.12
1958	0.09	0.06	0.04	0.12	0.07	0.03	0.07	0.06	0.05	0.06	0.11	0.11
1959	0.11	0.08	0.05	0.10	0.06	0.02	0.02	0.05	0.06	0.10	0.10	0.10
1960	0.07	0.05	0.03	0.02	0.03	0.26	0.15	0.16	0.13	0.10	0.10	0.08
1961	0.07	0.05	0.02	0.02	0.01	0.08	0.08	0.05	0.04	0.04	0.45	0.24
1962	0.19	0.13	0.05	0.09	0.05	0.36	0.27	0.14	0.10	0.09	0.08	0.07
1963	0.06	0.06	0.09	0.08	0.04	0.04	0.03	0.02	0.23	0.13	0.16	2.02
1964	0.75	0.15	0.07	0.03	0.01	0.03	0.04	0.06	0.07	0.06	0.05	0.05
1965	0.23	0.22	0.09	0.05	0.05	0.02	0.02	0.02	0.02	0.02	0.05	0.06
1966	0.06	0.07	0.04	0.02	0.01	0.01	0.35	0.27	0.15	0.12	0.12	0.17
1967	0.13	0.08	0.04	0.02	0.01	0.02	0.08	0.07	1.59	0.65	0.19	0.99
1968	0.43	0.12	0.06	0.03	0.02	0.02	0.02	0.02	0.03	0.04	0.04	0.05
1969	0.08	0.06	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.03	0.04
1970	0.06	0.05	0.17	0.07	0.06	0.05	0.33	0.27	0.18	1.04	2.91	1.01
1971	0.12	0.11	0.06	0.02	0.10	0.05	0.07	0.06	0.06	0.07	0.08	0.07
1972	0.04	0.03	0.01	0.01	0.01	0.04	0.05	0.04	0.04	0.02	0.02	0.03
1973	0.03	0.05	0.03	0.08	0.08	0.33	0.17	0.10	0.10	0.07	0.45	0.59
1974	0.25	0.08	0.04	0.03	0.05	0.09	0.05	0.02	0.03	0.04	0.08	0.14
1975	0.09	0.05	0.04	0.02	0.02	0.11	0.13	0.09	0.07	0.16	0.15	0.12
1976	0.28	0.20	0.08	0.04	0.15	0.08	0.05	0.67	0.34	0.12	0.10	0.20
1977	0.15	0.14	0.09	0.04	0.02	0.03	0.06	0.05	0.08	0.08	0.08	0.08
1978	0.14	0.15	0.09	0.07	0.05	0.03	0.02	0.03	0.05	0.14	1.25	0.61
1979	0.19	0.11	0.05	0.04	0.02	0.01	0.02	0.02	0.04	0.03	0.03	0.05
1980	0.07	0.08	0.06	0.16	0.08	0.80	0.34	0.28	0.20	0.13	0.87	0.42
1981	0.32	0.20	0.08	0.04	0.02	0.02	0.31	0.15	0.05	0.06	0.08	0.08
1982	0.07	0.05	0.02	0.01	0.01	0.01	0.01	0.02	0.03	1.78	0.72	0.14
1983	0.12	0.09	0.05	0.02	0.01	0.03	0.02	0.01	0.02	0.04	0.04	0.04
1984	0.03	0.02	0.03	0.06	0.05	0.02	0.03	0.03	0.06	0.06	0.06	0.04
1985	0.08	0.08	0.06	0.05	0.03	0.01	0.01	0.01	0.02	0.02	0.09	0.08
1986	0.30	0.19	0.07	0.03	0.02	0.01	0.05	0.04	0.15	0.09	0.07	0.19
1987	0.12	0.05	0.03	0.01	0.02	0.02	0.03	0.04	0.08	0.07	0.06	0.06
1988	0.06	0.05	0.04	0.02	0.02	0.01	0.05	0.04	0.02	0.04	0.04	0.07
1989	0.59	0.81	0.27	0.05	0.07	0.05	0.07	0.07	0.21	0.15	0.10	0.10
1990	0.18	0.12	0.05	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.04	0.04
1991	0.07	0.05	0.05	0.03	0.47	0.17	0.04	0.04	0.05	0.09	0.43	0.27
1992	0.48	0.38	0.13	0.07	0.04	0.02	0.05	0.04	0.55	0.26	0.13	2.20
1993	0.82	0.12	0.11	0.07	0.04	0.04	0.03	0.04	0.05	0.09	0.23	0.18
1994	0.14	0.08	0.14	0.13	0.11	0.10	0.08	0.09	0.07	0.06	0.06	0.07
1995	0.08	0.08	0.12	0.07	0.03	0.03	0.02	0.01	0.01	0.03	0.07	0.08
1996	0.48	2.21	0.75	0.06	0.03	0.02	0.32	0.20	0.17	0.15	0.15	0.12
1997	0.08	0.06	0.03	0.03	0.02	0.10	0.06	0.03	0.03	0.03	0.10	0.09
1998	0.06	0.06	0.05	0.03	0.02	0.02	0.02	0.02	0.02	0.11	0.08	0.05
1999	0.03	0.01	0.03	0.05	0.09	0.16	0.10	0.05	0.04	0.02	0.02	0.03
	1	<0.08			2	0.08-		3	>1.0			

ii. Flood regime for the Reference Condition

All floods reached the estuary, from freshettes to major floods. This led to resetting of the salinity profile and scouring particularly from the middle and lower reaches.

Return Period (years)	Peak Discharge – Reference Condition (m ³ /s)	Peak Discharge – Present State (m ³ /s)
2	45 ¹	20 ² (55%)
10	360	185 (49%)
20	720	445 (38%)

¹: Based on 11-year period (1993- 2004)

²: Percentage change in magnitude from Reference Condition

Confidence: High

iii. Changes in sediment processes under reference compared with present

Under Reference Condition, marine sediment in the lower reaches would have been flushed more regularly, thus the upstream intrusion of marine sediments into the estuary would have been less. Due to more regular flushing the channel in the lower reaches was probably also deeper.

In the absence of farm and major dams, sediment load from the catchments of the Kromme and Geelhoutboom rivers would have been much higher. As a result the upper sediments in the upper estuary would have been finer compared to the Present State. However, most of the silt and clays would have been flushed through the estuary during floods.

Confidence: High

iv. Occurrence and duration of different Abiotic States under the Reference Condition

Estimated occurrence and duration of the different Abiotic States in the Kromme Estuary and Geelhoutboom Tributary under the Reference Condition, based on simulated monthly river inflow from the Kromme and Geelhoutboom rivers are indicated in Tables 3-3 and 3-4, respectively.

To provide a conceptual overview of the annual distribution of Abiotic States under the Reference Condition for the Kromme Estuary and Geelhoutboom tributary, median monthly flows (representative of seasonal conditions) and 10%ile flows (representative of drought conditions) were used to depict the situation for normal and drought periods (Figure 3-2).

Confidence: Medium

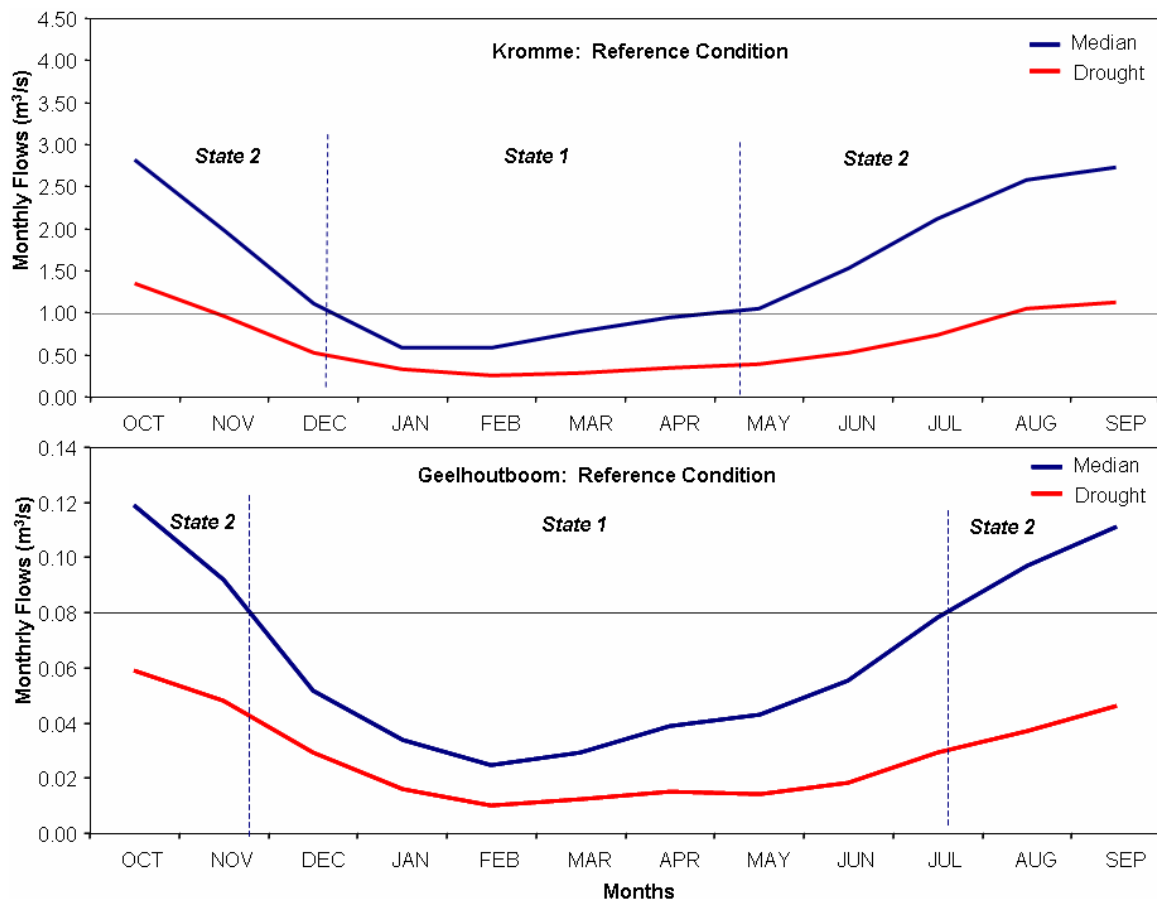


Figure 3-2 Predicted distribution of Abiotic States under the Reference Condition for the Kromme Estuary and Geelhoutboom tributary, based on median monthly flows (representative of seasonal conditions) and 10%ile flows (representative of drought conditions)

3.3.2 Biotic components

The predicted change in biotic characteristics in the Kromme Estuary (including the Geelhoutboom tributary), from the Reference Condition to the Present State, are discussed below.

Microalgae

The REI concept was developed in estuaries with a classical “cone-shaped” bathymetry. The upper reaches are narrow and shallow and thus become deeper and wider towards the lower reaches of the estuary. This means that as freshwater enters an estuary, a longitudinal salinity gradient develops from 0 ppt at the head of the estuary to marine (~35 ppt) near the mouth under average flow conditions. This bathymetry allows the ‘fresh’ water to flow over the denser saline water with gradual mixing. Results from studies in the Sundays and Gamtoos estuaries have shown that a well developed phytoplankton chl a maximum develops in the region of the estuary where vertically averaged salinity is 4–10 ppt, and is particularly strong at a flow of 1 m³/s or residence time of 3 tidal cycles (42 days). This region of the estuary is generally turbid due to the flocculation of particles (fine sediment, organic matter, nutrients and microalgae), which settle out and are an essential source of nutrients (for subtidal benthic microalgae in particular) during periods of low flow/poor nutrient input. In the case of the Kromme Estuary, the bathymetry is reversed (i.e. shallow at the mouth and deepest at the head of the estuary). Freshwater from the Kromme River flows off a rocky sill into a generally saline (>30 ppt) water body with limited mixing. The large volume of water in this reach of the estuary probably limits the effectiveness of freshwater mixing unless the input was over an extended period (a persistent flow of 4-8 m³/s would scour saline waters from deeper areas but residence time would only be 3-7 days under these conditions).

During the Reference Condition, a continuous input of freshwater will create a weak or diffused REI zone through the mixing of freshwater (anion-rich) and cation-rich seawater. The flocculation of fine particles (sediment, organic matter, nutrients and microalgae) creates a peak in phytoplankton chl a (>10 µg/l, particularly in the middle reaches of the estuary) and provides a more suitable environment for epipellic

(mud associated) microphytobenthos. Kromme River water is considered to be low in nutrients so the microalgal response will be limited. It is expected that a strong halocline will exist in the middle and upper reaches of the estuary (>5 km from the mouth) so a significant increase in benthic microalgal biomass will only be seen in the intertidal microalgae (commonly reaching >100 mg/m²). Mixing of water near the mouth will result in high intertidal and subtidal benthic chl a (>100 mg.m⁻²). Freshwater entering the estuary from the Impofu Dam is dominated by diatoms (>60% of phytoplankton), flagellates (~30%) and also contains chlorophytes (~5%). This creates a change in community structure from one dominated by diatoms near the head of the estuary to one dominated by flagellates closer to the mouth. Dinoflagellates will only occur in saline water near the mouth of the estuary. As flow decreases from Reference to Present State, average phytoplankton and intertidal chl a will decrease, and the community structure will change to one dominated by small flagellates throughout the estuary.

Confidence: High

Macrophytes

Species diversity, richness and rarity: There has been an increase in colonisation of the estuary by marine macroalgae, particularly *Codium tenue* and *Gracilaria verrucosa*. However, the scoring system only measures the loss of species that were part of the original community and does not take new introductions into account. Therefore this change does not influence the score. The increase in salinity and lack of sediment removal by floods may have resulted in the loss of some brackish species and primary colonisers. Approximately 80% of the original species probably remain.

Confidence: Medium

Biomass distribution: The reduction in freshwater inflow and flooding has led to increased sediment stability and stable high salinity. This has resulted in an increase in *Zostera capensis* biomass and aerial distribution. *Zostera* now covers 31 ha compared to 10.8 ha in 1942. There has also been an increase in the biomass of marine macroalgae. Because of the decrease in freshwater inflow, reeds and sedges have probably been lost from the Geelhoutboom tributary. In the Kromme Estuary they only occur in areas where there is freshwater seepage into the estuary. The marina development removed 7.2 ha of reed and sedge wetland area. However, there appears to have been an increase in the area covered by reeds in the lower reaches of the estuary (6 ha) which can be attributed to increased sediment stability and probably also increased freshwater seepage and nutrient input from surrounding developments. A decrease in freshwater inflow has led to high surface soil salinities, which has resulted in a number of bare patches in the salt marshes. The construction of the road bridge and numerous resort developments in the floodplain has resulted in the loss of 17 ha of salt marsh. There is some evidence of salt marsh erosion in the middle reaches of the estuary due to boat activity. Despite all these changes the large intertidal salt marsh areas have remained relatively intact, as they are dependent on an open mouth and daily tidal exchange.

Confidence: High

Seasonal variability and community composition: Because floods are greatly reduced, the increased sediment and salinity stability has resulted in increased colonisation of the estuary by *Zostera*, marine macroalgae and salt marsh. The macroalgae are free floating and occur in calm sheltered areas in the estuary. They are particularly abundant in the Kromme Estuary compared to other permanently open estuaries because of the lack of flushing and high stable salinities. Reed and sedge communities are restricted to areas of freshwater seepage and brackish marshes are reduced, particularly in the upper reaches of the Geelhoutboom tributary.

Confidence: Medium

Invertebrates (including zooplankton, benthic invertebrates and macrocrustaceans)

Species diversity, richness and rarity: Changes to the invertebrate community are probably very significant. Under the Reference Condition, zooplankton species richness would have been much lower compared to present. Marine associated species would have colonised the estuary intermittently in the mouth area. On the ebb tide, species would flush from the estuary, returning again on the flood. The common estuarine copepod *Acartia natalensis* was likely abundant every summer under the Reference Condition, while the copepod *Tortanus capensis* was likely absent from the estuary. Marine benthic species such as the redbait *Pyura stolonifera*, the gastropod *Notilittorina scabra* and the barnacle *Balanus elizabethae* would have been absent.

Confidence: Medium

Biomass distribution: The reduction in freshwater inflow has led to increased sediment stability, high salinity

values and low microalgal biomass throughout the estuary. Zooplankton biomass has probably declined significantly. Because of the increase in *Z. capensis* density and coverage, conditions favoured *Palaemon perengueyi*. This species is now responsible for about 25% of invertebrate annual production in the Kromme Estuary. Biomass of other species such as *Callinasa kraussi*, *Exosphaeroma hylocoetes*, *Cleistostoma edwardsii*, *Hymenosoma orbicular* and *Lamya capensis* probably also increased. The mudprawn *Upogebia africana* on the other hand, has probably reduced in biomass because of habitat loss.

Confidence: High

Seasonal variability and community composition: Because of the less frequent pulsing by freshettes and reduced flooding, seasonal variability would be less, particularly among the zooplankton.

Confidence: Medium

Fish

Species diversity, richness and rarity: Certain freshwater fish species such as the Cape kurper *Sandelia capensis* would have been able to colonise the headwaters of the Kromme Estuary. However, under present conditions, all primary freshwater species are excluded from any part of the estuary. Increased colonisation of the estuary by marine stragglers such as *Lithognathus mormyrus* and *Diplodus cervinus* has boosted the number of fish species recorded in the estuary. However, as pointed out above, the scoring system only measures the loss of species that were part of the original community and does not take new introductions into account. Therefore this marine species increase does not influence the score and about 90% of the original species probably remain.

Confidence: Medium

Biomass distribution: The reduction in planktonic productivity has negatively influenced the biomass of planktivorous fish species in this estuary, particularly in the middle and upper reaches. The increase in *Zostera* density and coverage will have increased the biomass of fish species such as *Rhabdosargus holubi*, especially in the middle and upper reaches. Consequently the overall fish biomass is likely to have shown only a moderate decline from the Reference Condition.

Confidence: Medium

Seasonal variability and community composition: Reduced river floods and freshettes will have reduced seasonal variability and resulted in a more uniform community composition throughout the year.

Confidence: Medium

Birds

Species diversity, richness and rarity: It is unlikely that there has been any absolute change in species richness, nor any major change in diversity in the sense of 'evenness' (but see community composition below). Certain species such as the Oystercatcher might have become rarer, because of human disturbance rather than flow related changes.

Confidence: Medium

Biomass distribution: Bird biomass might be more heavily skewed towards the mouth in the Present State than in the Reference Condition. In the Reference Condition the upper reaches and middle reaches would probably have been more productive due to fewer structures and less disturbance.

Confidence: Medium

Seasonal variability and community composition: Community composition is likely to have changed measurably from the Reference Condition, mainly due to changes in habitat and invertebrate communities. The loss of freshwater habitat from the upper reaches of the Kromme Estuary and Geelhoutboom tributary appears to have discouraged the presence of waterfowl, which might have been common in the past. Decreased reed and sedge habitats on the Geelhoutboom tributary will have resulted in fewer reedbed birds, though this may be compensated to some extent by the increase in reeds in the lower estuary. The loss of salt marsh may have been a deterrent to waders and wading birds that roost and feed in those habitats, and the loss would be greater if the roadbridge also displaced creek areas. Tripling of the area of *Zostera* is likely to have led to a change in the composition of waders in particular. The resultant increase in small invertebrate species and loss of large species (*Upogebia*) would have encouraged smaller, tactile

foraging birds over larger, visually foraging waders. Thus the relative proportion of larger species such as Whimbrel and Curlew is expected to have decreased. Changes in fish composition will not have affected piscivorous birds unless they involve changes in overall biomass of small to medium sized fish (details not provided above). The minor changes in turbidity are unlikely to have had a significant effect.

Confidence: Medium

3.4 Present Ecological Status of the Kromme Estuary

The Present Ecological Status is determined using the Estuarine Health Index (EHI) described in detail in Appendix C of the *Resource directed measures for protection of water resource: Methodology for the Determination of the Ecological Water Requirements for Estuaries, Version 2* (DWAf, 2004). Details regarding the individual scoring systems are included in that 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 determined as a '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.

For the scoring of hydrological, hydrodynamics and certain water quality scores (see below), it was deemed necessary to distinguish between the main Kromme Estuary and the Geelhoutboom tributary to accommodate complexities. This was not necessary from a biotic perspective, as the biotic components of the estuary functions as a holistic system.

Hydrology

Variable	Score	Motivation	Confidence
a. % similarity in period of low flows OR Present MAR as a % of MAR in the Reference Condition	33	For the Kromme Estuary low flows are defined as flows associated with State 1 (i.e. $< 1 \text{ m}^3/\text{s}$). Months with low flows of less than $1 \text{ m}^3/\text{s}$ increased from 4 (Jan – Apr) under the Reference Condition to 12 months under the Present State.	H
	58	For the Geelhoutboom tributary low flows are defined as flows associated with the State 1 (i.e. $< 0.08 \text{ m}^3/\text{s}$). Months with median low flows of less than $0.08 \text{ m}^3/\text{s}$ increased from 7 (Dec – Jun) under the Reference Condition to 12 months under the Present State.	L
b. % similarity in mean annual frequency of floods	20	The major floods (1:20) (magnitude and frequency) have been dramatically modified and most of the smaller floods (1:5 years) do not reach the estuary under the Present State. Allow for an 80% modification from Reference Condition.	H

	80	There are no large impoundments in the Geelhoutboom tributary; therefore most large floods (1:20) from this tributary still reach the estuary. This is also supported by the fact that monthly flows >1.0 m ³ /s reach the estuary. They occurred 15% of the years under the Reference Conditions and 13% of the years under the Present State.	M
Hydrology Score	33.65	Kromme - weight 85%; Geelhoutboom - weight 15%	

Hydrodynamics and mouth condition

Variable	Score	Motivation	Confidence
Change in mean duration of closure, e.g. over a 5 or 10 year period	100	Due to tidal flows the estuary mouth remains permanently open.	H
	100	Due to tidal flows the estuary mouth remains permanently open.	H
Hydrodynamic Score	100		

Water quality

Variable	Score	Motivation	Confidence
1. Change in the longitudinal salinity gradient (%) and vertical salinity stratification	30	State 3 occurred for 1 out of 2 years (52%) for about 1 – 2 months at a time under the Reference Conditions. For the Present State this has been reduced to 1 out of 4 years (26%) for a month at a time. Furthermore, State 2 is no longer present under the median flow conditions. Under the Present Conditions there is also a slight tendency to develop hypersaline conditions towards the end of summer. This signifies largely modified salinity conditions. Note: Under the Reference Condition the estuary fluctuated between State 1 (marine dominated) and State 2 (saline gradient) under its median flow conditions.	H
	25	Under the Present State, State 2 is no longer reflected in median flow conditions of the Geelhoutboom tributary. This implies that there is no significant gradient in the system anymore. It has become a homogenous water body, which takes on the salinity of the Kromme Estuary (middle reaches). Under the Reference Condition this would have varied between 20 to 35 ppt depending on whether State 1 or 2 were present in the Kromme Estuary. Under the Present State the Geelhoutboom tributary is around 35 ppt for ~12 months of the year under median flow conditions (as a result of only State 1 occurring in the Kromme Estuary under the Present State.	M
Kromme Score (weight 85%)	25.5	Geelhoutboom Score (weight 15%)	3.8

Variable	Score	Motivation	Confidence
2a. Nitrate/phosphate concentration in the estuary	33	The Kromme system (including the Geelhoutboom tributary) receives its inorganic nutrients through river inflow, either the Kromme and/or Geelhoutboom rivers. State 1 (little to no freshwater inflow) is therefore characteristic of nutrient depleted conditions. During States 2 and 3 river inflow introduced inorganic nutrients to the estuary. State 2 no longer occurs under the Present State and freshwater pulses (State 3) have also been reduced. Under the Present State, State 1 now occurs for 12 months (compared to 4 months (Jan – April) under the Reference Condition). Using Table 3.2b (DWAF, 2004), which is also used to derive scores for low flow periods, this translates into a score of 33.	L/M
2b. Suspended solids (turbidity) in the estuary	33	The Kromme system receives suspended solids through river inflow. States 2 and 3 (both in the Kromme and Geelhoutboom) are therefore characterised by higher suspended solid concentrations (or higher turbidity) than State 1. In the Present State, State 2 no longer occurs in the System and freshwater pulses (under which State 3 would have developed) have also been reduced. Under the Present State, State 1 now occurs for 12 months (compared to 4 months (Jan – April) under the Reference Condition). The estuary under the Present State is therefore considered to be less turbid than under the Reference Condition (used to be 'clear' for 4 months, now 'clear' for 12 months). Using Table 3.2b (DWAF, 2004), which is also used to derive scores for low flow periods this translates into a score of 33.	L/M

Variable	Score	Motivation	Confidence
2c. Dissolved oxygen in the estuary	70	The Kromme System is usually well oxygenated, except during prolonged periods of State 1, when a reduction in oxygen has been observed in the deeper areas in the upper reaches of the estuary, although after construction of the Impofu Dam this would seldom drop to below 5 mg/l as the dam probably cut off significant organic inputs to the upper reaches. Higher organic input during the Reference Condition, however, would probably have resulted in more severe reduction in DO in this region in the 4 months in which State 1 occurred. Allow for a modification of 10% during those periods. Also, the risk of lower oxygen conditions has been extended by about 66% from the Reference to Present State (State 1 occurs for 12 months instead of 4 months). However, DO reductions are not expected to be severe (seldom drop below 5 mg/l). Allow for a modification of 20% during those periods.	L/M
2d. Levels of toxins	100	Studies conducted on trace metal distribution patterns in the Kromme Estuary concluded that trace metals did not present a hazard due to the absence of urbanisation and industrialisation in the area. There are also no major agricultural sources of toxins, as the catchment is comprised largely of undisturbed rural areas and limited agriculture development (stock raising and grain cultivation).	M
Water Quality Score	33.2		

Physical habitat alteration

Variable	Score	Motivation	Confidence
1. Resemblance of intertidal sediment structure and distribution to Reference Condition			
1a. % similarity in intertidal area (size) exposed	70	The estuary was probably deeper under the Reference Condition and the sandbanks not as widespread. However, the rate at which sedimentation occurs is slow so the intertidal area will not have changed dramatically yet, but the process is still on a trajectory of change. Some intertidal areas were also lost locally due to sedimentation effects of the bridge.	M
1b. % similarity in sand fraction relative to total sand and mud	50	The marine sediment area (sandy habitat) stretches further upstream and in the upper part of the estuary all the fine sediments (muddy habitat) are being flushed away resulting in coarser bed sediment. This process is still on a trajectory of change (predicted that estuary will be a mainly sand habitat in 400 years).	M
2. Resemblance of sub-tidal sediment structure and distribution to Reference Condition			
2. Resemblance of subtidal estuary to Reference Condition: depth, bed or channel morphology	80	The estuary is shallower under the Present State and the marine sediment moves slowly upstream. The rate at which sedimentation occurs is, however, slow. Bed sediments are becoming coarser. This process is also still on a trajectory of	M

Variable	Score	Motivation	Confidence
		change (predictions show that if Present State proceeds the estuary will fill up in 2000 years not taking into account sea level rise).	
Physical habitat Score	70		

Microalgae

Variable	Score	Motivation	Confidence
Phytoplankton			
1. Species richness	17 (40%)	Dramatic reduction in flow has led to a decrease in freshwater species entering the estuary, and has led to a reduction in inorganic nutrients and Suspended Solids (SS) entering the estuary. A community associated with freshwater has been lost during extended periods of zero river input.	H
2a. Abundance/Biomass	67	The reduction in flow has caused a decrease in the concentration of inorganic nutrients and SS (turbidity) entering the estuary. Average chl a in the estuary has decreased by ~33%. The decrease would be greater but inorganic nutrient and SS (turbidity) levels in the Kromme River are considered to be low and a biomass similar to the nearby eutrophic Gamtoos Estuary (maximum chl a of ~50 µg.l ⁻¹) is unlikely.	H
2b. Community composition	40	Dramatic reduction in flow has led to a decrease in freshwater species entering the estuary. Reduced river inflow has also led to a reduction in inorganic nutrients and SS (turbidity) entering the estuary. Diatom dominated freshwater has almost been entirely stopped from entering the estuary.	H
Benthic microalgae			
1. Species richness	17 (40%)	The loss/reduction of inorganic nutrient and SS input from the river has the greatest impact on benthic microalgae. Therefore, flocculation of SS (and associated nutrients) on entering the estuary under the Reference Condition would have provided a more suitable habitat for <u>epipellic</u> (mud-associated) microalgae. Coarser sediment, as is the case under the Present State, supports <u>episammic</u> (sand-associated) species. Reduced freshwater and inorganic nutrients would also have adversely affected <u>epilithic</u> (rock-associated) microalgae, the primary community in the upper reaches of the estuary. Prolonged stable conditions favour the dominance of only a few species.	H
2a. Abundance/Biomass	50	The loss/reduction of inorganic nutrient and SS input from the river has reduced average benthic chl a. A relatively high biomass is still recorded towards the mouth of the estuary albeit different species than would have made up abundance in the Reference Condition.	H

Variable	Score	Motivation	Confidence
2b. Community composition	40	The loss/reduction of inorganic nutrients and SS input from the river has the greatest impact on benthic microalgae. The flocculation of SS (and associated nutrients) on entering the estuary provides a suitable habitat for epipellic (mud-associated) microalgae. Coarser sediment, as is currently the case, supports an episammic (sand-associated) community. Reduced freshwater and nutrients will adversely affect epilithic (rock-associated) microalgae, the primary community in the upper reaches of the estuary.	H
Microalgae Score	17		

Macrophytes

Variable	Score	Motivation	Confidence
1. Species richness	65 (80%)	Loss of brackish salt marsh species as well as reed and sedge species due to an increase in salinity and occurrence of hypersaline conditions. Loss of primary colonisers as a result of reduced flooding. 80% of original species probably remain. Note: The presence of marine macroalgae in the system (although not significant at present) suggests that if saline conditions remain dominant, these algae could out-compete endemic macrophytes. In this regard the estuary might still be on a trajectory of change (which will result in even larger modifications).	M
2a. Abundance/Biomass	50	Due to a reduction in freshwater input and the resultant increase in sediment stability, <i>Zostera capensis</i> biomass has increased three-fold. An increase in water column salinity has probably reduced the biomass of the reed and sedge communities but has resulted in an increase in macroalgal biomass. A decrease in freshwater inflow has led to high surface soil salinities which has resulted in a number of bare patches in the salt marsh. The construction of the road bridge and numerous resort developments in the flood plain has resulted in the loss of some salt marsh (17 ha) and reeds and sedges (1 ha). The construction of the marina removed a large reed and sedge wetland area. Boat activity has caused some erosion of salt marshes. Despite all these changes the large salt marsh areas have remained relatively intact as they are dependent on an open mouth and daily tidal exchange.	M
2b. Community composition	50	Because of increased salinity and stable water column conditions, macroalgae dominate the submerged community. Reed and sedge communities, restricted to areas of freshwater seepage and brackish marshes, are reduced.	M
Macrophyte Score	50		

Invertebrates

Variable	Score	Motivation	Confidence
Zooplankton			
1. Species richness	35 (60%)	Because of salinity remaining at or close to that of seawater for indefinite periods, species requiring reduced salinity conditions are now relatively rare (<i>Acartia natalensis</i>). Brackish water species are now only present when freshwater pulsing reduces salinity values significantly (infrequent).	M
2a. Abundance/Biomass	35	The loss of regular freshwater pulsing after construction of the Impofu Dam has led to a dramatic decline in abundance levels of dominant estuarine species. This is linked to reduced food availability (phytoplankton) and no salinity gradient along the estuary.	H
2b. Community composition	40	Species such as <i>Tortanus capensis</i> do not occur in systems having a horizontal salinity gradient. The mix of other species has also changed.	H
Macroinvertebrates (Macrobenthos)			
1. Species richness	35 (60%)	Because of salinity remaining at or close to that of seawater for indefinite periods, species requiring reduced salinity conditions are now relatively rare (typically some Polychaete and Oligochaete worms).	M
2a. Abundance/Biomass	80	Changes in density and coverage of <i>Zostera capensis</i> has led to significant changes in abundance levels of many species. Some have increased because of a positive association with eelgrass (<i>Hymenosoma orbiculare</i> , amphipods etc), and others have decreased because of their negative association with eelgrass (<i>Upogebia africana</i>). Brackishwater polychaetes have also declined in abundance.	H
2b. Community composition	20	The mix of species has probably changed significantly because of persistently high salinity values in the estuary, as well as the increase in <i>Zostera</i> coverage and biomass.	H
Macrocrustacea (Large crustacean)			
1. Species richness	57 (75%)	Due to the persistence of State 1 (marine state), freshwater associated species disappeared, e.g. <i>Macrobrachium</i> spp. (about 1 out of 4 possible species).	M
2a. Abundance/Biomass	50	Changes in density and coverage of <i>Zostera capensis</i> has probably led to change in abundance of some species. Eelgrass also provides protection from visually hunting predators. Species such as <i>Macrobrachium</i> spp. probably occurred in the brackish water reaches under natural conditions.	M

Variable	Score	Motivation	Confidence
2b. Community composition	40	The mix of species has probably changed significantly because of persistently high salinity values in the estuary, as well as the increase in <i>Zostera</i> coverage and biomass.	M
Invertebrate Score	20		

Fish

Variable	Score	Motivation	Confidence
1. Species richness	80 (90%)	All marine and estuarine fish species that colonised the Kromme Estuary are still present in the system. However, there has been a loss of a few freshwater species.	M
2a. Abundance/Biomass	80	There has probably been a major decline in the abundance of planktivorous fish species (30%-) but a slight increase in the abundance of macrophyte associated species (10%+).	M
2b. Community composition	40	Species composition has undergone major changes as a result of the increase in abundance of macrophyte associated species and decline in planktivorous fish species.	M
Fish Score	40		

Birds

Variable	Score	Motivation	Confidence
1. Species richness	80 (90%)	There has been no absolute loss of habitat or food type, but a dramatic reduction in freshwater habitat may have led to loss of some species.	M
2a. Abundance/Biomass	80	There has been a net loss in productivity of the most important food species and a massive increase in human disturbance.	M
2b. Community composition	70	Community composition is thought to have shifted towards smaller species, with loss or decreased numbers of freshwater and disturbance-sensitive species.	M
Bird score	70		

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

Component	% Change non-flow related	Motivation	Confidence
Physical habitat alteration: Intertidal and supratidal	15%	The development of the St Francis Bay Marina has contributed to the intertidal habitat of the estuary. The bridge approaches are implicated in the loss of some supratidal habitat. The construction of numerous jetties (and related bank stabilisation) has resulted in the loss/modification of some intertidal habitat.	M
Physical habitat alteration: Subtidal	10%	The development of the St Francis Bay Marina has contributed to the subtidal habitat of the estuary. The construction of numerous jetties (and related bank stabilisation) has resulted in the loss/modification of some subtidal habitat.	M
Microalgae	0% (no change)	Jetties and roads have a negligible effect on microalgae. Marina also found to have had a negligible impact in terms of nutrient enrichment and microalgal functioning.	H
Macrophytes	20%	The building of the road bridge, private roads and numerous resort developments has led to the destruction of salt marsh and reed and sedge communities. The largest reed bed was removed when the marina was expanded. Boat activity has caused erosion of salt marsh in the middle reaches of the estuary.	H
Invertebrates	20%	Loss and changes to vegetation will negatively influence faunal composition and abundance at the altered sites.	H
Fish	10%	Physical alterations to the estuarine vegetation in places (e.g. bridges), together with increasing fishing pressure on certain species, has impacted on the fish community.	M
Birds	50%	Much of the loss of biomass would be ascribed to direct human disturbance and loss of habitat.	H

The individual scores for each of the components (i.e. overall score listed) are incorporated into a Habitat health score and a Biological health score. This allows for the determination of the Estuarine Health Index (EHI) Score as illustrated in Table 3-5.

Table 3-5 Estuarine Health Score results for the Present State of the Kromme Estuary

Variable	Weight	Score	Weighted score
Hydrology	25	33.7	8
Hydrodynamics and mouth condition	25	100	25
Water quality	25	33.2	8
Physical habitat alteration	25	70	18
Habitat Health Score			59
Microalgae	20	17	3
Macrophytes	20	50	10
Invertebrates	20	20	4
Fish	20	40	8
Birds	20	70	14
Biotic Health Score			39
Estuarine Health Score			49

The EHI score for the Kromme Estuary, based on its Present State, is 49, translating into a Present Ecological Status of D as indicated in Table 3-6.

Table 3-6 Recommended guidelines for the classification of the Present Ecological Status (PES)

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

3.5 Importance of the Kromme 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 D of the *Resource directed measures for protection of water resource: Methodology for the Determination of the Ecological Water Requirements for Estuaries*, Version 2 (DWAF, 2004).

For this study, the Ecological importance determination of the Kromme Estuary was obtained from the Estuarine Prioritisation for RDM project (Turpie, 2004). The Functional Importance score, however, was derived at the Specialist Workshop held in Port Elizabeth on 23 and 24 February 2005.

The Estuarine Importance Index score for the Kromme Estuary, based on its Present State, is 76, indicating that the Estuary is important, as indicated below:

Estuary Size

Score	Motivation
100	Estuary size is defined as the total area (ha) within the geographical boundaries of the estuarine resource unit. Size is then converted to a measure of importance using scoring guidelines, which is based on 10% rank percentiles of estuaries of known size. With an area between 50.1–100 ha, the Kromme Estuary is assigned a score of 100.

Zonal Type Rarity

Score	Motivation
20	The Estuary is one of 29 permanently open estuaries in the Warm Temperature zone. The Zonal Type Rarity index is thus $1/29=3$. 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 ($x \text{ ha}/x \text{ ha}$) for each habitat is summed to obtain the rarity value. The value obtained falls within the second 10% percentile second from the top. The score assigned is thus 90.

Biodiversity Importance

Sub-component	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 $1/\text{number of estuaries in which the species occurs in South Africa}$ (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	100	This score is calculated by adding rarity scores for each species present in the estuary, where rarity scores for each species are calculated as $1/\text{number of estuaries in which the species occurs in South Africa}$ (based on interpolated presence records from species distributions). The summed value obtained falls within the top 10% percentile for the scores generated from all South African estuaries, and is thus assigned a score of 100.
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 $1/\text{number of estuaries in which the species occurs in South Africa}$ (based on actual records of presence). The summed value obtained falls within the second 10% for the scores generated from all South African estuaries, and is thus assigned a score of 90.
Birds	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 $1/\text{number of estuaries in which the species occurs in South Africa}$ (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.
Biodiversity score	87.5	

Functional Importance

Sub-component	Score	Motivation
a. Estuary: Input of detritus and nutrients generated in estuary	40	None = 0
b. Nursery function for marine-living fish and crustaceans	60	Little = 20
c. Movement corridor for river invertebrates and fish breeding in sea	60	Some = 40
d. Roosting area for marine or coastal birds	60	Important = 60
e. Catchment detritus, nutrients and sediments to sea	20	Very important = 80
Functional score	60*	Extremely important = 100

* Using the maximum score of the above

The individual scores obtained above are incorporated into the final Estuarine Importance Score as illustrated in Table 3-7.

Table 3-7 Estuarine Importance scores for the Kromme Estuary

Criterion	Score	Weight	Weighted Score
Estuary Size	100	15	15
Zonal Rarity Type	20	10	2
Habitat Diversity	90	25	22
Biodiversity Importance	87.5	25	22
Functional Importance	60	25	15
Estuarine Importance Score			76

The Estuarine Importance Score for the Kromme Estuary, based on its Present State, is 66, indicating that the estuary is important, as indicated in Table 3-8.

Table 3-8 Interpretation of Estuarine Importance scores for estuaries

Importance Score	Description
81 – 100	Highly important
61 – 80	Important
0 – 60	Of low to average importance

3.6 Recommended Ecological Reserve Category for the Kromme Estuary

The recommended Ecological Reserve Category (ERC) represents the level of protection assigned to an estuary. In turn, it is again used to determine the Ecological Reserve.

For estuaries the first step is to determine the 'minimum' ERC of an estuary, based on its Present Ecological Status (PES). The relationship between EHI Score, PES and ERC is set out in Table 3-9.

Table 3-9 Relationship between PES and minimum ERC

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

Note: Should the 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).

PES sets the minimum Ecological Reserve Category. The degree to which Ecological Category needs to be elevated higher than PES depends on level of **importance** and level of **protection** or **desired protection** of a particular estuary (Table 3-10). Estuaries that currently have protection status and the current list of desired protected areas are given in Appendix C of the Resource directed measures for protection of water resource: *Methodology for the Determination of the Ecological Water Requirements for Estuaries*, Version 2 (DWAF, 2004).

Table 3-10 Guidelines for assigning the recommended Ecological Category

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

* BAS = Best Attainable State

The Kromme Estuary has been targeted as a Desired Protected Area (DWAF, 2004). According to the guidelines for assigning a recommended ERC, the estuary needs to be in a Category A or the Best Attainable State (BAS).

At the specialist workshop (held on 23 and 24 February 2005 in Port Elizabeth) it was concluded that the changes that are currently largely contributing to the Present State of the estuary are related to large dam developments in the catchment (e.g. Impofu Dam). At this stage, it is unlikely that these interferences could be reversed even to get it into a Category B.

In this light the workshop decided that it should at least be recommended that the Kromme Estuary be improved into the minimum ERC for an 'Important estuary' which is a **Category C**.

4. QUANTIFICATION OF ECOLOGICAL RESERVE SCENARIOS

4.1 Simulated Runoff Scenarios

Simulated monthly runoff was supplied by project hydrologist (Mr A Sparks Ninham Shand Consulting Engineers, Cape Town, pers. comm.). A summary of the suite of future runoff scenarios evaluated as part of this project are provided in Table 4-1. Each comprises different inflow scenarios from the Kromme and Geelhoutboom rivers, respectively.

Table 4-1 Summary of Simulated Scenarios evaluated as part of Kromme Estuary Ecological Reserve Determination

Scenario	River		Volume (m ³ /year)
	Kromme	Geelhoutboom	
Reference	Natural Flows	Natural Flows	97 x 10 ⁶
Present	0.4 x 10 ⁶ m ³	Present inflows	35 x 10 ⁶
Scenario 1	5 x 10 ⁶ m ³ released in Nov	Present inflows	38 x 10 ⁶
Scenario 2	10 x 10 ⁶ m ³ released in Oct and Jan	Present inflows	43 x 10 ⁶
Scenario 3	0.4 x 10 ⁶ m ³ (Present inflows)	Inflows as per River Class C/D	35 x 10 ⁶
Scenario 4	5 x 10 ⁶ m ³ released in Nov	Inflows as per River Class C/D	38 x 10 ⁶
Scenario 5	7.5 x 10 ⁶ m ³ released in Oct and Nov	Present inflows	41 x 10 ⁶
Scenario 6	15.5 x 10 ⁶ m ³ released mainly in Oct - Jan	Present inflows	50 x 10 ⁶

4.2 Assessment of Scenarios

4.2.1 Scenario 1

Scenario 1 represents a 5 x 10⁶ m³ release into the Kromme Estuary (in November) while inflow into the Geelhoutboom tributary remains similar to its Present State.

i. Seasonal variability in river inflow

Monthly simulated runoff data (73-year period) for Scenario 1 into the Kromme Estuary and Geelhoutboom tributary are provided in Tables 4-2 and 3-2, respectively. A summary of the flow distributions (mean monthly flows in m³/s), derived from the simulated data set, is provided below (hatched months represent flows less than 0.2 m³/s when hypersaline conditions could potentially develop):

Kromme: Summary of flow distributions for Scenario 1 ($5 \times 10^6 \text{ m}^3$ release in Nov)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	13.66	25.96	5.02	4.68	2.32	3.63	4.55	26.02	14.72	16.25	22.94	26.05
90%ile	4.62	3.02	0.48	0.20	0.34	0.40	0.48	2.04	2.74	2.05	2.71	10.36
80%ile	1.95	2.41	0.27	0.15	0.16	0.23	0.22	0.38	0.52	0.38	1.10	3.17
70%ile	0.77	2.31	0.21	0.11	0.10	0.14	0.15	0.17	0.28	0.31	0.39	0.56
60%ile	0.41	2.22	0.16	0.08	0.09	0.10	0.12	0.14	0.18	0.23	0.31	0.40
50%ile	0.30	2.14	0.11	0.08	0.06	0.06	0.09	0.09	0.14	0.18	0.25	0.30
40%ile	0.24	2.11	0.11	0.06	0.04	0.05	0.07	0.08	0.11	0.15	0.20	0.22
30%ile	0.19	2.09	0.10	0.05	0.04	0.05	0.05	0.06	0.08	0.12	0.15	0.18
20%ile	0.16	2.06	0.08	0.05	0.04	0.03	0.05	0.05	0.06	0.09	0.11	0.13
10%ile	0.13	2.03	0.06	0.03	0.02	0.03	0.03	0.03	0.04	0.06	0.08	0.10
1%ile	0.05	0.52	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.04	0.06

Geelhoutboom: Summary of flow distributions for Scenario 1 (Present State)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	1.05	1.21	0.34	0.43	0.29	0.32	0.28	1.17	0.90	1.18	1.72	2.09
90%ile	0.37	0.36	0.05	0.00	0.05	0.07	0.08	0.18	0.21	0.18	0.41	0.57
80%ile	0.24	0.11	0.01	0.00	0.00	0.01	0.04	0.07	0.10	0.11	0.17	0.22
70%ile	0.13	0.06	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.07	0.13	0.16
60%ile	0.08	0.03	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.04	0.08	0.09
50%ile	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.05	0.06
40%ile	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.03
30%ile	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02
20%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

ii. Predicted flood regime for Scenario 1

Similar to the Present State

Confidence: High

iii. Predicted sediment processes under Scenario 1

Similar to the Present State

Confidence: High

iv. Occurrence and duration of different abiotic states under Scenario 1

Estimated occurrence and duration of the different Abiotic States in the Kromme Estuary and Geelhoutboom tributary under Scenario 1, based on simulated monthly river inflow into the Kromme Estuary and Geelhoutboom tributary are indicated Tables 4-2 and 3-2, respectively.

To provide a conceptual overview of the annual distribution of Abiotic States under Scenario 1 for the Kromme Estuary and Geelhoutboom tributary, median monthly flows (representative of seasonal conditions) and 10%ile flows (representative of drought conditions) were used to depict the situation for normal and drought periods (Figure 4-1).

Confidence: Medium

Table 4-2 Monthly simulated runoff data in m³/s (73-year period) for Scenario 1 (5 x 10⁶ m³ release in Nov) into the Kromme Estuary

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1927	0.09	2.02	0.05	0.03	0.03	1.00	0.49	0.10	0.09	0.07	0.09	0.21
1928	0.25	2.30	0.16	0.06	0.04	0.03	0.02	0.05	0.06	0.20	0.20	0.47
1929	0.31	2.09	0.08	0.03	0.17	0.14	0.10	0.08	0.14	0.13	0.26	0.29
1930	0.27	2.09	0.07	0.08	0.05	0.04	0.05	0.04	0.04	0.12	0.11	0.53
1931	1.09	2.46	0.69	1.90	0.74	0.15	0.10	0.06	0.09	0.13	0.11	27.16
1932	9.84	2.65	0.27	0.08	0.05	0.05	0.08	2.69	2.53	0.75	19.52	3.72
1933	0.27	2.34	0.16	0.08	0.09	0.11	0.08	0.06	0.06	0.23	0.21	0.16
1934	4.17	2.35	0.11	0.04	0.04	0.03	0.08	23.68	7.73	2.00	4.75	2.31
1935	0.77	2.35	0.23	0.09	0.04	0.05	0.05	0.18	0.15	0.15	0.13	0.12
1936	0.27	2.98	0.42	0.09	0.05	0.06	0.05	0.03	0.09	0.12	0.11	0.19
1937	0.16	2.08	0.11	0.08	0.04	0.02	0.05	0.08	0.09	0.08	0.08	0.12
1938	0.15	2.14	0.11	0.04	0.37	0.34	0.19	0.12	0.10	0.12	0.86	0.57
1939	0.33	2.22	0.27	0.19	0.33	0.37	0.21	0.14	0.23	0.27	0.20	0.30
1940	0.20	2.08	0.07	0.05	0.04	0.04	0.06	0.05	0.27	0.18	0.11	0.12
1941	0.19	2.08	0.37	0.24	0.09	0.05	0.05	0.15	0.18	0.15	0.15	0.12
1942	0.23	2.09	0.11	0.12	0.07	0.05	0.05	0.05	0.76	0.47	0.37	0.55
1943	0.33	2.67	0.42	0.13	0.08	0.16	0.15	32.06	8.85	2.67	1.10	3.21
1944	0.88	2.15	0.10	0.05	0.04	0.02	0.02	9.08	11.52	2.07	1.22	0.37
1945	1.82	2.25	0.10	0.05	0.03	0.31	0.17	0.06	0.05	0.21	0.28	0.26
1946	0.25	2.09	0.07	0.03	0.02	0.13	0.12	0.27	0.39	10.37	1.80	0.43
1947	0.23	2.11	0.10	0.05	0.04	0.06	0.43	0.23	0.14	0.12	0.11	0.18
1948	0.76	2.32	0.11	0.05	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.04
1949	0.03	3.60	0.64	0.05	0.03	0.02	0.04	0.04	0.04	0.18	0.37	0.38
1950	0.36	3.03	0.50	0.96	0.41	0.09	0.05	0.08	0.13	0.66	0.51	5.94
1951	2.62	2.13	0.09	0.07	0.62	0.24	0.07	0.08	0.11	0.10	0.35	13.39
1952	3.51	2.25	0.16	0.07	0.05	0.03	0.03	0.03	0.07	0.18	0.34	0.69
1953	23.49	8.88	0.24	0.09	0.04	0.40	0.24	1.25	2.14	6.15	18.28	6.47
1954	0.30	2.12	0.10	0.06	5.61	7.66	0.32	0.16	0.11	0.12	0.48	0.38
1955	0.21	6.53	4.50	0.08	0.09	0.13	0.09	2.16	2.79	0.38	0.24	11.08
1956	9.24	16.09	3.47	0.21	0.19	0.16	0.14	0.20	0.28	0.26	0.31	5.84
1957	5.21	2.17	0.09	0.03	0.02	0.08	0.06	0.47	0.31	0.17	0.36	0.31
1958	0.20	2.06	0.08	0.26	0.16	0.08	0.16	0.15	0.13	0.14	0.28	0.28
1959	0.29	2.09	0.11	0.23	0.12	0.05	0.05	0.10	0.14	0.25	0.25	0.26
1960	0.16	2.04	0.07	0.05	0.08	0.57	0.35	0.42	0.34	0.29	0.27	0.22
1961	0.16	2.04	0.05	0.03	0.03	0.18	0.18	0.11	0.08	0.08	1.10	0.63
1962	0.54	2.23	0.11	0.19	0.10	0.89	0.77	0.41	0.27	0.24	0.21	0.19
1963	0.13	2.06	0.21	0.18	0.09	0.08	0.07	0.05	0.52	0.35	0.46	10.79
1964	6.93	2.31	0.16	0.06	0.02	0.06	0.08	0.14	0.16	0.14	0.12	0.10
1965	0.52	3.09	0.21	0.11	0.10	0.05	0.04	0.05	0.05	0.04	0.12	0.14
1966	0.13	2.08	0.10	0.05	0.02	0.03	0.77	0.65	0.40	0.35	0.34	0.49
1967	0.33	2.11	0.09	0.04	0.02	0.03	0.18	0.16	22.95	7.51	2.68	25.62
1968	4.10	2.22	0.13	0.06	0.04	0.04	0.04	0.03	0.07	0.08	0.08	0.12
1969	0.18	2.06	0.05	0.03	0.04	0.03	0.02	0.01	0.02	0.02	0.06	0.08
1970	0.14	2.03	0.37	0.16	0.13	0.10	0.76	0.67	0.51	2.96	31.73	11.66
1971	2.04	2.21	0.13	0.05	0.22	0.11	0.15	0.14	0.15	0.17	0.20	0.17
1972	0.09	1.99	0.03	0.01	0.02	0.08	0.10	0.09	0.08	0.05	0.05	0.07
1973	0.07	2.03	0.06	0.18	0.17	0.75	0.40	0.25	0.26	0.17	1.29	6.69
1974	0.63	2.11	0.08	0.06	0.10	0.19	0.12	0.05	0.06	0.09	0.20	0.38
1975	0.21	2.04	0.08	0.05	0.06	0.24	0.29	0.19	0.18	0.37	0.41	0.32
1976	0.80	2.46	0.18	0.08	0.34	0.18	0.11	5.51	4.04	0.32	0.29	0.56
1977	0.39	2.29	0.21	0.09	0.04	0.07	0.14	0.11	0.19	0.19	0.19	0.19
1978	0.34	2.33	0.21	0.16	0.11	0.06	0.05	0.07	0.11	0.34	15.61	14.28
1979	0.50	2.18	0.11	0.08	0.04	0.02	0.05	0.05	0.08	0.08	0.07	0.12
1980	0.16	2.10	0.13	0.37	0.17	2.07	0.93	9.56	9.70	0.52	14.43	8.66
1981	5.45	2.44	0.18	0.08	0.04	0.05	0.70	0.34	0.13	0.19	0.22	0.21
1982	0.15	2.03	0.05	0.02	0.02	0.01	0.02	0.03	0.07	31.38	12.91	0.40
1983	3.76	2.14	0.10	0.04	0.02	0.06	0.05	0.03	0.04	0.09	0.09	0.09
1984	0.07	1.98	0.07	0.13	0.10	0.05	0.07	0.06	0.14	0.14	0.13	0.09
1985	0.17	2.12	0.13	0.10	0.06	0.03	0.03	0.02	0.04	0.04	0.20	0.19
1986	0.69	2.36	0.16	0.07	0.04	0.03	0.12	0.08	0.33	0.23	0.16	0.50
1987	0.27	2.05	0.06	0.03	0.04	0.03	0.07	0.08	0.19	0.16	0.15	0.15
1988	0.14	0.40	0.08	0.05	0.04	0.02	0.10	0.08	0.05	0.08	0.08	0.16
1989	1.43	4.22	0.65	0.11	0.15	0.10	0.16	0.16	0.59	0.39	0.28	0.26
1990	0.49	2.21	0.11	0.05	0.02	0.02	0.02	0.02	0.03	0.03	0.08	0.08
1991	0.16	0.57	0.11	0.06	1.05	0.38	0.08	0.09	0.13	0.22	1.23	0.71
1992	1.36	2.98	0.29	0.16	0.09	0.05	0.10	0.08	1.43	0.71	0.37	24.78
1993	7.63	2.23	0.26	0.15	0.09	0.08	0.07	0.09	0.11	0.23	2.71	3.12
1994	4.74	2.12	3.07	11.84	0.48	0.45	0.54	1.57	0.64	0.32	0.51	0.17
1995	0.20	2.13	0.30	0.15	0.08	0.06	0.05	0.03	0.02	0.06	0.15	0.19
1996	3.44	51.36	6.36	0.13	0.06	0.05	13.84	4.43	3.23	2.32	1.86	0.46
1997	0.18	2.06	0.06	0.06	0.04	0.22	0.13	0.07	0.07	0.07	0.24	0.24
1998	0.13	2.06	0.11	0.06	0.04	0.03	0.05	0.05	0.04	0.26	0.19	0.10
1999	0.06	1.96	0.07	0.10	0.20	0.36	0.23	0.11	0.08	0.05	0.05	0.07

1 <0.2 1 0.2-1.0 2 1.0-8.0 3 >8.0

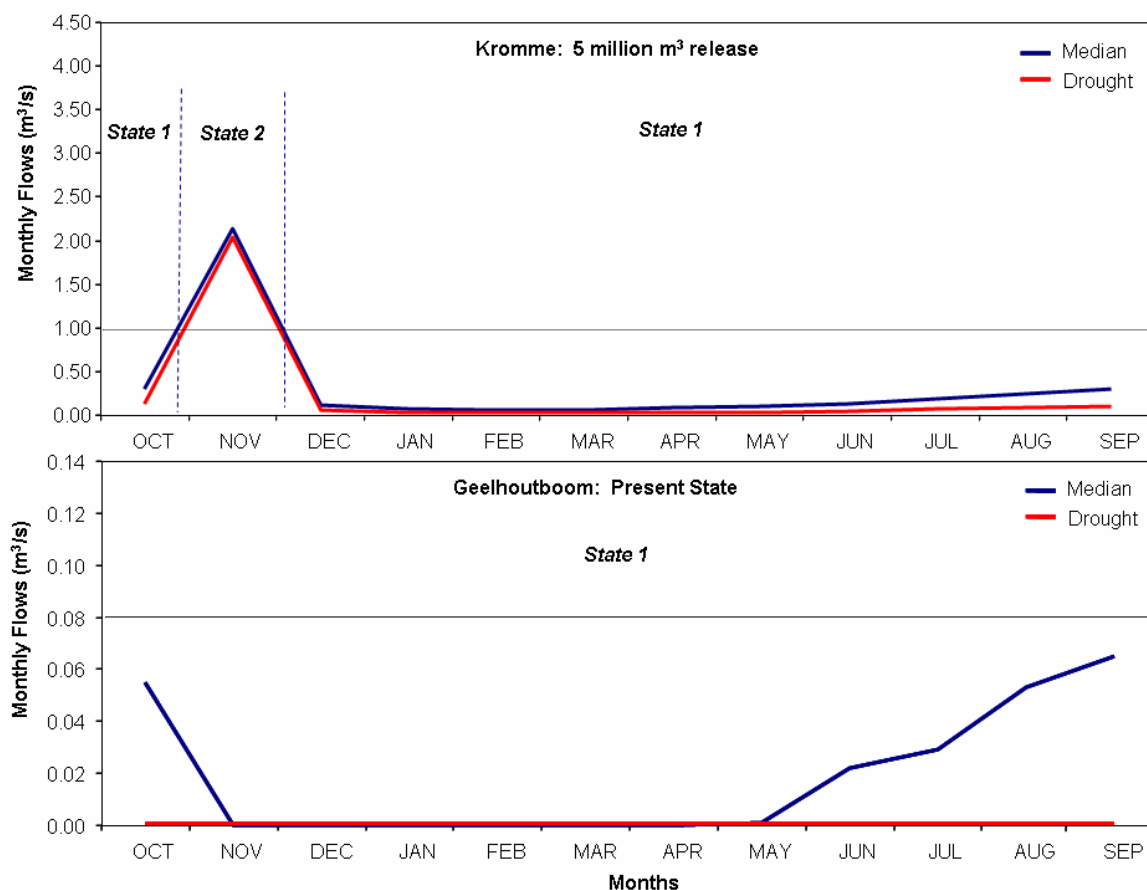


Figure 4-1 Predicted distribution of Abiotic States under Scenario 1 for the Kromme Estuary and Geelhoutboom tributary, based on median monthly flows (representative of seasonal conditions) and 10%ile flows (representative of drought conditions)

v. Predicted change in biotic characteristics under Scenario 1

Microalgae

For 11 months of the year, the flow will be similar to the Present State, i.e. no or very little flow. As a result, there will be no or very limited mixing of freshwater with estuarine water, which would result in the associated flocculation of nutrient-rich particles. Phytoplankton biomass will be highest in the middle reaches of the estuary, probably associated with nutrient recycling from fine sediments close to the Geelhoutboom tributary, but average chl a in the water column will be low ($\sim 5 \mu\text{g/l}$). The phytoplankton will be dominated by flagellates (>90%) throughout the estuary and <10% diatoms. The benthos will be dominated by marine episammic (sand associated) microalgae in the middle and lower reaches of the estuary and marine epilithic (rock associated) microalgae in the upper reaches. Average benthic chl a (rock substrate excluded) will be low ($< 50 \text{ mg/m}^2$) due to the depleted nutrients in the water column.

A $5 \times 10^6 \text{ m}^3$ release of freshwater in November will result in a flow of $\sim 2 \text{ m}^3/\text{s}$. This flow is insufficient to scour high salinity water at depth in the upper reaches of the estuary but will introduce some nutrients and TSS into the estuary. This will stimulate a 25-33% increase in phytoplankton chl a and a doubling in intertidal benthic chl a for a period of two months following the release. A strong halocline will develop in the upper and middle reaches of the estuary so subtidal benthic chl a is unlikely to change significantly in these regions. From about 1 week after the release, diatoms will dominate the phytoplankton (>50%) but this will not last for longer than 2-3 weeks before flagellates become dominant again.

Confidence: High

Macrophytes
Major floods and freshettes do not reach the estuary; however, as a result of the release of 5 million cumecs in November there is a salinity gradient during this time. This decrease in salinity will have little influence on the species richness and community composition of the macrophytes. However, germination and growth of intertidal salt marsh would benefit from 1 month of lower salinity. Biomass would show a small increase as the lower salinity would reduce sediment salinity resulting in macrophyte expansion into bare patches. Field studies showed that sediment salinity was higher in summer compared to winter as a result of evaporation. Hypersaline conditions would still occur at the end of summer and overall the lack of floods and flushing out of accumulated salts would still be detrimental to the extensive salt marshes. Salinity in the Geelhoutboom would be 35 ppt for 11 months of the year. During the flow release salinities will decrease to between 20-25 ppt which would stimulate germination and growth of the intertidal salt marsh species.
Confidence: High
Invertebrates (including zooplankton, benthic invertebrates and macrocrustaceans)
Similar to Present State, with zooplankton, benthos and hyperbenthos showing relatively little change during the annual cycle. Zooplankton biomass is likely to remain low, since natural pulses of freshwater will be infrequent (prevented by the presence of the Impofu Dam). Although the allocation of water is more than double the current allocation, stratification is likely to persist with no significant mixing of the water column. This would benefit the zooplankton, but not other components of the invertebrate community. <i>Zostera capensis</i> biomass and coverage is also unlikely to change and present patterns of invertebrate distribution will persist. Reduced salinity values in the Geelhoutboom tributary would lead to a temporary recovery of the zooplankton (1 month), but 1 month of reduced salinity is probably too short for the other invertebrate components.
Confidence: High
Fish
The increased freshwater release in November may well be sufficient to boost fish recruitment, both from the marine and estuarine environments. November is a peak month for the immigration of marine fish larvae and 0+ juveniles and it is also a major breeding period of many estuarine spawning species. The increase in zooplankton over this period will be particularly important for fish larvae since all species are dependent on this resource during their early life stages. By the time zooplankton stocks decline many of these larvae would have switched to their juvenile diets which are normally more closely associated with the benthos. Mortality amongst the juveniles of plantivorous species will be high when the zooplankton stocks decline and a new equilibrium is attained for the remaining 11 months.
Confidence: Medium
Birds
Similar to the Present State, with possible slight effects during the high flow period and possibly a slight increase in piscivorous birds in response to increased fish recruitment.
Confidence: Medium

vi. EHI scoring for Scenario 1

Hydrology

Variable	Score	Motivation	Confidence
a. % similarity in period of low flows OR Present MAR as a % of MAR in the Reference Condition	42	For the Kromme Estuary low flows are defined as flows associated with State 1 (i.e. $< 1 \text{ m}^3/\text{s}$). Months with low flows of less than $1 \text{ m}^3/\text{s}$ increased from 4 (Jan – Apr) under the Reference Condition to 11 months (Oct – Dec) under the Scenario 1.	H
	58	For the Geelhoutboom tributary low flows are defined as flows associated with the State 1 (i.e. $< 0.08 \text{ m}^3/\text{s}$). Months with median low flows of less than $0.08 \text{ m}^3/\text{s}$ increased from 7 (Dec – Apr) under the Reference Condition to 12 months under the Scenario 1.	L
b. % similarity in mean annual frequency of floods	20	The major floods (1:20) (magnitude and frequency) have been dramatically modified and most of the smaller floods (1:5 years) do not reach the estuary under the Present State. Allow for a 80% modification from Reference Condition.	H
	80	There are no large impoundments in the Geelhoutboom; therefore most large floods (1:20) from this tributary still reach the estuary. This is also supported by the fact that monthly flows $> 1.0 \text{ m}^3/\text{s}$ reach the estuary. They occurred 15% of the years under the Reference Condition and 13% of the years under the Present State.	M
Hydrology Score	38	Kromme - weight 85%; Geelhoutboom - weight 15%.	

Hydrodynamics and mouth condition

Variable	Score	Motivation	Confidence
Change in mean duration of closure, e.g. over a 5 or 10 year period	100	Similar to Present State	H
	100	Similar to Present State	H
Hydrodynamic Score	100		

Water quality

Variable	Score	Motivation	Confidence
1. Change in the longitudinal salinity gradient (%) and vertical salinity stratification	40	State 3 (fresh), which used to occur for 1 out of 2 (50%) years for about 1–2 months at a time under the Reference Condition, has been reduced to 1 out of 4 years (26%) under Scenario 1. Furthermore, State 2 only occurs for 1 month (Nov) of the year under Scenario 1, while it used to occur for 8 months (May – Dec) of the year under Reference Conditions. Under Scenario 1 there is also a slight tendency to develop hypersaline conditions towards the end of summer. This signifies largely modified salinity conditions. Note: Under the Reference Condition the estuary fluctuated between State 1 (marine dominated) and State 2 (saline gradient) under its median flow conditions.	H

Variable	Score	Motivation	Confidence
	30	As State 2 is no longer reflected in median flow conditions of the Geelhoutboom tributary (Present State), it implies that there is no significant gradient in this system. It is a homogenous water body that takes on the salinity (and other abiotic characteristics) of the Kromme Estuary (middle reaches). Under the Reference Condition salinities would have varied between 20 to 35 ppt depending on whether State 1 or 2 were present in the Kromme Estuary. Under Scenario 1, the Geelhoutboom tributary will be ~ 35 ppt for 11 months of the year under median flow conditions. During the flow release (Nov) salinities will decrease to between 20-25 ppt.	M
Kromme Score (weight 85%)	34	Geelhoutboom Score (weight 15%)	4.5
2a. Nitrate/phosphate concentration in the estuary	42	The Kromme system (including the Geelhoutboom tributary) receives its inorganic nutrients through river inflow, either the Kromme and/or Geelhoutboom rivers, particularly inorganic nitrogen. State 1 (little to no freshwater inflow) is therefore characteristic of nutrient depleted conditions. During States 2 and 3 river inflow introduced inorganic nutrients to the estuary. In Scenario 1, State 2 only occurs for 1 month (Nov) compared to 8 months (May - Dec) under the Reference Condition. Freshwater pulses (State 3) have also been reduced. Under Scenario 1, State 1 now occurs for 11 months (compared to 4 months under the Reference Condition - Jan - Apr). Using Table 3.2b (DWAF, 2004), which is also used to derive scores for low flow periods, this translates into a score of 42.	L/M

Variable	Score	Motivation	Confidence
2b. Suspended solids (turbidity) present in inflowing freshwater	42	The Kromme system receives suspended solids through river inflow. States 2 and 3 (both in the Kromme and Geelhoutboom) are therefore characterised by higher suspended solid concentrations (or higher turbidity) than State 1. In Scenario 1, State 2 only occurs for 1 month (Nov) compared to 8 months (May – Dec) under the Reference Condition. Freshwater pulses (under which State 3 would have developed) have also been reduced. Under Scenario 1, State 1 now occurs for 11 months (compared to 4 months under the Reference Condition – Jan - Apr). The estuary under Scenario 1 is therefore considered to be less turbid than under the Reference Condition (used to be 'clear' for 4 months [Jan – Apr], now 'clear' for 11 months [Dec – Oct]). Using Table 3.2b (DWAF, 2004), which is also used to derive scores for low flow periods, this translates into a score of 42.	L/M
2c. Dissolved oxygen in the estuary	75	The Kromme system is usually well oxygenated, except during prolonged periods of State 1, when a reduction in oxygen has been observed in the deeper areas in the upper reaches of the estuary. After construction of the Impofu Dam this would seldom drop to below 5 mg/l as the dam probably cut off significant organic inputs to the upper reaches. Higher organic input during the Reference Condition, however, would have resulted in more severe reduction in DO in this region in the 4 months in which State 1 occurred. Allow for a modification of 10% during those periods. Also, the risk of lower oxygen conditions has been extended from the Reference Condition to Scenario 1 (State 1 occurs for 11 months instead of 4 months) although DO reductions are not severe, i.e. seldom drop below 5 mg/l. Allow for an additional modification of 15% during those periods.	M
2d. Levels of toxins	100	Similar to Present State	M
Water Quality Score	41		

Physical habitat alteration

Variable		Score	Motivation	Confidence
1. Resemblance of <u>intertidal sediment</u> structure and distribution to Reference Condition				
1a. % similarity in intertidal area (size) exposed		70	The estuary was probably deeper under the Reference Condition and the sandbanks not as widespread. However, the rate at which sedimentation occurs is slow so the intertidal area will not have changed dramatically yet, but the process is still on a trajectory of change.	M
1b. % similarity in sand fraction relative to total sand and mud		50	The marine sediment area (sandy habitat) stretches further upstream and in the upper part of the estuary all the fine sediment (muddy habitat) is being flushed away resulting in coarser bed sediment. This process is still on a trajectory of change (predicted that estuary will be a mainly sand habitat in 400 years).	M
2. Resemblance of <u>sub-tidal sediment</u> structure and distribution to Reference Condition				
2. Resemblance of subtidal estuary to Reference Condition: depth, bed or channel morphology		80	The estuary is shallower under the Present State and the marine sediment currently moves slowly upstream. The rate at which sedimentation occurs is, however, slow. Bed sediments are becoming coarser. This process is also still on a trajectory of change (predictions show that if Present State proceeds the estuary will fill up in 2000 years not taking into account sea level rise).	M
2	Resemblance of subtidal estuary to Reference Condition: depth, bed or channel morphology	80	The estuary is shallower under the Present State and the marine sediment currently moves slowly upstream. The rate at which sedimentation occurs is however slow. Bed sediments are becoming coarser. This process is also still on a trajectory of change (predictions show that if Present State proceeds the estuary will fill up in 2000 years, not taking into account sea level rise).	M
Physical habitat Score		70		

Microalgae

Variable		Score	Motivation	Confidence
Phytoplankton				
1. Species richness		21 (45%)	The effects of the freshwater on the microalgae will only persist for ~2 months. The rest of the year will be similar to Present State. During the two months, diatoms will dominate (>50%) the phytoplankton for a couple of weeks before a gradual change back to a flagellate dominated (>90%) estuary. In addition, freshwater species of phytoplankton will be present in the estuary during the first 2-3 weeks following the release.	H

Variable	Score	Motivation	Confidence
2a. Abundance/Biomass	75	The effects of the freshwater on the microalgae will only persist for ~2 months. The rest of the year will be similar to the Present State. There will be an initial drop in average chl a to <2 µg/l but will increase over the following few days to a concentration that is ~25-33% higher than before the release. This biomass should persist for a further 2 months. No REI will form so a higher phytoplankton biomass is not expected.	H
2b. Community composition	45	The effects of the freshwater on the microalgae will only persist for ~ 2 months. The rest of the year will be similar to Present State. The release will introduce freshwater from the Impofu Dam dominated by diatoms (>60% of phytoplankton), flagellates (~30%) and chlorophytes (~5%). This creates a change in community structure from one dominated by diatoms near the head of the estuary to one dominated by flagellates closer to the mouth. Dinoflagellates will only occur in saline water close to the mouth of the estuary. This dramatic change in community composition will only last while water with a salinity of <4ppt persists in the estuary before there will be a gradual change over two months back to that before the release.	H
Benthic microalgae			
1. Species richness	17 (40%)	It is unlikely that the freshwater will change the species richness in the estuary because sediment structure is the most important driver.	H
2a. Abundance/Biomass	60	The effects of the freshwater on the microalgae will only persist for ~2 months. The rest of the year will be similar to Present State. It is unlikely that the release of freshwater will erode the benthic sediments so an immediate increase in intertidal benthic chl a is expected over the first week from an average of <40 mg/m ² to ~60 mg/m ² . The mixing of water in the lower reaches of the estuary should result in intertidal and subtidal chl a increasing to >150 and >100 mg/m ² respectively in this region within the first week.	H
2b. Community composition	40	It is unlikely that the additional freshwater (Nov release) will change the community composition because sediment structure is the most important driver.	H
Microalgae Score	17		

Macrophytes

Variable	Score	Motivation	Confidence
1. Species richness	65 (80%)	A salinity gradient for 1 month of the year will not cause a change in species richness. Conditions would be similar to that of the Present State i.e. loss of brackish salt marsh species as well as reed and sedge species due to an increase in salinity and occurrence of hypersaline conditions. Loss of primary colonisers as a result of reduced flooding. 80% of original species probably remain.	M
2a. Abundance/Biomass	52	Conditions similar to present except for a slight decrease in salinity in November, which would stimulate the germination and growth of intertidal salt marsh.	M
2b. Community composition	55	A salinity gradient for 1 month of the year will cause the die-back of marine macroalgae. However, these will quickly colonise the estuary again. Reed and sedge communities are restricted to areas of freshwater seepage and brackish marshes are reduced.	M
Macrophyte Score	52		

Invertebrates

Variable	Score	Motivation	Confidence
Zooplankton			
1. Species richness	57 (75%)	Because salinity will remain at or close to that of seawater for 11 months of the year, no change is likely in zooplankton species richness. Stratification is likely to be present in November in the upper estuary during the release period and will not benefit species such as <i>Acartia natalensis</i> (eggs remain dormant in the sediments when salinity values are above ca 20 ppt).	M
2a. Abundance/Biomass	50	The loss of regular freshwater pulsing after construction of the Impofu Dam has led to a dramatic decline in abundance levels of dominant estuarine species. This is linked to reduced food availability (phytoplankton) and no salinity gradient along the estuary. The release will, however, result in a small sharp increase in abundance.	H
2b. Community composition	45	Species such as <i>Tortanus capensis</i> do not occur in systems having a horizontal salinity gradient. In this system it is less common under Scenario 1 in comparison to the Present State because of freshwater being introduced (State 2). The mix of other species has also changed as a result of State 2 being introduced for one month (salinity driven).	H
Macroinvertebrates (Macrobenthos)			
1. Species richness	57 (75%)	The species richness will remain similar to that of the Present State, except that some brackish/freshwater species are likely to return due to the presence of State 2 during November.	H

Variable	Score	Motivation	Confidence
2a. Abundance/Biomass	80	Although the species richness increased slightly, abundance will remain static because brackish water forms will replace marine forms.	H
2b. Community composition	20	Remains similar to the Present State, except for limited change due to the return of brackish/freshwater species (presence of State 2 during November). Due to the continued imbalance of the <i>Zostera</i> beds, the community composition change remains significant.	H
Macrocrustaceans (Large crustaceans)			
1. Species richness	57 (75%)	With the extended period of State 2 (2 months), freshwater species, e.g. <i>Macrobrachium</i> spp. are likely to return but for shorter periods relative to the Reference Condition.	M
2a. Abundance/Biomass	50	Changes in density and coverage of <i>Zostera capensis</i> has probably led to change in abundance of some species. Eelgrass also provides protection from visually hunting predators. Species such as <i>Macrobrachium</i> spp. probably occurred in the brackish water reaches under natural conditions (similar to the Present State).	M
2b. Community composition	40	The mix of species has probably changed significantly because of persistently high salinity values in the estuary, as well as the increase in <i>Zostera</i> coverage and biomass (similar to the Present State).	M
Invertebrate Score	20		

Fish

Variable	Score	Motivation	Confidence
1. Species richness	80 (90%)	Most fish species in the system will persist under this scenario and only a few freshwater species will be lost due to the lack of any REI in the upper reaches.	H
2a. Abundance/Biomass	80	Fish abundance, especially for the larval component in November, is likely to be excellent. However, once the zooplankton stocks decline this will impact negatively on the abundance of both fish larvae and the adults of planktivorous species.	H
2b. Community composition	50	The composition of the fish community will remain very similar to the Present State for approximately 9 months of the year but the release in November will have an impact on this community that will probably persist for at least 3 months.	M
Fish Score	50		

Birds

Variable	Score	Motivation	Confidence
1. Species richness	85 (93%)	There may be a slight increase in the appearance of waterfowl species during spring.	M
2a. Abundance/Biomass	85	Piscivorous species may become more abundant, particularly during spring because of increases in smaller species (<i>Gilchristella aestuaria</i>) and juvenile marine fish species; wader and wading bird abundance could increase slightly if the increase in salt marsh productivity is significant.	M
2b. Community composition	75	The composition will be very similar to the Present State for most of the year, but might differ slightly from the present during spring.	M
Bird Score	75		

4.2.2 Scenario 2

i. Seasonal variability in river inflow

Scenario 2 represents a $10 \times 10^6 \text{ m}^3$ release into the Kromme Estuary (in October and January) while inflow into the Geelhoutboom tributary remains similar to its Present State.

ii. Seasonal variability in river inflow

Monthly simulated runoff data (73-year period) for Scenario 2 into the Kromme Estuary and Geelhoutboom tributary are provided in Tables 4-3 and 3-2, respectively. A summary of the flow distributions (mean monthly flows in m^3/s), derived from the simulated data set, is provided below (hatched months represent flows less than $0.2 \text{ m}^3/\text{s}$ when hypersaline conditions could potentially develop):

Kromme: Summary of flow distributions for Scenario 2 ($10 \times 10^6 \text{ m}^3$ released in Oct and Jan)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	14.33	26.15	5.61	6.08	2.03	3.68	4.20	26.53	14.61	17.05	23.44	26.19
90%ile	4.82	1.64	0.61	2.07	0.34	0.40	0.48	1.62	2.87	2.19	3.50	10.87
80%ile	3.16	0.61	0.28	2.02	0.16	0.23	0.22	0.43	0.52	0.48	1.19	3.33
70%ile	2.44	0.38	0.21	1.98	0.10	0.14	0.15	0.18	0.28	0.32	0.40	0.59
60%ile	2.26	0.30	0.16	1.95	0.09	0.10	0.12	0.14	0.17	0.23	0.31	0.42
50%ile	2.17	0.22	0.11	1.94	0.06	0.06	0.09	0.09	0.13	0.18	0.24	0.31
40%ile	2.11	0.18	0.11	1.93	0.04	0.05	0.07	0.08	0.10	0.15	0.19	0.21
30%ile	2.06	0.16	0.10	1.92	0.04	0.05	0.05	0.06	0.08	0.12	0.15	0.17
20%ile	2.03	0.13	0.08	1.91	0.04	0.03	0.05	0.05	0.06	0.09	0.11	0.13
10%ile	1.97	0.11	0.06	1.90	0.02	0.03	0.03	0.03	0.04	0.06	0.08	0.10
1%ile	0.57	0.04	0.04	0.11	0.02	0.02	0.02	0.02	0.02	0.02	0.04	0.06

Geelhoutboom: Summary of flow distributions for Scenario 2 (Present State)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	1.05	1.21	0.34	0.43	0.29	0.32	0.28	1.17	0.90	1.18	1.72	2.09
90%ile	0.37	0.36	0.05	0.00	0.05	0.07	0.08	0.18	0.21	0.18	0.41	0.57
80%ile	0.24	0.11	0.01	0.00	0.00	0.01	0.04	0.07	0.10	0.11	0.17	0.22
70%ile	0.13	0.06	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.07	0.13	0.16
60%ile	0.08	0.03	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.04	0.08	0.09
50%ile	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.05	0.06
40%ile	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.03
30%ile	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02
20%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

iii. Predicted flood regime for Scenario 2

Similar to the Present State

Confidence: High

iv. Predicted sediment processes under Scenario 2

Similar to the Present State

Confidence: High

v. Occurrence and duration of different abiotic states under Scenario 2

Estimated occurrence and duration of the different Abiotic States in the Kromme Estuary and Geelhoutboom tributary under Scenario 2, based on simulated monthly river inflow into the Kromme Estuary and Geelhoutboom tributary, are indicated in Tables 4-3 and 3-2, respectively.

To provide a conceptual overview of the annual distribution of Abiotic States under Scenario 2 for the Kromme Estuary and Geelhoutboom tributary, median monthly flows (representative of seasonal conditions) and 10%ile flows (representative of drought conditions) were used to depict the situation for normal and drought periods (Figure 4-2).

Confidence: Medium

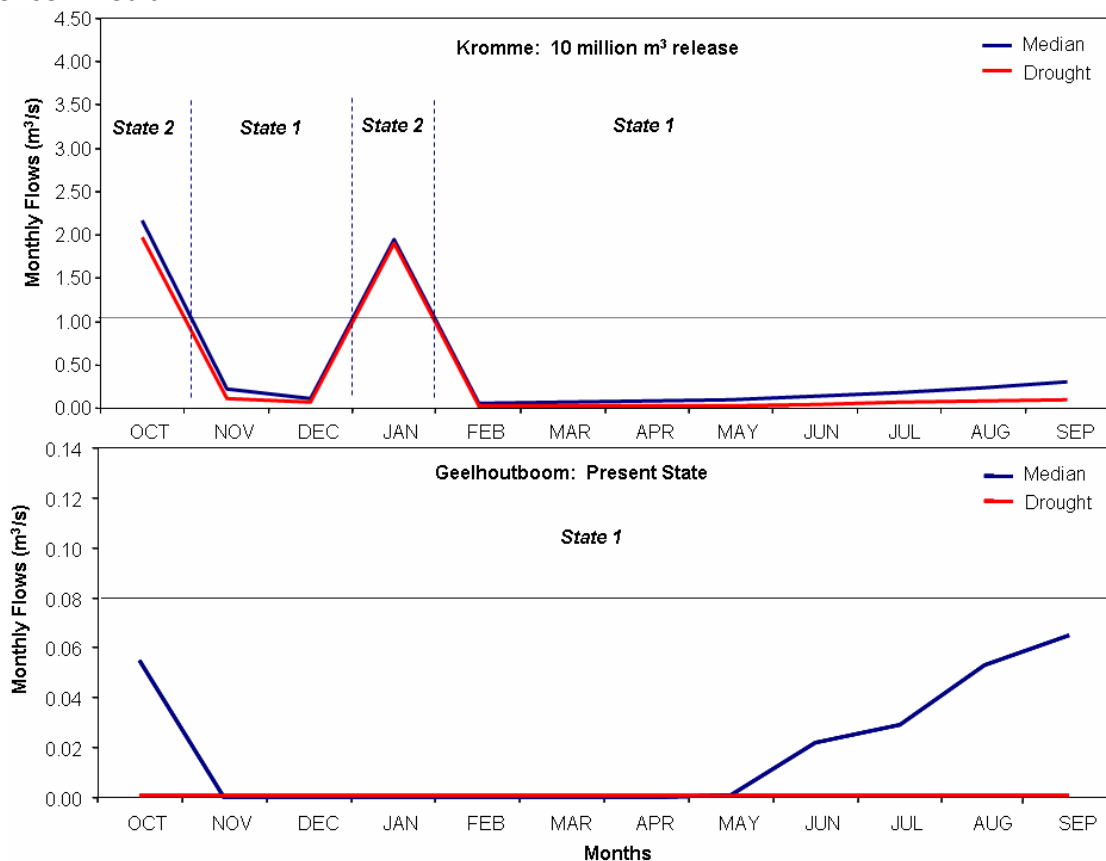


Figure 4-2 Predicted distribution of Abiotic States under Scenario 2 for the Kromme Estuary and Geelhoutboom tributary, based on median monthly flows (representative of seasonal conditions) and 10%ile flows (representative of drought conditions)

Table 4-3 Monthly simulated runoff data in m³/s (73-year period) for Scenario 2 (10 x 10⁶ m³ release in Oct and Jan) into the Kromme Estuary

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1927	1.96	0.09	0.05	1.90	0.03	1.00	0.49	0.10	0.09	0.07	0.09	0.21
1928	2.12	0.37	0.16	1.93	0.04	0.03	0.02	0.05	0.06	0.19	0.19	0.41
1929	2.17	0.16	0.08	1.90	0.17	0.14	0.10	0.08	0.13	0.13	0.24	0.25
1930	2.16	0.17	0.07	1.95	0.05	0.04	0.05	0.04	0.04	0.12	0.11	0.46
1931	3.05	0.53	0.69	3.76	0.74	0.15	0.10	0.06	0.08	0.14	0.11	27.26
1932	10.02	1.89	0.27	1.94	0.05	0.05	0.08	2.69	2.67	0.89	19.66	3.88
1933	2.14	0.41	0.16	1.95	0.09	0.11	0.08	0.06	0.06	0.22	0.20	0.15
1934	4.40	0.65	0.11	1.90	0.04	0.03	0.08	24.57	7.87	2.14	4.88	2.47
1935	2.31	0.42	0.23	1.96	0.04	0.05	0.05	0.18	0.14	0.15	0.13	0.12
1936	2.13	1.47	0.42	1.96	0.05	0.06	0.05	0.03	0.08	0.12	0.11	0.17
1937	2.03	0.15	0.11	1.94	0.04	0.02	0.05	0.08	0.09	0.08	0.08	0.12
1938	2.01	0.21	0.11	1.91	0.37	0.34	0.19	0.12	0.09	0.12	0.86	0.57
1939	2.19	0.29	0.27	2.05	0.33	0.37	0.21	0.14	0.23	0.27	0.19	0.30
1940	2.07	0.15	0.07	1.91	0.04	0.04	0.06	0.05	0.26	0.18	0.11	0.11
1941	2.05	0.15	0.37	2.11	0.09	0.05	0.05	0.15	0.17	0.15	0.15	0.12
1942	2.09	0.17	0.11	1.99	0.07	0.05	0.05	0.05	0.76	0.49	0.37	0.55
1943	2.19	0.74	0.42	1.99	0.08	0.16	0.15	31.58	8.98	2.81	1.23	3.36
1944	2.35	0.22	0.10	1.91	0.04	0.02	0.02	8.94	11.65	2.20	1.35	0.35
1945	2.57	0.32	0.10	1.91	0.03	0.31	0.17	0.06	0.05	0.20	0.25	0.23
1946	2.15	0.16	0.07	1.90	0.02	0.13	0.12	0.27	0.39	11.37	1.93	0.58
1947	2.10	0.18	0.10	1.92	0.04	0.06	0.43	0.23	0.13	0.12	0.11	0.16
1948	2.65	0.39	0.11	1.92	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.04
1949	1.90	1.67	0.64	1.92	0.03	0.02	0.04	0.04	0.04	0.17	0.35	0.31
1950	2.24	1.17	0.50	2.83	0.41	0.09	0.05	0.08	0.12	0.66	0.51	6.01
1951	2.81	0.20	0.09	1.93	0.62	0.24	0.07	0.08	0.10	0.10	0.35	15.11
1952	3.69	0.32	0.16	1.93	0.05	0.03	0.03	0.03	0.06	0.18	0.31	0.66
1953	25.40	9.07	0.24	1.96	0.04	0.40	0.24	1.25	1.34	6.28	18.41	6.63
1954	2.17	0.19	0.10	1.93	4.55	7.82	0.45	0.29	0.11	0.12	0.53	0.36
1955	2.09	5.50	4.69	1.95	0.09	0.13	0.09	1.07	2.92	0.51	0.24	11.38
1956	9.42	16.27	3.65	2.07	0.19	0.16	0.14	0.20	0.28	0.26	0.31	5.29
1957	5.39	0.24	0.09	1.90	0.02	0.08	0.06	0.47	0.31	0.16	0.34	0.30
1958	2.08	0.13	0.08	2.13	0.16	0.08	0.16	0.15	0.12	0.14	0.30	0.28
1959	2.16	0.17	0.11	2.10	0.12	0.05	0.05	0.10	0.13	0.24	0.23	0.37
1960	2.03	0.11	0.07	1.92	0.08	0.57	0.36	0.44	0.34	0.29	0.27	0.20
1961	2.03	0.11	0.05	1.90	0.03	0.18	0.18	0.11	0.08	0.08	1.12	0.63
1962	2.40	0.30	0.11	2.06	0.10	0.89	0.77	0.41	0.27	0.24	0.21	0.17
1963	1.99	0.13	0.21	2.04	0.09	0.08	0.07	0.05	0.52	0.36	0.46	12.23
1964	7.11	0.38	0.16	1.93	0.02	0.06	0.08	0.14	0.15	0.13	0.12	0.10
1965	2.39	3.25	0.21	1.98	0.10	0.05	0.04	0.05	0.05	0.04	0.11	0.14
1966	2.00	0.15	0.10	1.91	0.02	0.03	0.77	0.65	0.40	0.35	0.34	0.49
1967	2.20	0.18	0.09	1.91	0.02	0.03	0.18	0.16	22.20	7.64	2.81	25.78
1968	4.29	0.30	0.13	1.93	0.04	0.04	0.04	0.03	0.07	0.08	0.08	0.12
1969	2.05	0.13	0.05	1.90	0.04	0.03	0.02	0.01	0.02	0.01	0.06	0.08
1970	2.01	0.10	0.37	2.03	0.13	0.10	0.76	0.67	0.51	2.96	33.18	11.82
1971	2.22	1.52	0.13	1.92	0.22	0.11	0.15	0.14	0.14	0.17	0.21	0.15
1972	1.96	0.06	0.03	1.88	0.02	0.08	0.10	0.09	0.08	0.05	0.05	0.06
1973	1.94	0.10	0.06	2.04	0.17	0.75	0.40	0.25	0.26	0.17	1.29	7.19
1974	2.50	0.19	0.08	1.93	0.10	0.19	0.12	0.05	0.06	0.09	0.19	0.31
1975	2.08	0.11	0.08	1.91	0.06	0.24	0.29	0.19	0.17	0.42	0.43	0.31
1976	2.67	0.54	0.18	1.94	0.34	0.18	0.11	5.01	4.17	0.46	0.29	0.67
1977	2.26	0.36	0.21	1.96	0.04	0.07	0.14	0.11	0.18	0.18	0.18	0.17
1978	2.26	0.41	0.21	2.03	0.11	0.06	0.05	0.07	0.10	0.34	15.67	14.44
1979	2.36	0.25	0.11	1.94	0.04	0.02	0.05	0.05	0.08	0.08	0.07	0.12
1980	2.03	0.17	0.13	2.23	0.17	2.08	0.93	9.05	9.83	0.65	14.56	8.81
1981	5.64	1.09	0.18	1.95	0.04	0.05	0.70	0.78	0.13	0.31	0.22	0.20
1982	2.02	0.10	0.05	1.89	0.02	0.01	0.02	0.03	0.06	31.65	13.04	0.50
1983	4.00	0.25	0.10	1.91	0.02	0.06	0.05	0.03	0.04	0.09	0.09	0.09
1984	1.93	0.05	0.07	1.99	0.10	0.05	0.07	0.06	0.13	0.14	0.12	0.09
1985	2.04	0.19	0.13	1.97	0.06	0.03	0.03	0.02	0.04	0.04	0.19	0.17
1986	2.56	0.43	0.16	1.93	0.04	0.03	0.12	0.08	0.33	0.22	0.15	0.46
1987	2.14	0.12	0.06	1.03	0.04	0.03	0.07	0.08	0.18	0.16	0.14	0.14
1988	0.61	0.10	0.08	0.08	0.04	0.02	0.10	0.08	0.05	0.08	0.08	0.15
1989	3.31	2.29	0.65	1.98	0.15	0.10	0.16	0.16	0.59	0.39	0.28	0.26
1990	2.36	0.28	0.11	1.91	0.02	0.02	0.02	0.02	0.03	0.03	0.08	0.08
1991	0.45	0.12	0.11	0.13	1.05	0.38	0.08	0.09	0.12	0.23	1.23	0.71
1992	3.23	1.06	0.29	2.03	0.09	0.05	0.10	0.08	1.43	0.71	0.37	25.22
1993	7.82	0.30	0.84	2.01	0.09	0.08	0.07	0.09	0.11	0.22	3.67	3.28
1994	4.92	0.24	5.25	12.02	0.67	0.61	0.67	1.71	0.77	0.46	0.65	0.33
1995	2.07	0.20	0.30	2.01	0.08	0.06	0.05	0.03	0.02	0.06	0.15	0.17
1996	3.67	51.55	6.54	2.00	0.06	0.05	12.58	4.57	3.36	2.45	1.99	0.61
1997	2.05	0.13	0.06	1.93	0.04	0.22	0.13	0.07	0.07	0.07	0.22	0.20
1998	2.00	0.13	0.11	1.93	0.04	0.03	0.05	0.05	0.04	0.25	0.18	0.10
1999	1.93	0.03	0.07	1.97	0.20	0.36	0.23	0.11	0.08	0.05	0.05	0.06

1 <0.2 1 0.2-1.0 2 1.0-8.0 3 >8.0

vi. Predicted changes in biotic characteristics under Scenario 2

Microalgae For 10 months of the year, the flow will be similar to Present State, i.e. no or very little flow. As a result, there will be no or very limited mixing of freshwater with estuarine water, which would result in the associated flocculation of nutrient-rich particles. Phytoplankton biomass will be highest in the middle reaches of the estuary, probably associated with nutrient recycling from fine sediments close to the Geelhoutboom tributary, but average chl a in the water column will be low (~5 mg/l). The phytoplankton will be dominated by flagellates (>90%) throughout the estuary and <10% diatoms. The benthos will be dominated by marine episammic (sand associated) microalgae in the middle and lower reaches of the estuary and marine epilithic (rock associated) microalgae in the upper reaches. Average benthic chl a (rock substrate excluded) will be low (<50 mg/m²) due to the depleted nutrients in the water column. A 5 x 10⁶ m³ release of freshwater in October and another in January will introduce nutrients and TSS into the estuary. This will stimulate a 25% increase in phytoplankton chl a and a doubling in intertidal benthic chl a for a period of two months after the releases. A strong halocline will develop in the upper and middle reaches of the estuary so subtidal benthic chl a is unlikely to change significantly in these regions. From about 1 week after the release, diatoms will dominate the phytoplankton (>50%) but this will not last for longer than 2-3 weeks before flagellates become dominant again. Confidence: High
Macrophytes In the Kromme Estuary the salinity gradient is present for 2 months (October and January). In the Geelhoutboom tributary salinity will range between 20–25 ppt for the months of October and January. There will be a slight increase in germination and growth of intertidal salt marsh. Lower water column salinity would influence sediment and groundwater conductivity and promote the growth of supratidal salt marsh as well. There will be no change in species richness and community composition. Confidence: High
Invertebrates (including zooplankton, benthic invertebrates and macrocrustaceans) Similar to Present State for most of the year (9-10 months) for the zooplankton. During November a spike in the euryhaline zooplankton abundance will persist for 4-5 weeks. A second spike will follow after the release in January. In total, zooplankton should respond positively for about 3-4 months. The benthos is likely to show little change during the annual cycle compared to the present, but hyperbenthos is likely to respond in a similar way to the zooplankton. Although the allocation of water is 5x the current allocation, freshwater is unlikely to benefit the benthos, particularly as <i>Zostera capensis</i> biomass and coverage is also unlikely to change and current patterns of invertebrate distribution will persist. Reduced salinity values in the Geelhoutboom tributary (tidal pumping) would lead to a temporary recovery of the zooplankton (3-4 months). Benefit will also accrue to the benthos and hyperbenthos because of the shallow nature of the tributary. Confidence: High
Fish The twin releases of freshwater will boost fish recruitment, both from the marine and estuarine environments. October is a peak month for the recruitment of marine fish larvae and 0+ juveniles, and it is also a major breeding period of many estuarine spawning species. The increase in zooplankton over this period will be particularly important for fish larvae since all species are dependent on this resource during their early life stages. The January release does not coincide with peak fish recruitment but will contribute to the survival of larger planktivorous fish populations during the latter half of the summer. Mortalities amongst the juveniles and adults of planktivorous species will therefore not be as high as for Scenario 1. Confidence: High
Birds Similar to the Present State, with possible slight effects during the high flow period and possibly a slight increase in piscivorous birds in response to increased fish recruitment. Confidence: Medium

vii. EHI scoring for the Scenario 2

Hydrology

Variable	Score	Motivation	Confidence
a. % similarity in period of low flows OR Present MAR as a % of MAR in the Reference Condition	45	For the Kromme Estuary low flows are defined as flows associated with State 1 (i.e. $< 1 \text{ m}^3/\text{s}$). Months with low flows of less than $1 \text{ m}^3/\text{s}$ increased from 4 (Jan – Apr) under the Reference Condition to 10 months under the Scenario 2 (State 2 in Oct and Jan).	H
	58	For the Geelhoutboom tributary low flows are defined as flows associated with State 1 (i.e. $< 0.08 \text{ m}^3/\text{s}$). Months with median low flows of less than $0.08 \text{ m}^3/\text{s}$ increased from 7 (Dec – Jun) under the Reference Condition to 12 months under the Scenario 2.	L
b. % similarity in mean annual frequency of floods	20	The major floods (1:20) (magnitude and frequency) have been dramatically modified and most of the smaller floods (1:5 years) do not reach the estuary under the Present State. Allow for a 80% modification from Reference Condition.	H
	80	There are no large impoundments in the Geelhoutboom; therefore most large floods (1:20) from this tributary still reach the estuary. This is also supported by the fact that monthly flows $> 1.0 \text{ m}^3/\text{s}$ reach the estuary. They occurred 15% of the years under the Reference Condition and 13% of the years under the Present State.	M
Hydrology Score	42	Kromme - weight 85%; Geelhoutboom - weight 15%	

Hydrodynamics and mouth condition

Variable	Score	Motivation	Confidence
Change in mean duration of closure, e.g. over a 5 or 10 year period	100	Similar to Present State	H
	100	Similar to Present State	H
Hydrodynamic Score	100		

Water quality

Variable	Score	Motivation	Confidence
1. Change in the longitudinal salinity gradient (%) and vertical salinity stratification	45	State 3: Fresh, which used to occur for 1 out of 2 (52%) years for about 1–2 months at a time under the Reference Condition in the Kromme Estuary, has been reduced to 1 out of 4 years (26%) under Scenario 2. Furthermore, State 2: Salinity Gradient is only present for 2 months (Oct and Jan) of the year under Scenario 2, while it used to persist for about 8 months (May – Dec) of the year under the Reference Condition. This signifies a largely modified salinity gradient. Note: Under the Reference Condition the estuary fluctuated between State 1 (marine dominated) and State 2 (saline gradient) under its median flow conditions.	H

Variable	Score	Motivation	Confidence
	35	Under Scenario 2, there is a loss of State: 2 Salinity Gradient in the Geelhoutboom tributary. This implies that there is no significant gradient in the system and that the homogenous water body takes on the salinity of the Kromme Estuary. Under the Reference Condition this would have varied between 20 to 35 ppt depending on the inflow. Under Scenario 2 the Geelhoutboom tributary would be 35ppt for ~ 10 months of the year under median flow conditions. During the months of the Kromme flow release (Oct and Jan) it would be between 20 -25ppt.	M
Kromme Score (weight 85%)	38.3	Geelhoutboom Score (weight 15%)	5.3
2a. Nitrate/phosphate concentration in the estuary	50	The Kromme system (including the Geelhoutboom tributary) receives its inorganic nutrients through river inflow, either the Kromme and/or Geelhoutboom rivers. State 1 (little to no freshwater inflow) is therefore characteristic of nutrient depleted conditions. During States 2 and 3 river inflow introduced inorganic nutrients to the estuary. In Scenario 2, State 2 only occurs for 2 months (Oct, Jan) compared to 8 months (May – Dec) under the Reference Condition. Freshwater pulses (under which State 3 would have developed) have also been reduced. Under Scenario 2, State 1 now occurs for 10 months (compared to 4 months under the Reference Condition (Jan – Apr). Using Table 3.2b (DWAF, 2004), which is also used to derive scores for low flow periods, this translates into a score of 50.	L/M
2b. Suspended solids present in inflowing freshwater	50	The Kromme system receives suspended solids through river inflow. States 2 and 3 (both in the Kromme and Geelhoutboom) are therefore characterised by higher suspended solid concentrations (or higher turbidity) than State 1. In Scenario 2, State 2 only occurs for 2 months (Oct, Jan) compared to 8 months (May – Dec) under the Reference Condition. Freshwater pulses (under which State 3 would have developed) have also been reduced. Under Scenario 2, State 1 now occurs for 10 months (compared to 4 months under the Reference Condition (Jan – Apr). The estuary under Scenario 2 is therefore considered to be less turbid than under the Reference Condition (used to be 'clear' for 4 months (Jan – Apr), now 'clear' for 10 months (Feb – Sep, Nov - Dec).	L/M

Variable	Score	Motivation	Confidence
		Using Table 3.2b (DWAF, 2004), which is also used to derive scores for low flow periods, this translates into a score of 50.	
2c. Dissolved oxygen in the estuary	80	The Kromme System is usually well oxygenated, except during prolonged periods of State 1, when a reduction in oxygen has been observed in the deeper areas in the upper reaches of the estuary. As a result of the construction of the Impofu Dam the dissolved Oxygen levels would seldom drop to below 5 mg/l as the dam cuts off significant organic inputs to the upper reaches. Higher organic input during the Reference Condition, however, would have resulted in more severe reductions in DO in this region in the 4 months in which State 1 occurred. Allow for a modification of 10% during those periods. Also, the risk of lower oxygen conditions has been extended from the Reference Condition to Scenario 1 (State 1 occurs for 10 months instead of 4 months) although DO reduction are not severe (i.e. seldom drop below 5 mg/l). Allow for a modification of 10% during those periods.	M
2d. Levels of toxins	100	Similar to Present State	M
Water Quality Score	47		

Physical habitat alteration

Variable	Score	Motivation	Confidence
1. Resemblance of <u>intertidal sediment</u> structure and distribution to Reference Condition			
1a. % similarity in intertidal area (size) exposed	70	The estuary was probably deeper under the Reference Condition and the sandbanks not as widespread. However, the rate at which sedimentation occurs is slow so the intertidal area will not have changed dramatically yet, but the process is still on a trajectory of change. Losing intertidal areas due to <u>localised</u> sedimentation effects of the bridge.	M
1b. % similarity in sand fraction relative to total sand and mud	50	The marine sediment area (sandy habitat) stretches further upstream and in the upper part of the estuary all the fine sediment (muddy habitat) is being flushed away resulting in coarser bed sediment. This process is still on a trajectory of change (predicted that estuary will be mainly sand habitat in 400 years).	M
2. Resemblance of <u>sub-tidal sediment</u> structure and distribution to Reference Condition			
2. Resemblance of subtidal estuary to Reference Condition: depth, bed or channel morphology	80	The estuary is shallower under the Present State and the marine sediment moves slowly upstream. The rate at which sedimentation occurs is, however, slow. Bed sediments are becoming coarser. This process is also still on a trajectory of change (predictions show that if Present State proceeds the estuary will fill up in 2000 years not taking into account sea level rise).	M
2 Resemblance of	80	The estuary is shallower under the Present	M

Variable	Score	Motivation	Confidence
subtidal estuary to Reference Condition: depth, bed or channel morphology		State and the marine sediment moves slowly upstream. The rate at which sedimentation occurs is however slow. Bed sediments are becoming coarser. This process is also still on a trajectory of change (predictions show that if Present State continues the estuary will fill up in 2000 years not taking into account sea level rise).	
Physical habitat Score	70		

Microalgae

Variable	Score	Motivation	Confidence
Phytoplankton			
1. Species richness	25 (50%)	The effects of the freshwater releases on the microalgae will only persist for ~2 months after each release. The rest of the year will be similar to Present State. During the two months following each release, diatoms will dominate (>50%) the phytoplankton for a couple of weeks before a gradual change back to a flagellate dominated (>90%) estuary. In addition, freshwater species of phytoplankton will be present in the estuary during the first 2-3 weeks following each release.	H
2a. Abundance/Biomass	80	The effects of the pulses on the microalgae will only persist for ~2 months after each release. The rest of the year will be similar to Present State. There will be an initial drop in average chl a to <2 µg/l but will increase over the following few days to a concentration that is ~25-33% higher than before the release. This biomass should persist for a further 2 months after each release. No REI will form so a higher phytoplankton biomass is not expected.	H
2b. Community composition	50	The effects of the pulses on the microalgae will only persist for ~2 months after each release. The rest of the year will be similar to Present State. The releases will introduce freshwater from the Impofu Dam dominated by diatoms (>60% of phytoplankton), flagellates (~30%) and chlorophytes (~5%). This creates a change in community structure from one dominated by diatoms near to the head of the estuary to one dominated by flagellates nearer to the mouth. Dinoflagellates will only occur in saline water nearer to the mouth of the estuary. This dramatic change in community composition will only last while water with a salinity of <4 ppt persists in the estuary before a gradual change over two months back to that before the releases.	H
Benthic microalgae			
1. Species richness	17 (40%)	It is unlikely that there will be a significant change in species richness after the releases because sediment structure is the most important driver.	M

Variable	Score	Motivation	Confidence
2a. Abundance/Biomass	60	The effects of the pulses on the microalgae will only persist for ~2 months after each release. The rest of the year will be similar to Present State. It is unlikely that the releases of freshwater will erode the benthic sediments so an immediate increase in intertidal benthic chl a is expected over the first week after the releases from an average of <40 mg/m ² to ~60 mg/m ² . The mixing of water in the lower reaches of the estuary should result in intertidal and subtidal chl a increasing to >150 and >100 mg/m ² respectively in this region within the first week after each release.	H
2b. Community composition	40	It is unlikely that there will be a significant change in community composition after the releases because sediment structure is the most important driver.	M
Microalgae Score	17		

Macrophytes

Variable	Score	Motivation	Confidence
1. Species richness	65 (80%)	A salinity gradient for 2 months of the year will not cause a change in species richness. Conditions would be similar to that of the Present State i.e. loss of brackish salt marsh species as well as reed and sedge species due to an increase in salinity and occurrence of hypersaline conditions. Loss of primary colonisers as a result of reduced flooding. 80% of original species probably remain.	M
2a. Abundance/Biomass	56	Conditions similar to present except for a slight decrease in salinity in October and January, which would stimulate the germination and growth of intertidal salt marsh. Lower water column salinity could reduce sediment and groundwater conductivity also promoting the growth of supratidal salt marsh. Reduced risk of hypersaline conditions will favour macrophyte growth.	H
2b. Community composition	60	A salinity gradient for 2 months of the year will cause the die-back of marine macroalgae. However, these will colonise the estuary quickly again. Reed and sedge communities, restricted to areas of freshwater seepage and brackish marshes, are reduced.	M
Macrophyte Score	56		

Invertebrates

Variable	Score	Motivation	Confidence
Zooplankton			
1. Species richness	65 (80%)	Because salinity will remain at or close to that of seawater for 10 months of the year, little change is likely in zooplankton species richness. However, reduced salinity values in November and again in January is likely to benefit euryhaline species such as <i>Acartia natalensis</i> (occasionally present in the Kromme under current conditions). This species has dormant eggs that remain in bottom sediments during times when conditions are adverse. Suitable salinity conditions are likely to arise in shallower middle reaches.	M
2a. Abundance/Biomass	70	Abundance levels will remain at low levels during 8-9 months of the year. During the first release, abundance levels of the estuarine copepods <i>Pseudodiaptomus hessei</i> and <i>Acartia natalensis</i> will spike, but the duration will not persist for more than a 4-6 weeks. A second spike in January will augment abundance levels for a further 4-6 weeks. However, abundance will be linked to food availability (response of phytoplankton to the release).	H
2b. Community composition	45	Species such as <i>Tortanus capensis</i> do not occur in systems having a horizontal salinity gradient. In this system it is less common under Scenario 2 in comparison to the Present State because of freshwater being introduced (State 2). The mix of other species has also changed as a result of State 2 being introduced for one month (salinity driven).	H
Macroinvertebrates (Macrobenthos)			
1. Species richness	57 (75%)	The species richness will remain similar to that of the Present State, except that some brackish/freshwater species are likely to return due to the presence of State 2 during November (as for Scenario 1, turnover rates are accommodated within 1 month).	H
2a. Abundance/Biomass	85	Abundance levels are slightly higher than for Scenario 1 because of the additional month of State 2.	H
2b. Community composition	20	Remains similar to the Present State, except for limited change due to the return of brackish/freshwater species (presence of State 2 during November). Due to the continued imbalance of the <i>Zostera</i> beds, the community composition change remains significant.	H
Macrocrustaceans (Large crustaceans)			
1. Species richness	65 (80%)	Species richness marginally higher than for Scenario 1 due to the return of the freshwater species e.g. <i>Macrobrachium</i> spp. for the 2 months during which Abiotic State 2 exists.	M

2a. Abundance/Biomass	60	Abundance marginally higher than for Scenario 1 due to the return of the freshwater species e.g. <i>Macrobrachium</i> spp. for the 2 months during which Abiotic State 2 exists.	M
2b. Community composition	65	The mix of species is closer to Reference with the extended period of State 2 (2 months compared to 6 months under the Reference Condition)	M
Invertebrate Score	20		

Fish

Variable	Score	Motivation	Confidence
1. Species richness	80 (90%)	Most fish species in the system will persist under this scenario and only a few freshwater species will be lost due to the lack of any REI in the upper reaches.	H
2a. Abundance/Biomass	85	Fish abundance, especially for the larval component in October, is likely to be excellent. Improved survival of planktivorous fish species is likely due to the January freshwater release. However, once the zooplankton stocks decline in autumn this will impact negatively on the abundance of both fish larvae and the adults of planktivorous species. Marine migrant fish species will benefit especially from the November pulse (recruit) and to a limited extent from the Jan release (feed) because most species have completed their migrations by that time.	H
2b. Community composition	55	The composition of the fish community will remain very similar to the Present State approximately 8 months of the year but the releases in October and January will have an impact on this community that will probably persist for at least 4 months.	M
Fish Score	55		

Birds

Variable	Score	Motivation	Confidence
1. Species richness	85 (90%)	There may be a slight increase in the appearance of waterfowl species during spring and summer.	M
2a. Abundance	90	Piscivorous species may become more abundant, particularly during spring; wader and wading bird abundance could increase slightly if the increase in salt marsh productivity is significant.	M
2b. Community composition	80	The composition will be very similar to the Present State for most of the year, but might differ slightly from the present during spring.	M
Bird score	80		

4.2.3 Scenario 3

Scenario 3 represents a $2 \times 10^6 \text{ m}^3$ release into the Kromme Estuary (as for the Present State) while inflow into the Geelhoutboom tributary is that required for a River Class C/D.

i. Seasonal variability in river inflow

Monthly simulated runoff data (73-year period) for Scenario 3 into the Kromme Estuary and Geelhoutboom tributary are provided in Tables 3-1 and 4-4, respectively. A summary of the flow distributions (mean monthly flows in m^3/s), derived from the simulated data set, is provided below (hatched months represent flows less than $0.2 \text{ m}^3/\text{s}$ when hypersaline conditions can potentially develop):

Kromme: Summary of flow distributions for Scenario 2 (Present State)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	13.60	25.85	5.08	4.70	2.48	3.67	4.41	26.39	14.37	16.56	22.96	25.98
90%ile	4.50	1.72	0.56	0.28	0.40	0.45	0.48	1.48	2.66	1.97	2.98	10.39
80%ile	1.79	0.82	0.35	0.23	0.24	0.31	0.25	0.49	0.56	0.44	1.09	3.08
70%ile	0.76	0.48	0.28	0.19	0.18	0.22	0.21	0.22	0.32	0.31	0.43	0.61
60%ile	0.47	0.39	0.23	0.16	0.16	0.17	0.17	0.18	0.21	0.26	0.36	0.41
50%ile	0.36	0.30	0.19	0.15	0.13	0.14	0.14	0.15	0.18	0.22	0.29	0.35
40%ile	0.31	0.27	0.18	0.14	0.11	0.13	0.13	0.14	0.15	0.20	0.25	0.26
30%ile	0.25	0.24	0.17	0.13	0.11	0.12	0.11	0.11	0.13	0.17	0.20	0.22
20%ile	0.22	0.22	0.15	0.12	0.11	0.11	0.10	0.10	0.11	0.13	0.17	0.17
10%ile	0.19	0.19	0.14	0.11	0.10	0.10	0.09	0.09	0.08	0.11	0.14	0.16
1%ile	0.11	0.13	0.11	0.09	0.07	0.03	0.07	0.06	0.06	0.05	0.09	0.10

Geelhoutboom: Summary of flow distributions for Scenario 3 (as per River Class C/D)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	1.07	1.21	0.36	0.43	0.32	0.35	0.28	1.18	0.90	1.18	1.72	2.08
90%ile	0.37	0.36	0.10	0.05	0.08	0.09	0.09	0.20	0.21	0.18	0.41	0.58
80%ile	0.24	0.14	0.07	0.03	0.04	0.05	0.04	0.08	0.11	0.12	0.17	0.23
70%ile	0.15	0.11	0.05	0.03	0.02	0.03	0.03	0.04	0.07	0.08	0.13	0.17
60%ile	0.10	0.08	0.04	0.02	0.02	0.02	0.03	0.03	0.04	0.05	0.09	0.11
50%ile	0.08	0.05	0.03	0.02	0.01	0.01	0.02	0.02	0.03	0.04	0.06	0.08
40%ile	0.06	0.04	0.02	0.01	0.01	0.01	0.02	0.02	0.02	0.04	0.04	0.05
30%ile	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.03	0.04
20%ile	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.03
10%ile	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02
1%ile	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01

Table 4-4 Monthly simulated runoff data in m³/s (73-year period) for Scenario 3 (as per River Class C/D) into the Geelhoutboom tributary

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1927	0.02	0.02	0.01	0.01	0.01	0.22	0.13	0.02	0.02	0.01	0.03	0.07
1928	0.08	0.12	0.04	0.01	0.01	0.01	0.01	0.01	0.01	0.04	0.04	0.08
1929	0.06	0.04	0.02	0.01	0.04	0.03	0.02	0.02	0.03	0.03	0.05	0.05
1930	0.08	0.04	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.03	0.03	0.10
1931	0.34	0.14	0.24	0.67	0.22	0.03	0.02	0.01	0.02	0.04	0.03	1.95
1932	0.77	0.25	0.06	0.02	0.01	0.01	0.02	0.10	0.07	0.06	0.57	0.29
1933	0.06	0.14	0.04	0.02	0.02	0.03	0.02	0.01	0.01	0.05	0.04	0.03
1934	0.24	0.12	0.02	0.01	0.01	0.01	0.02	1.01	0.55	0.17	0.20	0.19
1935	0.14	0.13	0.05	0.02	0.01	0.01	0.01	0.04	0.03	0.03	0.03	0.03
1936	0.06	0.35	0.11	0.02	0.01	0.01	0.01	0.01	0.02	0.03	0.02	0.04
1937	0.04	0.03	0.03	0.02	0.01	0.00	0.01	0.02	0.02	0.02	0.02	0.03
1938	0.03	0.05	0.02	0.01	0.08	0.07	0.04	0.02	0.02	0.03	0.26	0.19
1939	0.10	0.08	0.07	0.04	0.09	0.13	0.06	0.04	0.08	0.09	0.05	0.11
1940	0.05	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.06	0.04	0.03	0.03
1941	0.04	0.03	0.08	0.05	0.02	0.01	0.01	0.03	0.04	0.03	0.03	0.03
1942	0.05	0.04	0.02	0.03	0.02	0.01	0.01	0.01	0.16	0.15	0.13	0.19
1943	0.08	0.26	0.12	0.03	0.02	0.04	0.03	1.64	0.70	0.18	0.12	0.23
1944	0.16	0.05	0.02	0.01	0.01	0.00	0.01	0.22	0.34	0.17	0.15	0.11
1945	0.25	0.07	0.02	0.01	0.01	0.07	0.04	0.01	0.01	0.04	0.05	0.05
1946	0.09	0.04	0.01	0.01	0.00	0.03	0.03	0.06	0.08	0.39	0.21	0.11
1947	0.06	0.04	0.02	0.01	0.01	0.01	0.09	0.05	0.03	0.03	0.02	0.03
1948	0.27	0.10	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.01
1949	0.01	0.41	0.18	0.01	0.01	0.00	0.01	0.01	0.01	0.04	0.08	0.07
1950	0.10	0.41	0.14	0.34	0.11	0.02	0.01	0.02	0.03	0.22	0.18	0.28
1951	0.14	0.05	0.02	0.01	0.13	0.05	0.02	0.02	0.02	0.03	0.13	0.89
1952	0.36	0.09	0.04	0.01	0.01	0.01	0.01	0.01	0.01	0.04	0.07	0.16
1953	1.82	0.72	0.05	0.02	0.01	0.09	0.05	0.42	0.26	0.23	1.19	0.49
1954	0.08	0.04	0.02	0.01	0.57	0.24	0.03	0.03	0.03	0.04	0.17	0.12
1955	0.06	0.36	0.09	0.02	0.02	0.03	0.02	0.31	0.19	0.08	0.08	0.38
1956	0.72	0.37	0.19	0.05	0.04	0.04	0.03	0.06	0.10	0.09	0.11	0.25
1957	0.18	0.05	0.02	0.01	0.00	0.02	0.01	0.10	0.07	0.04	0.07	0.09
1958	0.06	0.03	0.02	0.06	0.03	0.02	0.03	0.03	0.03	0.03	0.10	0.08
1959	0.09	0.04	0.03	0.05	0.03	0.01	0.01	0.02	0.03	0.05	0.05	0.08
1960	0.04	0.03	0.01	0.01	0.02	0.12	0.08	0.16	0.11	0.10	0.09	0.05
1961	0.04	0.03	0.01	0.01	0.01	0.04	0.04	0.03	0.02	0.02	0.31	0.20
1962	0.19	0.08	0.03	0.04	0.02	0.24	0.27	0.14	0.08	0.08	0.07	0.04
1963	0.03	0.03	0.05	0.04	0.02	0.02	0.02	0.01	0.11	0.12	0.17	2.04
1964	0.71	0.12	0.04	0.01	0.00	0.01	0.02	0.03	0.03	0.03	0.03	0.02
1965	0.11	0.21	0.05	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.03	0.03
1966	0.03	0.03	0.02	0.01	0.00	0.01	0.17	0.15	0.14	0.12	0.11	0.17
1967	0.09	0.04	0.02	0.01	0.01	0.01	0.04	0.04	1.43	0.63	0.19	1.00
1968	0.39	0.08	0.03	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.03
1969	0.04	0.03	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.02
1970	0.03	0.02	0.08	0.04	0.03	0.02	0.16	0.17	0.18	1.05	2.92	0.97
1971	0.08	0.08	0.03	0.01	0.05	0.03	0.03	0.03	0.03	0.04	0.06	0.03
1972	0.02	0.01	0.01	0.00	0.00	0.02	0.02	0.02	0.02	0.01	0.01	0.01
1973	0.01	0.02	0.01	0.04	0.04	0.16	0.08	0.06	0.08	0.05	0.46	0.60
1974	0.19	0.04	0.02	0.01	0.02	0.04	0.03	0.01	0.01	0.02	0.04	0.07
1975	0.05	0.03	0.02	0.01	0.01	0.05	0.06	0.04	0.04	0.12	0.15	0.09
1976	0.29	0.17	0.04	0.02	0.07	0.04	0.02	0.64	0.34	0.10	0.10	0.20
1977	0.12	0.11	0.05	0.02	0.01	0.01	0.03	0.03	0.04	0.04	0.04	0.04
1978	0.13	0.13	0.05	0.04	0.02	0.01	0.01	0.01	0.02	0.07	1.25	0.61
1979	0.16	0.05	0.03	0.02	0.01	0.00	0.01	0.01	0.02	0.02	0.01	0.03
1980	0.04	0.04	0.03	0.08	0.04	0.62	0.32	0.28	0.20	0.12	0.88	0.38
1981	0.32	0.15	0.04	0.02	0.01	0.01	0.15	0.08	0.04	0.07	0.07	0.06
1982	0.03	0.02	0.01	0.00	0.00	0.00	0.00	0.01	0.01	1.52	0.69	0.12
1983	0.09	0.05	0.02	0.01	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.02
1984	0.01	0.01	0.01	0.03	0.02	0.01	0.02	0.01	0.03	0.03	0.03	0.02
1985	0.04	0.04	0.03	0.02	0.01	0.01	0.01	0.00	0.01	0.01	0.04	0.04
1986	0.15	0.09	0.04	0.01	0.01	0.01	0.03	0.02	0.07	0.05	0.03	0.12
1987	0.06	0.03	0.01	0.01	0.01	0.01	0.02	0.02	0.04	0.04	0.03	0.03
1988	0.03	0.02	0.02	0.01	0.01	0.00	0.02	0.02	0.01	0.02	0.02	0.03
1989	0.37	0.81	0.17	0.03	0.03	0.02	0.03	0.03	0.21	0.13	0.09	0.08
1990	0.17	0.07	0.02	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.02
1991	0.04	0.03	0.02	0.01	0.23	0.08	0.02	0.02	0.03	0.07	0.44	0.23
1992	0.48	0.37	0.06	0.04	0.02	0.01	0.02	0.02	0.43	0.24	0.13	2.21
1993	0.78	0.08	0.07	0.03	0.02	0.02	0.02	0.02	0.02	0.05	0.22	0.16
1994	0.11	0.04	0.08	0.09	0.08	0.08	0.08	0.09	0.05	0.05	0.06	0.05
1995	0.06	0.05	0.09	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.03	0.04
1996	0.37	2.22	0.67	0.03	0.01	0.01	0.17	0.20	0.17	0.14	0.14	0.08
1997	0.04	0.03	0.01	0.01	0.01	0.05	0.03	0.01	0.02	0.01	0.05	0.04
1998	0.03	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.06	0.04	0.02
1999	0.01	0.01	0.01	0.02	0.04	0.08	0.05	0.03	0.02	0.01	0.01	0.01

1 <0.08 2 0.08-1.0 3 >1.0

ii. Predicted flood regime for Scenario 3

Similar to the Present State

Confidence: High

iii. Predicted sediment processes under Scenario 3

Similar to the Present State

Confidence: High

iv. Occurrence and duration of different abiotic states under Scenario 3

Estimated occurrence and duration of the different Abiotic States in the Kromme Estuary and Geelhoutboom tributary under Scenario 3, based on simulated monthly river inflow into the Kromme Estuary and Geelhoutboom tributary are indicated Tables 3-1 and 4-4, respectively.

To provide a conceptual overview of the annual distribution of Abiotic States under the Reference Condition for the Kromme Estuary and Geelhoutboom tributary, median monthly flows (representative of seasonal conditions) and 10%ile flows (representative of drought conditions) were used to depict the situation for normal and drought periods (Figure 4-3).

Confidence: Medium

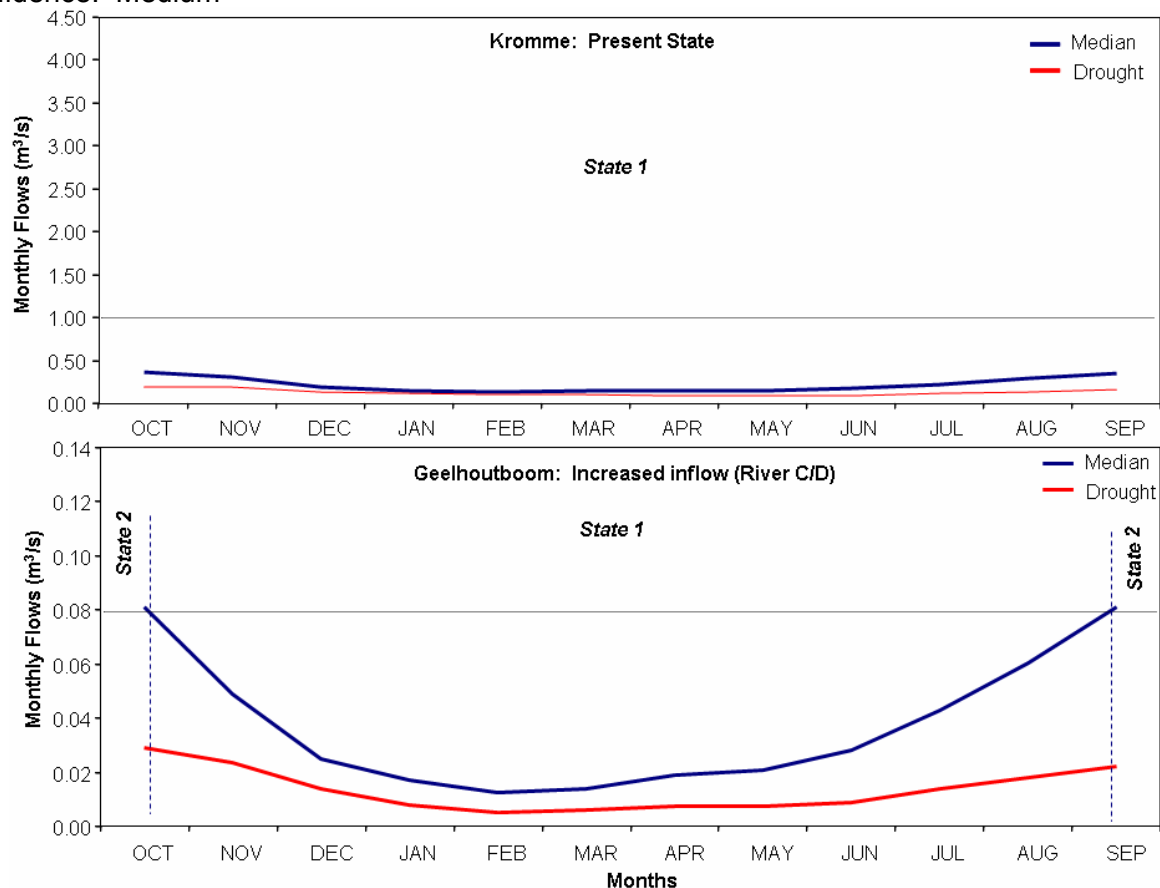


Figure 4-3 Predicted distribution of Abiotic States under Scenario 3 for the Kromme Estuary and Geelhoutboom tributary, based on median monthly flows (representative of seasonal conditions) and 10%ile flows (representative of drought conditions)

v. Predicted change in biotic characteristics under Scenario 3

Microalgae
During this scenario the Kromme will be in its Present State and the Geelhoutboom will have a flow >0.08 m ³ /s for a possible 2 months per year. The Geelhoutboom tributary is shallow in its upper reaches and deepens towards the confluence with the Kromme. This bathymetry is ideal for the formation of a REI zone provided flow creates a longitudinal salinity gradient and the tributary is not flushed out too quickly, i.e. flow must not exceed 1.0 m ³ /s. However, nutrients are low in the Geelhoutboom River and the volume of the tributary is small relative to the Kromme so contributions to the overall system are small. Increases in microalgal biomass and richness will be restricted to in or near the tributary.
Confidence: Medium/high
Macrophytes
Salinity conditions in the Kromme Estuary are similar to present conditions. Salinity in the Geelhoutboom tributary is reduced for approximately 2 months of the year. This is similar to Scenario 1. This would benefit the marshes in the Geelhoutboom but because most of the macrophyte biomass is in the Kromme Estuary the overall score does not change by much. There will be no change in species richness and community composition.
Confidence: High
Invertebrates (including zooplankton, benthic invertebrates and macrocrustaceans)
The invertebrate community in the main Kromme tributary is unlikely to change under Scenario 3 in comparison to the Present State. Although the Geelhoutboom will receive a freshwater inflow under Scenario 3, the tributary is shallow and the volume low. Invertebrates will benefit from the release, but in comparison to the area and volume of the main estuary, the benefit will be localised and on a small scale overall.
Confidence: High
Fish
The marine migrant fish component in the Kromme Estuary is likely to be very similar to the Present State. The freshwater flow that the Geelhoutboom tributary receives will be very important in maintaining planktivorous fish components, especially the estuarine roundherring <i>Gilchristella aestuaria</i> . Spawning by this species will be possible in the Geelhoutboom tributary when no breeding activities are possible in the main estuary.
Confidence: High
Birds
The bird community is unlikely to show any significant changes relative to the Present State.
Confidence: High

v. EHI for the Future Scenario 3

Hydrology

Variable	Score	Motivation	Confidence
a. % similarity in period of low flows OR Present MAR as a % of MAR in the Reference Condition	33	For the Kromme Estuary low flows are defined as flows associated with State 1 (i.e. $< 1 \text{ m}^3/\text{s}$). Months with low flows of less than $1 \text{ m}^3/\text{s}$ increased from 4 (Jan – Apr) under the Reference Condition to 12 months under Scenario 3 (Present State).	H
	75	For the Geelhoutboom tributary low flows are defined as flows associated with State 1 (i.e. $< 0.08 \text{ m}^3/\text{s}$). Months with median low flows of less than $0.08 \text{ m}^3/\text{s}$ increased from 7 (Dec – Jun) under the Reference Condition to 10 months (Nov – Aug) under Scenario 3.	L
b. % similarity in mean annual frequency of floods	20	The major floods (1:20) (magnitude and frequency) have been dramatically modified and most of the smaller floods (1:5 years) do not reach the estuary under the Present State. Allow for a 80% modification from Reference Condition.	H
	80	There are no large impoundments in the Geelhoutboom; therefore most large floods (1:20) from this tributary still reach the estuary. This is also supported by the fact that monthly flows $> 1.0 \text{ m}^3/\text{s}$ reach the estuary. They occurred 15% of the years under the Reference Condition and 13% of the years under the Present State.	M
Hydrology Score	35	Kromme - weight 85%; Geelhoutboom - weight 15%	

Hydrodynamics and mouth condition

Variable	Score	Motivation	Confidence
Change in mean duration of closure, e.g. over a 5 or 10 year period	100	Due to tidal flows the estuary mouth remains permanently open.	H
	100	Due to tidal flows the estuary mouth remains permanently open.	H
Hydrodynamic Score	100		

Water quality

Variable	Score	Motivation	Confidence
1. Change in the longitudinal salinity gradient (%) and vertical salinity stratification	35	State 3 occurred for 1 out of 2 years (52%) for about 1–2 months at a time under the Reference Condition. For Scenario 3 this has been reduced to 1 out of 4 years (26%) for a month at a time. Furthermore, State 2 is no longer present under the median flow conditions. Under Scenario 3 there is also a slight tendency to develop hypersaline conditions towards the end of summer. This signifies largely modified salinity conditions. Note: Under the Reference Condition the estuary fluctuated between State 1 (marine dominated) and State 2 (saline gradient) under its median flow conditions.	H

Variable	Score	Motivation	Confidence
	30	Under Scenario 3, there is a loss of State 2: Salinity Gradient. This implies that there is no significant gradient in the system for about 10 months (Nov - Aug) (7 under Reference Conditions (Dec - Jun)) and that the homogenous water body takes on the salinity of the Kromme Estuary. Under the Reference Condition this homogenous body of water would have varied between 20 to 35 ppt depending on the inflow. Under Scenario 3 the Geelhoutboom Tributary would be 35ppt for ~ 10 months of the year under median flow conditions.	M
Kromme Score (weight 85%)	29.8	Geelhoutboom Score (weight 15%)	4.5
2a. Nitrate/phosphate concentration in the estuary	35	Similar to the Present State, except that there might be a slight increase in inorganic nutrients in the top 1 km of the Geelhoutboom tributary during Sept and Oct. Allow for a 2% adjustment (increase) from Present State, i.e. slightly closer to Reference Condition.	L/M
2b. Suspended solids present in inflowing freshwater	35	Similar to the Present State, except that there might be a slightly more turbid conditions in the top 1 km of the Geelhoutboom Tributary during Sept and Oct. Allow for a 2% adjustment (increase) from Present State, i.e. slightly closer to Reference Condition.	L/M
2c. Dissolved oxygen in the estuary	70	Similar to Present State	M
2d. Levels of toxins	100	Similar to Present State	M
Water Quality Score	35		

Physical habitat alteration

Variable	Score	Motivation	Confidence
1. Resemblance of <u>intertidal sediment</u> structure and distribution to Reference Condition			
1a. % similarity in intertidal area (size) exposed	70	The estuary was probably deeper under the Reference Condition and the sandbanks not as widespread. However, the rate at which sedimentation occurs is slow so the intertidal area will not have changed dramatically yet, but the process is still on a trajectory of change. Losing intertidal areas due to <u>localised</u> sedimentation effects of the bridge.	M
1b. % similarity in sand fraction relative to total sand and mud	50	The marine sediment area (sandy habitat) stretches further upstream and in the upper part of the estuary all the fine sediment (muddy habitat) is being flushed away resulting in coarser bed sediment. This process is still on a trajectory of change (predicted that estuary will be mainly sand habitat in 400 years).	M
2. Resemblance of <u>sub-tidal sediment</u> structure and distribution to Reference Condition			
2. Resemblance of subtidal estuary to Reference Condition: depth, bed or	80	The estuary is shallower under the Present State and the marine sediment moves slowly upstream. The rate at which sedimentation	M

channel morphology		occurs is, however, slow. Bed sediments are becoming coarser. This process is also still on a trajectory of change (predictions show that if Present State proceeds the estuary will fill up in 2000 years not taking into account sea level rise).	
Physical habitat Score	70		

Microalgae

Variable	Score	Motivation	Confidence
Phytoplankton			
1. Species richness	18 (41%)	The additional freshwater during the 2-month period will introduce freshwater species of microalgae. However, freshwater input is limited to 2 months and overall contribution to the Kromme Estuary is small.	M/H
2a. Abundance/Biomass	71	The possible formation of a REI zone in the tributary as well as the input of nutrients and SS (turbidity) from the freshwater input will increase chl a within the Geelhoutboom to 6-10 µg/ℓ. However, freshwater input is limited to 2 months and overall contribution to the Kromme Estuary is small.	M/H
2b. Community composition	41	The additional freshwater during the 2-month period will introduce freshwater species of microalgae. Diatoms are more dominant in the Kromme River than flagellates so a similar community is expected in the Geelhoutboom River. There will be a gradient from diatom to flagellate dominated water in the tributary. However, freshwater input is limited to 2 months and overall contribution to the Kromme Estuary is small.	M/H
Benthic microalgae			
1. Species richness	17 (40%)	The gradual increase in organic matter, fine sediment and nutrient content in the sediment of the Geelhoutboom tributary will increase species richness by favouring epipellic (mud associated) microalgae, particularly diatoms. In addition, freshwater species will colonise the upper reaches of the tributary during periods of freshwater input. However, the period of freshwater input is short and the overall contribution to the Kromme Estuary is small.	M/H
2a. Abundance/biomass	51	The gradual increase in organic matter, fine sediment and nutrient content in the sediment of the Geelhoutboom tributary will favour an average increase in microalgal biomass. Microalgal biomass is generally higher in fine sediment than silts and sand. However, the period of freshwater input is short and the overall contribution to the Kromme Estuary is small.	M/H

Variable	Score	Motivation	Confidence
2b. Community composition	41	The gradual increase in organic matter, fine sediment and nutrient content in the sediment of the Geelhoutboom tributary will favour epipellic (mud associated) microalgae. However, the period of freshwater input is short and the overall contribution to the Kromme Estuary is small.	M/H
Microalgae Score	17		

Macrophytes

Variable	Score	Motivation	Confidence
1. Species richness	65 (80%)	A salinity gradient for 2 months of the year in the Geelhoutboom tributary will not cause a change in species richness. Conditions would be similar to that of the Present State i.e. loss of brackish salt marsh species as well as reed and sedge species due to an increase in salinity and occurrence of hypersaline conditions. Loss of primary colonisers as a result of reduced flooding. 80% of original species probably remain.	M
2a. Abundance/Biomass	51	Salinity conditions in the Kromme Estuary are similar to present conditions. Salinity in the Geelhoutboom is reduced for approximately 2 months of the year. This is similar to Scenario 1. This would benefit the marshes in the Geelhoutboom but because most of the macrophyte biomass is in the Kromme Estuary the overall score does not change by much.	L
2b. Community composition	52	A salinity gradient for 2 months of the year in the Geelhoutboom tributary will cause a small decrease in total macroalgal biomass. Reed and sedge communities are restricted to areas of freshwater seepage and brackish marshes are reduced.	M
Macrophyte Score	51		

Invertebrates

Variable	Score	Motivation	Confidence
Zooplankton			
1. Species richness	65 (80%)	Because salinity will remain at or close to that of seawater in the main estuary, little or no change is likely in zooplankton species richness compared to the Present State. In the Geelhoutboom, a brackish water community may develop, but on the scale of the whole estuary, changes are likely to be limited.	M

Variable	Score	Motivation	Confidence
2a. Abundance/Biomass	45	Abundance levels will remain at low levels in the main estuary throughout the year. In the Geelhoutboom, abundance levels of the estuarine copepod <i>Pseudodiaptomus hessei</i> , <i>Acartia natalensis</i> and mysid shrimps (dominant estuarine species) will spike, but the duration will depend on the duration of the release. The overall benefit of the release will therefore be confined to the Geelhoutboom. On the scale of the whole system, benefits are likely to be limited. The spike in abundance will be linked to food availability (response of phytoplankton to the release).	H
2b. Community composition	45	Species such as <i>Tortanus capensis</i> do not occur in systems having a horizontal salinity gradient. In this system it is less common under Scenario 3 in comparison to the Present State because of freshwater being introduced (State 2). The mix of other species has also changed as a result of State 2 being introduced for one month (salinity driven).	H
Macroinvertebrates (Macrobenthos)			
1. Species richness	57 (75%)	Because salinity will remain at or close to that of seawater in the main estuary, little or no change in species richness is likely. In the Geelhoutboom, a brackish water community will develop leading to an increase in species richness overall.	H
2a. Abundance/Biomass	80	Abundance levels will remain at low levels in the main estuary throughout the year. In the Geelhoutboom, abundance levels of euryhaline macrobenthic species will spike, but the overall benefit of the release will be confined to the Geelhoutboom. On the scale of the whole estuary, benefits are likely to be limited.	H
2b. Community composition	20	Remains similar to the Present State, except for limited change due to the return of brackish/freshwater species (presence of State 2 during November). Due to the continued imbalance of the <i>Zostera</i> beds, the community composition change remains significant.	H
Macrocrustaceans (Large crustaceans)			
1. Species richness	65 (80%)	The same as for Scenario 2, but now the species are reintroduced in the Geelhoutboom tributary because of greater freshwater input. However, on the scale of the whole estuary, changes will be minimal.	M
2a. Abundance/Biomass	51	Geelhoutboom now has a gradient established but because of the size of the tributary the overall change will be marginal compared to Present State.	M
2b. Community composition	40	Similar to the Present State - the mix of species has probably changed significantly because of persistently high salinity values in the estuary, as well as the increase in <i>Zostera</i> coverage and biomass.	M
Invertebrate score	20		

Fish

Variable	Score	Motivation	Confidence
1. Species richness	80 (90%)	The fish species richness under this scenario will be almost identical to the Present State. Under perennial flow conditions in the headwater region of the Geelhoutboom, one or two freshwater species may be present.	M
2a. Abundance	80	Similar to the Present State.	H
2b. Community composition	45	Fish species composition is likely to be very similar to present with the slight increase in abundance of planktivorous fish (e.g. <i>Gilchristella aestuaria</i>) species improving the situation closer to natural.	M
Fish score	45		

Birds

Variable	Score	Motivation	Confidence
1. Species richness	80 (90%)	Bird species richness will be similar to the Present State, though some waterfowl species may occur more commonly in the Geelhoutboom.	H
2a. Abundance	82	Small increases could occur in the Geelhoutboom but the overall change will be small relative to Present State.	M
2b. Community composition	72	Species composition will remain very similar to the Present State, with possible very small increase in numbers of waterfowl.	M
Bird score	72		

4.2.4 Scenario 4

Scenario 4 represents a $5 \times 10^6 \text{ m}^3$ release into the Kromme Estuary (in November) while inflow into the Geelhoutboom tributary is that required for a River Class C/D.

i. Seasonal variability in river inflow

Monthly simulated runoff data (73-year period) for Scenario 4 into the Kromme Estuary and Geelhoutboom tributary are provided in Tables 4-2 and 4-4, respectively. A summary of the flow distributions (mean monthly flows in m^3/s), derived from the simulated data set, is provided below (hatched months represent flows less than $0.2 \text{ m}^3/\text{s}$ when hypersaline conditions can potentially develop):

Kromme: Summary of flow distributions for Scenario 4 ($5 \times 10^6 \text{ m}^3$ release in Nov)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	13.66	25.96	5.02	4.68	2.32	3.63	4.55	26.02	14.72	16.25	22.94	26.05
90%ile	4.62	3.02	0.48	0.20	0.34	0.40	0.48	2.04	2.74	2.05	2.71	10.36
80%ile	1.95	2.41	0.27	0.15	0.16	0.23	0.22	0.38	0.52	0.38	1.10	3.17
70%ile	0.77	2.31	0.21	0.11	0.10	0.14	0.15	0.17	0.28	0.31	0.39	0.56
60%ile	0.41	2.22	0.16	0.08	0.09	0.10	0.12	0.14	0.18	0.23	0.31	0.40
50%ile	0.30	2.14	0.11	0.08	0.06	0.06	0.09	0.09	0.14	0.18	0.25	0.30
40%ile	0.24	2.11	0.11	0.06	0.04	0.05	0.07	0.08	0.11	0.15	0.20	0.22
30%ile	0.19	2.09	0.10	0.05	0.04	0.05	0.05	0.06	0.08	0.12	0.15	0.18
20%ile	0.16	2.06	0.08	0.05	0.04	0.03	0.05	0.05	0.06	0.09	0.11	0.13
10%ile	0.13	2.03	0.06	0.03	0.02	0.03	0.03	0.03	0.04	0.06	0.08	0.10
1%ile	0.05	0.52	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.04	0.06

Geelhoutboom: Summary of flow distributions for Scenario 4 (as per River Class C/D)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	1.07	1.21	0.36	0.43	0.32	0.35	0.28	1.18	0.90	1.18	1.72	2.08
90%ile	0.37	0.36	0.10	0.05	0.08	0.09	0.09	0.20	0.21	0.18	0.41	0.58
80%ile	0.24	0.14	0.07	0.03	0.04	0.05	0.04	0.08	0.11	0.12	0.17	0.23
70%ile	0.15	0.11	0.05	0.03	0.02	0.03	0.03	0.04	0.07	0.08	0.13	0.17
60%ile	0.10	0.08	0.04	0.02	0.02	0.02	0.03	0.03	0.04	0.05	0.09	0.11
50%ile	0.08	0.05	0.03	0.02	0.01	0.01	0.02	0.02	0.03	0.04	0.06	0.08
40%ile	0.06	0.04	0.02	0.01	0.01	0.01	0.02	0.02	0.02	0.04	0.04	0.05
30%ile	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.03	0.04
20%ile	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.03
10%ile	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02
1%ile	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01

ii. Predicted flood regime for Scenario 4

Similar to the Present State

Confidence: High

iii. Predicted sediment processes under Scenario 4

Similar to the Present State

Confidence: High

iv. Occurrence and duration of different abiotic states for Scenario 4

Estimated occurrence and duration of the different Abiotic States in the Kromme Estuary and Geelhoutboom tributary under Scenario 4, based on simulated monthly river inflow into the Kromme Estuary and Geelhoutboom tributary are indicated Tables 4-2 and 4-4, respectively.

To provide a conceptual overview of the annual distribution of Abiotic States under Scenario 4 for the Kromme Estuary and Geelhoutboom tributary, median monthly flows (representative of seasonal conditions) and 10%ile flows (representative of drought conditions) were used to depict the situation for normal and drought periods (Figure 4-4).

Confidence: Medium

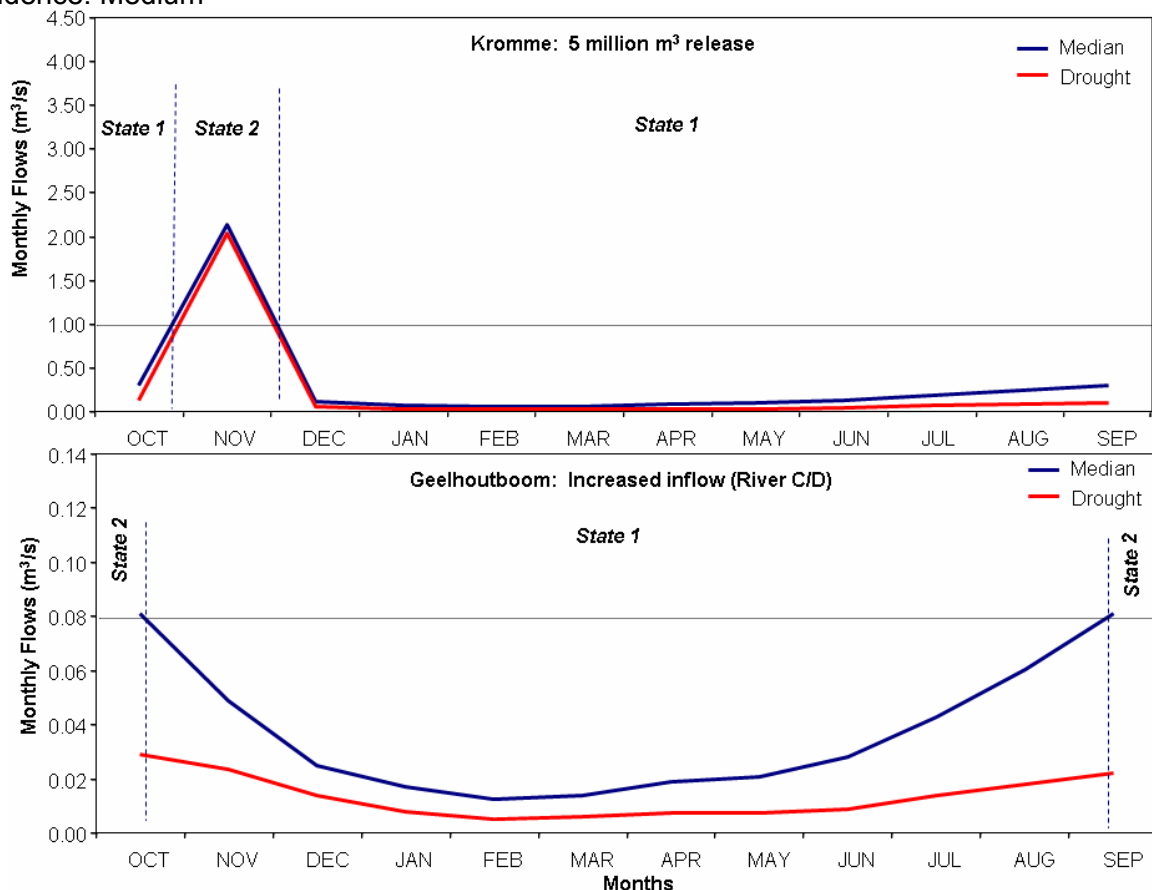


Figure 4-4 Predicted distribution of Abiotic States under Scenario 4 for the Kromme Estuary and Geelhoutboom tributary, based on median monthly flows (representative of seasonal conditions) and 10%ile flows (representative of drought conditions)

v. Predicted change in biotic characteristics under Scenario 4

Microalgae For 11 months of the year, the flow will be similar to the Present State, i.e. no or very little flow. As a result, there will be no or very limited mixing of freshwater with estuarine water, which would result in the associated flocculation of nutrient-rich particles. Phytoplankton biomass will be highest in the middle reaches of the estuary, probably associated with nutrient recycling from fine sediments close to the Geelhoutboom tributary, but average chl a in the water column will be low (~5 µg/l). The phytoplankton will be dominated by flagellates (>90%) throughout the estuary and <10% diatoms. The benthos will be dominated by marine episammic (sand associated) microalgae in the middle and lower reaches of the estuary and marine epilithic (rock associated) microalgae in the upper reaches. Average benthic chl a (rock substrate excluded) will be low (<50 mg/m²) due to the depleted nutrients in the water column. A 5 x 10⁶ m³ release of freshwater in November will result in a flow of ~2 m³/s. This flow is insufficient to scour high salinity water at depth in the upper reaches of the estuary but will introduce some nutrients and TSS into the estuary. This will stimulate a 25-33% increase in phytoplankton chl a and a doubling in intertidal benthic chl a for a period of two months following the release. A strong halocline will develop in the upper and middle reaches of the estuary so subtidal benthic chl a is unlikely to change significantly in these regions. From about 1 week after the release, diatoms will dominate the phytoplankton (>50%) but this will not last for longer than 2-3 weeks before flagellates become dominant again. The Geelhoutboom will have a flow >0.08 m³/s for a possible 2 months per year. The Geelhoutboom is shallow in its upper reaches and deepens towards the confluence with the Kromme. This bathymetry is ideal for the formation of a REI zone provided flow creates a longitudinal salinity gradient and the tributary is not flushed out too quickly, i.e. flow must not exceed 1.0 m³s⁻¹. However, nutrients are low in the Geelhoutboom River and the volume of the tributary is small relative to the Kromme so contributions to the overall system are small. Increases in microalgal biomass and richness will be restricted to in or near to the tributary. Confidence: High
Macrophytes This scenario is similar to Scenario 1 as the freshwater release will create a salinity gradient in the Kromme Estuary in November. However, conditions are improved in the Geelhoutboom tributary, which will have a salinity gradient in September, October and November. This would only benefit the small salt marsh areas in the Geelhoutboom tributary as most of the macrophytes are situated in the Kromme Estuary. The reduction in salinity would increase the germination and growth of intertidal salt marsh. Lower water column salinity would influence sediment and groundwater conductivity and promote the growth of supratidal salt marsh as well. Confidence: High
Invertebrates (including zooplankton, benthic invertebrates and macrocrustaceans) Similar to Present State in the main estuary, with zooplankton, benthos and hyperbenthos showing relatively little change during the annual cycle. Zooplankton biomass is likely to remain low, since pulses of freshwater will not become more frequent (prevented by the presence of the Impofu Dam). Although the allocation of water is more than double the current allocation, stratification is likely to persist with no significant mixing of the water column. <i>Zostera capensis</i> biomass and coverage is also unlikely to change and current patterns of invertebrate distribution will persist. Although the Geelhoutboom will also receive a freshwater inflow under Scenario 4, the tributary is shallow and the volume low. Invertebrates will benefit from the release, but in comparison to the area and volume of the main estuary, the benefit will be localised and on a small scale overall. Confidence: High
Fish The marine migrant fish component in the Kromme Estuary is likely to be similar to Future Scenario 1. In addition, the freshwater flow that the Geelhoutboom tributary receives will be very important in maintaining planktivorous fish components, especially the estuarine roundherring <i>Gilchristella aestuaria</i>. Spawning by this species will be possible in the Geelhoutboom tributary when no breeding activities are possible in the main estuary. Confidence: High

Birds
The avifaunal community remains similar to the Present State, but with slight increases in the occurrence of waterfowl, piscivorous birds, and possibly waders as a result of increased invertebrate productivity.
Confidence: Medium

vi. EHI scoring for the Scenario 4

Hydrology

Variable	Score	Motivation	Confidence
a. % similarity in period of low flows OR Present MAR as a % of MAR in the Reference Condition	42	For the Kromme Estuary low flows are defined as flows associated with State 1 (i.e. $< 1 \text{ m}^3/\text{s}$). Months with low flows of less than $1 \text{ m}^3/\text{s}$ increased from 4 (Jan – Apr) under the Reference Condition to 11 months (Oct – Dec) under Scenario 4.	H
	75	For the Geelhoutboom tributary low flows are defined as flows associated with State 1 (i.e. $< 0.08 \text{ m}^3/\text{s}$). Months with median low flows of less than $0.08 \text{ m}^3/\text{s}$ increased from 7 (Dec – Jun) under the Reference Condition to 10 months (Nov – Aug) under Scenario 4.	L
b. % similarity in mean annual frequency of floods	20	The major floods (1:20) (magnitude and frequency) have been dramatically modified and most of the smaller floods (1:5 years) do not reach the estuary under the Present State. Allow for a 80% modification from Reference Condition.	H
	80	There are no large impoundments in the Geelhoutboom; therefore most large floods (1:20) from this tributary still reach the estuary. This is also supported by the fact that monthly flows $> 1.0 \text{ m}^3/\text{s}$ reach the estuary. They occurred 15% of the years under the Reference Condition and 13% of the years under the Present State.	M
Hydrology Score	44	Kromme - weight 85%; Geelhoutboom - weight 15%	

Hydrodynamics and mouth condition

Variable	Score	Motivation	Confidence
Change in mean duration of closure, e.g. over a 5 or 10 year period	100	Due to tidal flows the estuary mouth remains permanently open.	H
	100	Due to tidal flows the estuary mouth remains permanently open.	H
Hydrodynamic Score	100		

Water quality

Variable	Score	Motivation	Confidence
1. Change in the longitudinal salinity gradient (%) and vertical salinity stratification	40	State 3: Fresh, which used to occur for 1 out of 2 (50%) years for about 1 – 2 months at a time under the Reference Condition in the Kromme Estuary, has been reduced to 1 out of 4 years (26%) under Scenario 4. Furthermore, State 2: Salinity Gradient only occurs for 1 month (Nov) of the year under Scenario 4, while it used to occur for 8 months (May – Dec) of the year under Reference Condition. Under Scenario 4 there is also a slight tendency to develop hypersaline conditions towards the end of summer. This signifies largely modified salinity conditions. Under Reference Condition the estuary fluctuated between a marine dominated and a saline gradient state under its median flow conditions.	H
	35	Under Scenario 4, there is a loss of State 2: Salinity Gradient. This implies that there is no significant gradient in the system for about 10 months (Nov – Aug) (7 under Reference Condition) and that the homogenous water body takes on the salinity of the Kromme Estuary. Under the Reference Condition this homogenous body of water would have varied between 20 to 35 ppt depending on the inflow. Under Scenario 4 the Geelhoutboom tributary would be 35 ppt for ~9 months of the year under median flow conditions, i.e. gradient state Sep - Oct and flow release in Nov.	M
Kromme Score (weight 85%)	34	Geelhoutboom Score (weight 15%)	5.3
2a. Nitrate/phosphate concentration in the estuary	42	The Kromme system (including Geelhoutboom tributary) receives its inorganic nutrients through river inflow, either the Kromme and/or Geelhoutboom rivers. State 1 (little to no freshwater inflow) is therefore characteristic of nutrient depleted conditions. During States 2 and 3 river inflow introduced inorganic nutrients to the estuary. In Scenario 4, State 2 only occurs for 1 month (Nov) compared to 8 months (May - Dec) under the Reference Condition. Freshwater pulses (State 3) have also been reduced. Under Scenario 4, State 1 now occurs for 11 months (compared to 4 months under the Reference Condition (Jan - Apr)). Using Table 3.2b (DWAf, 2004), which is also used to derive scores for low flow periods, this translates into a score of 42. However, there might be a slight increase in inorganic nutrients at the top 1 km of the Geelhoutboom tributary during Sept and Oct.	L/M

Variable	Score	Motivation	Confidence
		Allow for a 2% adjustment (increase) from Present State, i.e. slightly closer to Reference Condition.	
2b. Suspended solids in the estuary	42	The Kromme system receives suspended solids through river inflow. States 2 and 3 (both in the Kromme and Geelhoutboom) are therefore characterised by higher suspended solid concentrations (or higher turbidity) than State 1. In Scenario 4, State 2 only occurs for 1 month (Nov) compared to 8 months (May – Dec) under the Reference Condition. Freshwater pulses (under which State 3 would have developed) have also been reduced. Under Scenario 4, State 1 now occurs for 11 months (compared to 4 months under the Reference Condition – Jan - Apr). The estuary under Scenario 4 is therefore considered to be less turbid than under the Reference Condition (used to be 'clear' for 4 months [Jan – Apr], now 'clear' for 11 months [Dec – Oct]). Using Table 3.2b (DWAF, 2004), which is also used to derive scores for low flow periods, this translates into a score of 42. However, there might be slightly more turbid conditions in the top 1 km of the Geelhoutboom tributary during Sept and Oct. Allow for a 2% adjustment (increase) from Present State, i.e. slightly closer to Reference Condition.	L/M
2c. Dissolved oxygen in the estuary	75	The Kromme System is usually well oxygenated, except during prolonged periods of State 1, when a reduction in oxygen has been observed in the deeper areas in the upper reaches of the estuary. After construction of the Impofu Dam this would seldom drop to below 5 mg/l as the dam probably cut off significant organic inputs to the upper reaches. Higher organic input during the Reference Condition, however, would have resulted in more severe reductions in DO in this region in the 4 months in which State 1 occurred. Allow for a modification of 10% during those periods. Also, the risk of lower oxygen conditions has been extended from the Reference Condition to Scenario 1 (State 1 occurs for 11 months instead of 4 months) although DO reductions are not severe, i.e. seldom drop below 5 mg/l. Allow for a modification of 15% during those periods.	M
2d. Levels of toxins	100	Similar to Present State	M
Water Quality Score	42		

Physical habitat alteration

Variable		Score	Motivation	Confidence
1. Resemblance of <u>intertidal sediment</u> structure and distribution to Reference Condition				
1a	% similarity in intertidal area (size) exposed	70	The estuary was probably deeper under the Reference Condition and the sandbanks not as widespread. However, the rate at which sedimentation occurs is slow so the intertidal area will not have changed dramatically yet, but the process is still on a trajectory of change. Losing intertidal areas due to <u>localised</u> sedimentation effects of the bridge.	M
1b	% similarity in sand fraction relative to total sand and mud	50	The marine sediment area (sandy habitat) stretches further upstream and in the upper part of the estuary all the fine sediment (muddy habitat) is being flushed away resulting in coarser bed sediment. This process is still on a trajectory of change (predicted that estuary will be mainly sand habitat in 400 years).	M
2. Resemblance of <u>sub-tidal sediment</u> structure and distribution to Reference Condition				
2	Resemblance of subtidal estuary to Reference Condition: depth, bed or channel morphology	80	The estuary is shallower under the Present State and the marine sediment moves slowly upstream. The rate at which sedimentation occurs is, however, slow. Bed sediments are becoming coarser. This process is also still on a trajectory of change (predictions show that if Present State proceeds the estuary will fill up in 2000 years not taking into account sea level rise).	M
Physical habitat Score		70		

Microalgae

Variable		Score	Motivation	Confidence
Phytoplankton				
1. Species richness		23 (46%)	The effects of the freshwater into the Kromme Estuary on the microalgae will only persist for ~2 months. The rest of the year will be similar to Present State. During the two months, diatoms will dominate (>50%) the phytoplankton for a couple of weeks before a gradual change back to a flagellate dominated (>90%) estuary. In addition, freshwater species of phytoplankton will be present in the estuary during the first 2-3 weeks following the release. The additional freshwater into the Geelhoutboom during the 2-month period will introduce freshwater species of microalgae. However, freshwater input is limited to 2 months and overall contribution to the Kromme Estuary is small.	M/H

Variable	Score	Motivation	Confidence
2a. Abundance/Biomass	76	The effects of the freshwater on the microalgae will only persist for ~2 months. The rest of the year will be similar to Present State. There will be an initial drop in average chl a to <2 µg/l but will increase over the following few days to a concentration that is ~25-33% higher than before the release. This biomass should persist for a further 2 months. No REI will form so a higher phytoplankton biomass is not expected. The possible formation of a REI zone in the Geelhoutboom tributary as well as the input of nutrients and TSS from the freshwater input will increase chl a within the Geelhoutboom to 6-10 µg/g. However, freshwater input is limited to 2 months and overall contribution to the Kromme Estuary is small.	H
2b. Community composition	46	The effects of the freshwater on the microalgae will only persist for ~2 months. The rest of the year will be similar to Present State. The release will introduce freshwater from the Impofu Dam dominated by diatoms (>60% of phytoplankton), flagellates (~30%) and chlorophytes (~5%). This creates a change in community structure from one dominated by diatoms near to the head of the estuary to one dominated by flagellates closer to the mouth. Dinoflagellates will only occur in saline water close to the mouth of the estuary. This dramatic change in community composition will only last while water with a salinity of <4 ppt persists in the estuary before a gradual change over two months back to that before the release. In the Geelhoutboom, the additional freshwater during the 2-month period will introduce freshwater species of microalgae. Diatoms are more dominant in the Kromme River than flagellates so a similar community is expected in the Geelhoutboom River. There will be a gradient from diatom to flagellate dominated water in the tributary. However, freshwater input is limited to 2 months and overall contribution to the Kromme Estuary is small.	M/H

Benthic microalgae

1. Species richness	17 (40%)	It is unlikely that the freshwater will change the species richness in the Kromme Estuary. The gradual increase in organic matter, fine sediment and nutrient content in the sediment of the Geelhoutboom tributary will increase species richness by favouring epipellic (mud associated) microalgae, particularly diatoms. In addition, freshwater species will colonise the upper reaches of the tributary during periods of freshwater input. However, the period of freshwater input is short and the overall contribution to the Kromme Estuary is small.	M/H
2a. Abundance/Biomass	61	The effects of the freshwater on the microalgae will only persist for ~2 months. The rest of the year will be similar to Present State. It is unlikely that the release of freshwater will erode the benthic sediments so an immediate increase in intertidal benthic chl a is expected over the first week from an average of <40 mg/m² to ~60 mg/m². The mixing of water in the lower reaches of the estuary should result in intertidal and subtidal chl a increasing to >150 and >100 mg/m² in this region within the first week. The gradual increase in organic matter, fine sediment and nutrient content in the sediment of the Geelhoutboom tributary will favour an average increase in microalgal biomass. Microalgal biomass is generally higher in fine sediment than silts and sand. However, the period of freshwater input is short and the overall contribution to the Kromme Estuary is small.	M/H
2b. Community composition	41	It is unlikely that the freshwater will change the community composition. The gradual increase in organic matter, fine sediment and nutrient content in the sediment of the Geelhoutboom tributary will favour epipellic (mud associated) microalgae. However, the period of freshwater input is short and the overall contribution to the Kromme Estuary is small.	M/H
Microalgae Score	17		

Macrophytes

Variable	Score	Motivation	Confidence
1. Species richness	65 (80%)	A salinity gradient for 1 month of the year in the Kromme Estuary and 3 months in the Geelhoutboom tributary will not cause a change in species richness. Conditions would be similar to that of the Present State i.e. loss of brackish salt marsh species as well as reed and sedge species due to an increase in salinity and occurrence of hypersaline conditions. Loss of primary colonisers as a result of reduced flooding. 80% of original species probably remain.	M
2a. Abundance/Biomass	54	This scenario is similar to Scenario 1 as the freshwater release will create a salinity gradient in the Kromme Estuary in November. However, conditions are improved in the Geelhoutboom tributary which will have a salinity gradient in September, October and November. This would only benefit the Geelhoutboom tributary as most of the macrophytes are situated in the Kromme Estuary. The reduction in salinity would increase the germination and growth of intertidal salt marsh. Lower water column salinity would influence sediment and groundwater conductivity and promote the growth of supratidal salt marsh as well.	H
2b. Community composition	55	A salinity gradient for 1 month of the year in the Kromme Estuary and 3 months in the Geelhoutboom tributary will cause die-back of marine macroalgae. However, these will colonise the estuary quickly again. Reed and sedge communities are restricted to areas of freshwater seepage and brackish marshes are reduced.	M
Macrophyte Score	54		

Invertebrates

Variable	Score	Motivation	Confidence
Zooplankton			
1. Species richness	73 (85%)	Because salinity will remain at or close to that of seawater for 11 months of the year, no change is likely in zooplankton species richness in the main estuary. Stratification is likely to be present in the upper estuary during the release period (November) and will not benefit species such as <i>Acartia natalensis</i> (eggs remain dormant in the sediments when salinity values are above ca 20 ppt). In the Geelhoutboom, a brackish water community may develop, but on the scale of the whole estuary, changes are likely to be limited.	M

Variable	Score	Motivation	Confidence
2a. Abundance/Biomass	60	Abundance levels in the main estuary will remain at low levels during 11 months of the year. During the release, abundance levels of the estuarine copepod <i>Pseudodiaptomus hessei</i> will spike, but the duration will not persist for more than a few weeks. The spike in abundance will be linked to food availability (response of phytoplankton to the release). In the Geelhoutboom, abundance levels of the estuarine copepod <i>Pseudodiaptomus hessei</i> , <i>Acartia natalensis</i> and mysid shrimps (dominant estuarine species) will spike, but the duration will depend on the duration of the release. On the scale of the whole estuary, benefits to the Geelhoutboom are likely to be limited. The spike in abundance will be linked to food availability.	H
2b. Community composition	45	Species composition is unlikely to change.	H

Macroinvertebrates

1. Species richness	63 (78%)	Some change in species richness is likely. Slightly higher than in the previous scenarios because of different habitats (i.e. sediment types associated with the head region of the main estuary and Geelhoutboom tributary both moving into State 2 for short periods).	H
2a. Abundance/Biomass	82	Very similar to Scenario 3, but with a small increase in numbers in the Geelhoutboom tributary.	H
2b. Community composition	20	Similar to the Present State.	H

Macrocrustacea

1. Species richness	57 (75%)	Similar to Scenario 1 - inflow to the Geelhoutboom tributary does not contribute anything because the habitats are already covered in main Kromme system.	M
2a. Abundance/Biomass	51	Similar to Scenario 1, except for additional biomass associated with the availability of freshwater habitat in the Geelhoutboom input (albeit small).	M
2b. Community composition	40	Similar to Scenario 1 and 3 (which, in turn, are similar to the Present State).	M
Invertebrate score	20		

Fish

Variable	Score	Motivation	Confidence
1. Species richness	80 (90%)	Most fish species in the system will persist under this scenario and only a few freshwater species will be lost due to the lack of any REI in the upper reaches.	H
2a. Abundance	85	Marine fish abundance, especially for the larval component in November, is likely to be similar to Future Scenario 1. The abundance of planktivorous fish species is likely to increase during the summer due to improved recruitment from the Geelhoutboom tributary.	M

Variable	Score	Motivation	Confidence
2b. Community composition	60	The composition of the fish community will remain very similar to present for approximately 8 months of the year. The freshwater release in November, together with river flow from the Geelhoutboom tributary, will have an impact on this community that will probably persist for at least 4 months each year.	M
Fish score	60		

Birds

Variable	Score	Motivation	Confidence
1. Species richness	85 (93%)	Certain species such as waterfowl may occur more frequently in the Geelhoutboom and Kromme above the confluence.	H
2a. Abundance	87	Small increase in abundance of piscivores and possibly other marsh users and waders compared to Scenario 1.	M
2b. Community composition	77	A slight change in community composition due to the above.	M
Bird score	77		

4.2.5 Scenario 5

Scenario 5 represents a $7.5 \times 10^6 \text{ m}^3$ release into the Kromme Estuary (in October and November) while inflow into the Geelhoutboom tributary remains in its Present State.

i. Seasonal variability in river inflow

Monthly simulated runoff data (73-year period) for Scenario 5 into the Kromme Estuary and Geelhoutboom tributary are provided in Tables 4-5 and 3-2, respectively. A summary of the flow distributions (mean monthly flows in m^3/s), derived from the simulated data set, is provided below (hatched months represent flows less than $0.2 \text{ m}^3/\text{s}$ when hypersaline conditions can potentially develop):

Kromme: Summary of flow distributions for Scenario 5 ($7.5 \times 10^6 \text{ m}^3$ release in Oct and Nov)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	14.29	26.06	5.12	4.71	2.24	3.66	4.64	27.62	15.03	17.43	23.57	26.39
90%ile	4.76	2.02	0.48	0.20	0.34	0.40	0.48	2.39	2.83	2.12	4.15	10.73
80%ile	3.07	1.39	0.27	0.15	0.16	0.23	0.22	0.43	0.52	0.43	1.17	3.25
70%ile	2.35	1.25	0.21	0.11	0.10	0.14	0.15	0.18	0.28	0.31	0.40	0.57
60%ile	2.16	1.16	0.16	0.08	0.09	0.10	0.12	0.14	0.17	0.22	0.32	0.43
50%ile	2.07	1.08	0.11	0.08	0.06	0.06	0.09	0.09	0.13	0.18	0.24	0.30
40%ile	2.02	1.05	0.11	0.06	0.04	0.05	0.07	0.08	0.10	0.15	0.19	0.21
30%ile	1.97	1.02	0.10	0.05	0.04	0.05	0.05	0.06	0.08	0.12	0.15	0.17
20%ile	1.93	1.00	0.08	0.05	0.04	0.03	0.05	0.05	0.06	0.09	0.11	0.13
10%ile	1.87	0.97	0.06	0.03	0.02	0.03	0.03	0.03	0.04	0.06	0.08	0.10
1%ile	0.57	0.52	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.04	0.06

Geelhoutboom: Summary of flow distributions for Scenario 5 (Present State)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	1.05	1.21	0.34	0.43	0.29	0.32	0.28	1.17	0.90	1.18	1.72	2.09
90%ile	0.37	0.36	0.05	0.00	0.05	0.07	0.08	0.18	0.21	0.18	0.41	0.57
80%ile	0.24	0.11	0.01	0.00	0.00	0.01	0.04	0.07	0.10	0.11	0.17	0.22
70%ile	0.13	0.06	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.07	0.13	0.16
60%ile	0.08	0.03	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.04	0.08	0.09
50%ile	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.05	0.06
40%ile	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.03
30%ile	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02
20%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 4-5 Monthly simulated runoff data in m³/s (73-year period) for Scenario 5 (7.5 x 10⁶ m³ release in Oct and Nov) into the Kromme Estuary

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1927	1.87	0.95	0.05	0.03	0.03	1.00	0.49	0.10	0.09	0.07	0.09	0.21
1928	2.02	1.24	0.16	0.06	0.04	0.03	0.02	0.05	0.06	0.19	0.19	0.41
1929	2.07	1.03	0.08	0.03	0.17	0.14	0.10	0.08	0.13	0.13	0.24	0.25
1930	2.06	1.03	0.07	0.08	0.05	0.04	0.05	0.04	0.04	0.12	0.11	0.46
1931	2.96	1.40	0.69	1.90	0.74	0.15	0.10	0.06	0.08	0.14	0.11	28.18
1932	9.93	1.80	0.27	0.08	0.05	0.05	0.08	4.06	2.60	0.82	19.59	3.80
1933	2.04	1.28	0.16	0.08	0.09	0.11	0.08	0.06	0.06	0.22	0.20	0.15
1934	4.50	1.29	0.11	0.04	0.04	0.03	0.08	25.26	7.80	2.07	4.81	2.39
1935	2.22	1.29	0.23	0.09	0.04	0.05	0.05	0.18	0.14	0.15	0.13	0.12
1936	2.04	1.94	0.42	0.09	0.05	0.06	0.05	0.03	0.08	0.12	0.11	0.17
1937	1.94	1.02	0.11	0.08	0.04	0.02	0.05	0.08	0.09	0.08	0.08	0.12
1938	1.92	1.08	0.11	0.04	0.37	0.34	0.19	0.12	0.09	0.12	0.86	0.57
1939	2.10	1.16	0.27	0.19	0.33	0.37	0.21	0.14	0.23	0.27	0.19	0.30
1940	1.97	1.02	0.07	0.05	0.04	0.04	0.06	0.05	0.26	0.18	0.11	0.11
1941	1.96	1.02	0.37	0.24	0.09	0.05	0.05	0.15	0.17	0.15	0.15	0.12
1942	1.99	1.03	0.11	0.12	0.07	0.05	0.05	0.05	0.76	0.49	0.37	0.55
1943	2.10	1.61	0.42	0.13	0.08	0.16	0.15	33.69	8.92	2.74	1.17	3.29
1944	2.26	1.09	0.10	0.05	0.04	0.02	0.02	9.40	11.58	2.13	1.29	0.35
1945	2.47	1.19	0.10	0.05	0.03	0.31	0.17	0.06	0.05	0.20	0.25	0.23
1946	2.05	1.03	0.07	0.03	0.02	0.13	0.12	0.27	0.39	11.82	1.86	0.50
1947	2.01	1.05	0.10	0.05	0.04	0.06	0.43	0.23	0.13	0.12	0.11	0.16
1948	2.56	1.26	0.11	0.05	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.04
1949	1.81	2.54	0.64	0.05	0.03	0.02	0.04	0.04	0.04	0.17	0.35	0.31
1950	2.15	2.04	0.50	0.96	0.41	0.09	0.05	0.08	0.12	0.66	1.18	6.05
1951	2.71	1.07	0.09	0.07	0.62	0.24	0.07	0.08	0.10	0.10	0.35	15.31
1952	3.60	1.19	0.16	0.07	0.05	0.03	0.03	0.03	0.06	0.18	0.31	0.66
1953	25.50	8.97	0.24	0.09	0.04	0.40	0.24	1.25	2.70	6.22	18.35	6.55
1954	2.07	1.06	0.10	0.06	5.30	7.74	0.39	0.23	0.11	0.12	0.48	0.36
1955	1.99	5.18	4.60	0.08	0.09	0.13	0.09	2.54	2.86	0.44	0.24	11.23
1956	9.33	16.18	3.56	0.21	0.19	0.16	0.14	0.20	0.28	0.26	0.38	6.45
1957	5.30	1.10	0.09	0.03	0.02	0.08	0.06	0.47	0.31	0.16	0.34	0.30
1958	1.99	1.00	0.08	0.26	0.16	0.08	0.16	0.15	0.12	0.14	0.30	0.28
1959	2.07	1.03	0.11	0.23	0.12	0.05	0.05	0.10	0.13	0.24	0.23	0.93
1960	1.93	0.98	0.07	0.05	0.08	0.57	0.36	0.44	0.34	0.29	0.27	0.20
1961	1.94	0.98	0.05	0.03	0.03	0.18	0.18	0.11	0.08	0.08	1.12	0.63
1962	2.31	1.17	0.11	0.19	0.10	0.89	0.77	0.41	0.27	0.24	0.21	0.17
1963	1.90	1.00	0.21	0.18	0.09	0.08	0.07	0.05	0.52	0.36	0.46	12.99
1964	7.02	1.25	0.16	0.06	0.02	0.06	0.08	0.14	0.15	0.13	0.12	0.10
1965	2.30	3.35	0.21	0.11	0.10	0.05	0.04	0.05	0.05	0.04	0.11	0.14
1966	1.90	1.02	0.10	0.05	0.02	0.03	0.77	0.65	0.40	0.35	0.34	0.49
1967	2.10	1.05	0.09	0.04	0.02	0.03	0.18	0.16	23.89	7.58	2.74	25.70
1968	4.20	1.16	0.13	0.06	0.04	0.04	0.04	0.03	0.07	0.08	0.08	0.12
1969	1.95	1.00	0.05	0.03	0.04	0.03	0.02	0.01	0.02	0.01	0.06	0.08
1970	1.91	0.97	0.37	0.16	0.13	0.10	0.76	0.67	0.51	2.96	33.81	11.74
1971	2.13	1.43	0.13	0.05	0.22	0.11	0.15	0.14	0.14	0.17	0.21	0.15
1972	1.86	0.93	0.03	0.01	0.02	0.08	0.10	0.09	0.08	0.05	0.05	0.06
1973	1.84	0.97	0.06	0.18	0.17	0.75	0.40	0.25	0.26	0.17	1.29	8.64
1974	2.41	1.05	0.08	0.06	0.10	0.19	0.12	0.05	0.06	0.09	0.19	0.31
1975	1.98	0.98	0.08	0.05	0.06	0.24	0.29	0.19	0.17	0.42	0.43	0.31
1976	2.58	1.40	0.18	0.08	0.34	0.18	0.11	5.84	4.11	0.39	0.29	0.56
1977	2.16	1.23	0.21	0.09	0.04	0.07	0.14	0.11	0.18	0.18	0.18	0.17
1978	2.16	1.27	0.21	0.16	0.11	0.06	0.05	0.07	0.10	0.34	16.08	14.36
1979	2.27	1.12	0.11	0.08	0.04	0.02	0.05	0.05	0.08	0.08	0.07	0.12
1980	1.94	1.04	0.13	0.37	0.17	2.08	0.93	9.70	9.77	0.59	14.49	8.73
1981	5.54	1.38	0.18	0.08	0.04	0.05	0.70	1.79	0.13	0.19	0.22	0.20
1982	1.92	0.97	0.05	0.02	0.02	0.01	0.02	0.03	0.06	31.84	12.97	0.42
1983	3.90	1.08	0.10	0.04	0.02	0.06	0.05	0.03	0.04	0.09	0.09	0.09
1984	1.84	0.92	0.07	0.13	0.10	0.05	0.07	0.06	0.13	0.14	0.12	0.09
1985	1.94	1.06	0.13	0.10	0.06	0.03	0.03	0.02	0.04	0.04	0.19	0.17
1986	2.46	1.30	0.16	0.07	0.04	0.03	0.12	0.08	0.33	0.22	0.15	0.46
1987	2.04	0.99	0.06	0.03	0.04	0.03	0.07	0.08	0.18	0.16	0.14	0.14
1988	0.61	0.40	0.08	0.05	0.04	0.02	0.10	0.08	0.05	0.08	0.08	0.15
1989	3.22	3.16	0.65	0.11	0.15	0.10	0.16	0.16	0.59	0.39	0.28	0.26
1990	2.27	1.15	0.11	0.05	0.02	0.02	0.02	0.02	0.03	0.03	0.08	0.08
1991	0.45	0.57	0.11	0.06	1.05	0.38	0.08	0.09	0.12	0.23	1.23	0.71
1992	3.14	1.92	0.29	0.16	0.09	0.05	0.10	0.08	1.43	0.71	0.37	25.20
1993	7.73	1.17	0.26	0.15	0.09	0.08	0.07	0.09	0.11	0.22	4.50	3.20
1994	4.83	1.06	4.28	11.93	0.58	0.53	0.60	1.64	0.70	0.39	0.58	0.25
1995	1.98	1.07	0.30	0.15	0.08	0.06	0.05	0.03	0.02	0.06	0.15	0.17
1996	3.76	51.45	6.45	0.13	0.06	0.05	14.17	4.50	3.29	2.39	1.93	0.53
1997	1.95	1.00	0.06	0.06	0.04	0.22	0.13	0.07	0.07	0.07	0.22	0.20
1998	1.91	1.00	0.11	0.06	0.04	0.03	0.05	0.05	0.04	0.25	0.18	0.10
1999	1.83	0.90	0.07	0.10	0.20	0.36	0.23	0.11	0.08	0.05	0.05	0.06

1 <0.2 1 0.2-1.0 2 1.0-8.0 3 >8.0

ii. Predicted flood regime for Scenario 5

Similar to the Present State

Confidence: High

iii. Predicted sediment processes under Scenario 5

Similar to the Present State

Confidence: High

iv. Occurrence and duration of different abiotic states under Scenario 5

Estimated occurrence and duration of the different Abiotic States in the Kromme Estuary and Geelhoutboom tributary under Scenario 5, based on simulated monthly river inflow into the Kromme Estuary and Geelhoutboom tributary are indicated Tables 4-5 and 3-2, respectively.

To provide a conceptual overview of the annual distribution of Abiotic States under Scenario 5 for the Kromme Estuary and Geelhoutboom tributary, median monthly flows (representative of seasonal conditions) and 10%ile flows (representative of drought conditions) were used to depict the situation for normal and drought periods (Figure 4-5).

Confidence: Medium

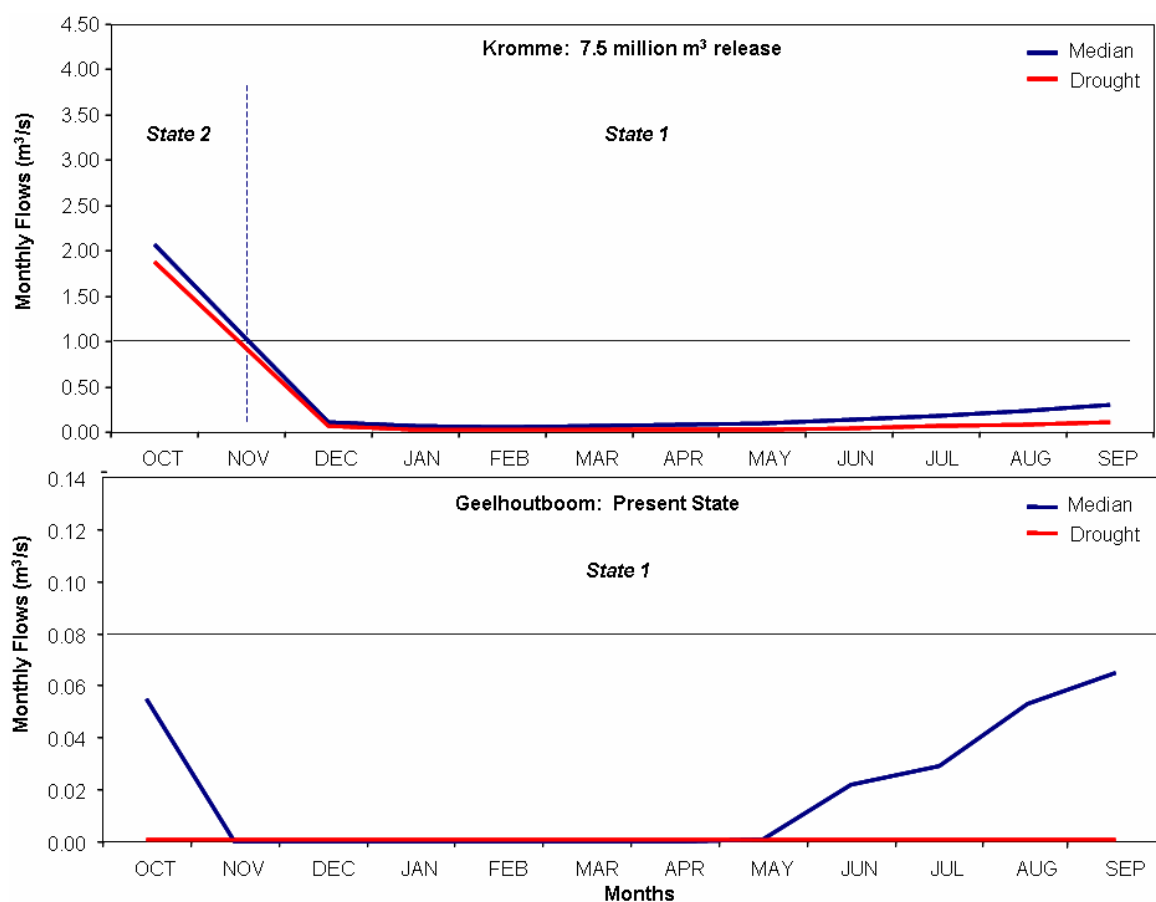


Figure 4-5 Predicted distribution of Abiotic States under Scenario 5 for the Kromme Estuary and Geelhoutboom tributary, based on median monthly flows (representative of seasonal conditions) and 10%ile flows (representative of drought conditions)

v. Predicted change in biotic characteristics under Scenario 5

Microalgae Based on hydrological information, there is little difference between this Scenario and Scenario 2. The only difference is that the release will be over two consecutive months and will have a flow of between 1 and 2 m³/s, in contrast to a slightly stronger flow for two months but separated by two months in Scenario 2. There is an expected slight decrease in salinity in the Geelhoutboom tributary. Only extended flows of 4-8 m³/s will scour high salinity water out of the deeper upper reaches so the flow in this scenario is not expected to create a strong longitudinal salinity gradient. No REI zone is expected to develop so changes to the microalgae are similar to Scenario 2. For 10 months of the year, the flow will be similar to Present State, i.e. none or very little flow. As a result, there will be no or very limited mixing of freshwater with estuarine water, which would result in the associated flocculation of nutrient-rich particles. Phytoplankton biomass will be highest in the middle reaches of the estuary, probably associated with nutrient recycling from fine sediments close to the Geelhoutboom tributary, but average chl a in the water column will be low (~5 µg/l). The phytoplankton will be dominated by flagellates (>90%) throughout the estuary and <10% diatoms. The benthos will be dominated by marine episammic (sand associated) microalgae in the middle and lower reaches of the estuary and marine epilithic (rock associated) microalgae in the upper reaches. Average benthic chl a (rock substrate excluded) will be low (<50 mg/m²) due to the depleted nutrients in the water column. A 7.5 x 10⁶ m³ release of freshwater in October and November will introduce nutrients and TSS into the estuary. This will stimulate a 25% increase in phytoplankton chl a and a doubling in intertidal benthic chl a for a period of two months after the release. A strong halocline will develop in the upper and middle reaches of the estuary so subtidal benthic chl a is unlikely to change significantly in these regions. From about 1 week after the release, diatoms will dominate the phytoplankton (>50%) but this will not last for longer than 2-3 weeks before flagellates become dominant again. Confidence: Medium
Macrophytes There will be a salinity gradient in the Kromme Estuary as a result of the flow release in October and November. During these months the salinity of the Geelhoutboom would range between 20–25 ppt. There will be a slight increase in germination and growth of intertidal salt marsh. Lower water column salinity would influence sediment and groundwater conductivity and promote the growth of supratidal salt marsh as well. Confidence: High
Invertebrates (including zooplankton, benthic invertebrates and macrocrustaceans) The establishment of a euryhaline-brackish water zone in the upper estuary will benefit the zooplankton, benthos and hyperbenthos. Zooplankton biomass will remain low for 8-9 months of the year, increasing significantly during October and November when water is released to the estuary. A similar pattern is predicted for the hyperbenthos. <i>Zostera capensis</i> biomass and coverage is unlikely to change and current patterns of invertebrate distribution will persist, although a more brackish water community will develop after the start of the release. This will be linked to the time needed for mixing of the water column. The Geelhoutboom should also benefit, due to tidal pumping of water of reduced salinity into the tributary. Confidence: High
Fish The marine migrant fish component in the Kromme Estuary is likely to be closer to the natural state than Future Scenario 1 due to the increased flow over the peak recruitment phase of these species. In addition, the improved river flow to the main estuary will compensate for the reduction in freshwater input to the Geelhoutboom tributary. Confidence: High
Birds Similar to the Present State, with possible slight effects during the high flow period and possibly a slight increase in piscivorous birds in response to increased fish recruitment. Confidence: Medium

vi. EHI scoring for the Scenario 5

Hydrology

Variable	Score	Motivation	Confidence
a. % similarity in period of low flows OR Present MAR as a % of MAR in the Reference Condition	45	For the Kromme Estuary low flows are defined as flows associated with State 1 (i.e. $< 1 \text{ m}^3/\text{s}$). Months with low flows of less than $1 \text{ m}^3/\text{s}$ increased from 4 (Jan – Apr) under the Reference Condition to 10 months under Scenario 5 (State 2 in Oct - Nov).	H
	58	For the Geelhoutboom tributary low flows are defined as flows associated with the State 1 (i.e. $< 0.08 \text{ m}^3/\text{s}$). Months with median low flows of less than $0.08 \text{ m}^3/\text{s}$ increased from 7 (Dec – Jun) under the Reference Condition to 12 months under Scenario 5 (Present State).	L
b. % similarity in mean annual frequency of floods	20	The major floods (1:20) (magnitude and frequency) have been dramatically modified and most of the smaller floods (1:5 years) do not reach the estuary under the Present State. Allow for a 80% modification from Reference Condition.	H
	80	There are no large impoundments in the Geelhoutboom; therefore most large floods (1:20) from this tributary still reach the estuary. This is also supported by the fact that monthly flows $> 1.0 \text{ m}^3/\text{s}$ reach the estuary. They occurred 15% of the years under the Reference Condition and 13% of the years under the Present State.	M
Hydrology Score	38	Kromme - weight 85%; Geelhoutboom - weight 15%	

Hydrodynamics and mouth condition

Variable	Score	Motivation	Confidence
Change in mean duration of closure, e.g. over a 5 or 10 year period	100	Due to tidal flows the estuary mouth remains permanently open.	H
	100	Due to tidal flows the estuary mouth remains permanently open.	H
Hydrodynamic Score	100		

Water quality

Variable	Score	Motivation	Confidence
1. Change in the longitudinal salinity gradient (%) and vertical salinity stratification	45	State 3: Fresh, which used to occur for 1 out of 2 (50%) years for about 1–2 months at a time under the Reference Condition, has been reduced to 1 out of 4 years (27.4%) under Scenario 5. Furthermore, State 2: Salinity Gradient only occurs for 2 months (Oct - Nov) of the year under Scenario 5, while it use to occur for 8 months (May – Dec) of the year under Reference Condition. Some hypersalinity ($< 40 \text{ ppt}$) may still develop at the end of summer. This signifies largely modified salinity conditions. Under Reference Condition the estuary fluctuated between a marine dominated and a saline gradient state under its median flow conditions.	H

Variable	Score	Motivation	Confidence
	35	Under Scenario 5, there is a loss of State 2: Salinity Gradient. This implies that there is no significant gradient in the system and that the homogenous water body takes on the salinity of the Kromme Estuary. Under the Reference Condition this would have varied between 20 to 35 ppt depending on the inflow. Under Scenario 5 the Geelhoutboom tributary would be 35 ppt for ~10 months of the year under median flow conditions. During the months of the Kromme flow release (Oct - Nov) it would be between 20 – 25 ppt.	M
Kromme Score (weight 85%)	38.3	Geelhoutboom Score (weight 15%)	5.3
2a. Nitrate/phosphate concentration in the estuary	50	Similar to Scenario 2: The Kromme system (including Geelhoutboom tributary) receives its inorganic nutrients through river inflow, either the Kromme and/or Geelhoutboom rivers. State 1 (little to no freshwater inflow) is therefore characteristic of nutrient depleted conditions. During States 2 and 3 river inflow introduced inorganic nutrients to the estuary. In Scenario 5, State 2 only occurs for 2 months (Oct-Nov) compared to 8 months (May – Dec) under the Reference Condition. Freshwater pulses (under which State 3 would have developed) have also been reduced. Under Scenario 5, State 1 now occurs for 10 months (compared to 4 months under the Reference Condition (Jan – Apr)). Using Table 3.2b (DWAF, 2004), which is also used to derive scores for low flow periods, this translates into a score of 50.	L/M
2b. Suspended solids present in inflowing freshwater	50	Similar to Scenario 2, the Kromme system receives suspended solids through river inflow. States 2 and 3 (both in the Kromme and Geelhoutboom) are therefore characterised by higher suspended solid concentrations (or higher turbidity) than State 1. In Scenario 5, State 2 only occurs for 2 months (Oct- Nov) compared to 8 months (May – Dec) under the Reference Condition. Freshwater pulses (under which State 3 would have developed) have also been reduced. Under Scenario 5, State 1 now occurs for 10 months (compared to 4 months under the Reference Condition (Jan – Apr)). The estuary under Scenario 5 is therefore considered to be less turbid than under the Reference Condition (used to be 'clear' for 4 months (Jan – Apr), now 'clear' for 10 months (Dec - Sep)).	L/M

Variable	Score	Motivation	Confidence
		Using Table 3.2b (DWAF, 2004), which is also used to derive scores for low flow periods this translates into a score of 50.	
2c. Dissolved oxygen in the estuary	80	Similar to Scenario 2, the Kromme system is usually well oxygenated, except during prolonged periods of State 1, when a reduction in oxygen has been observed in the deeper areas in the upper reaches of the estuary. After construction of the Impofu Dam this would seldom drop to below 5 mg/l as the dam cut off significant organic inputs to the upper reaches. Higher organic input during the Reference Condition, however, would have resulted in more severe reductions in DO in this region in the 4 months in which State 1 occurred. Allow for a modification of 10% during those periods. Also, the risk of lower oxygen conditions has been extended from the Reference Condition to Scenario 1 (State 1 occurs for 10 months instead of 4 months) although DO reductions are not severe (i.e. seldom drop below 5 mg/l). Allow for a modification of 10% during those periods.	M
2d. Levels of toxins	100	Similar to Present State.	M
Water quality Score	47		

Physical habitat alteration

Variable	Score	Motivation	Confidence
1. Resemblance of <u>intertidal sediment</u> structure and distribution to Reference Condition			
1a. % similarity in intertidal area (size) exposed	70	The estuary was probably deeper under the Reference Condition and the sandbanks not as widespread. However, the rate at which sedimentation occurs is slow so the intertidal area will not have changed dramatically yet, but the process is still on a trajectory of change. Losing intertidal areas due to <u>localised</u> sedimentation effects of the bridge.	M
1b. % similarity in sand fraction relative to total sand and mud	50	The marine sediment area (sandy habitat) stretches further upstream and in the upper part of the estuary all the fine sediment (muddy habitat) is being flushed away resulting in coarser bed sediment. This process is still on a trajectory of change (predicted that estuary will be mainly sand habitat in 400 years).	M
2. Resemblance of <u>sub-tidal sediment</u> structure and distribution to Reference Condition			
2. Resemblance of subtidal estuary to Reference Condition: depth, bed or channel morphology	80	The estuary is shallower under the Present State and the marine sediment moves slowly upstream. The rate at which sedimentation occurs is, however, slow. Bed sediments are becoming coarser. This process is also still on a trajectory of change (predictions show that if Present State proceeds the estuary will fill up in 2000 years not taking into account sea level rise).	M
Physical habitat score	70		

Microalgae

Variable	Score	Motivation	Confidence
Phytoplankton			
1. Species richness	30 (55%)	The effects of the 2-month release of water on the microalgae will only persist for ~2 months after the release. The rest of the year will be similar to Present State. During the two months following the release, diatoms will dominate (>50%) the phytoplankton for a couple of weeks before a gradual change back to a flagellate dominated (>90%) estuary. In addition, freshwater species of phytoplankton will be present in the estuary during the first 2-3 weeks following the release.	M
2a. Abundance/Biomass	80	The effects of the freshwater release on the microalgae will only persist for ~2 months after each release. The rest of the year will be similar to Present State. There will be an initial drop in average chl a to <2 µg.l ⁻¹ but will increase over the following few days to a concentration that is ~25-33% higher than before the release. This biomass should persist for a further 2 months after each release. No REI is expected to form so a higher phytoplankton biomass is not expected.	M
2b. Community composition	50	The effects of the freshwater release on the microalgae will only persist for ~2 months after each release. The rest of the year will be similar to Present State. The releases will introduce freshwater from the Impofu Dam dominated by diatoms (>60% of phytoplankton), flagellates (~30%) and chlorophytes (~5%). This creates a change in community structure from one dominated by diatoms near to the head of the estuary to one dominated by flagellates closer to the mouth. Dinoflagellates will only occur in saline water close to the mouth of the estuary. This dramatic change in community composition will only last while water with a salinity of <4ppt persists in the estuary before a gradual change over two months back to that before the releases.	M
Benthic microalgae			
1. Species richness	17 (40%)	It is unlikely that there will be a significant change in species richness after the releases because sediment structure is the most important driver.	M

Variable	Score	Motivation	Confidence
2a. Abundance/Biomass	60	The effects of the freshwater release on the microalgae will only persist for ~2 months after each release. The rest of the year will be similar to Present State. It is unlikely that the releases of freshwater will erode the benthic sediments so an immediate increase in intertidal benthic chl a is expected over the first week after the releases from an average of <40 mg/m ² to ~60 mg/m ² . The mixing of water in the lower reaches of the estuary should result in intertidal and subtidal chl a increasing to >150 and >100 mg/m ² in this region within the first week after each release.	M
2b. Community composition	40	It is unlikely that there will be a significant change in community composition after the releases because sediment structure is the most important driver.	M
Microalgae score	17		

Macrophytes

Variable	Score	Motivation	Confidence
1. Species richness	65 (80%)	A salinity gradient for 2 months of the year will not cause a change in species richness. Conditions would be similar to that of the Present State i.e. loss of brackish salt marsh species as well as reed and sedge species due to an increase in salinity and occurrence of hypersaline conditions. Loss of primary colonisers as a result of reduced flooding. 80% of original species probably remain.	M
2a. Abundance/Biomass	55	There will be a salinity gradient in the Kromme Estuary as a result of the flow release in October and November. During these months the salinity of the Geelhoutboom would range between 20–25 ppt. There will be a slight increase in germination and growth of intertidal salt marsh. Lower water column salinity would influence sediment and groundwater conductivity and promote the growth of supratidal salt marsh as well. The response would be similar to that of Scenario 2.	H
2b. Community composition	60	A salinity gradient for 2 months of the year will cause the die-back of marine macroalgae. However, these will colonise the estuary quickly again. Reed and sedge communities are restricted to areas of freshwater seepage and brackish marshes are reduced.	M
Macrophyte Score	55		

Invertebrates

Variable	Score	Motivation	Confidence
Zooplankton			
1. Species richness	65 (80%)	Because salinity will remain at or close to that of seawater for 10 months of the year in the main estuary, little change is likely in zooplankton species richness. However, reduced salinity values over 2-3 months following the release in October-November will benefit <i>Acartia natalensis</i> (occasionally present in the Kromme under current conditions). This species has dormant eggs that remain in bottom sediments during times when conditions are adverse. Suitable salinity conditions should develop in the middle-upper reaches.	M
2a. Abundance/Biomass	75	Abundance levels will remain at low levels during 8-9 months of the year. After the release, abundance levels of the estuarine copepod <i>Pseudodiaptomus hessei</i> and <i>Acartia natalensis</i> will spike and persist for 2-3 months (October to the end of December). Abundance will be linked to food availability (response of phytoplankton to the release).	H
2b. Community composition	45	Species such as <i>Tortanus capensis</i> do not occur in systems having a horizontal salinity gradient. In this system it is less common under Scenario 5 in comparison to the Present State because of freshwater being introduced (State 2). The mix of other species has also changed as a result of State 2 being introduced for one month (salinity driven).	H

Macroinvertebrates (Macrobenthos)			
1. Species richness	57 (75%)	The species richness will remain similar to that of the Present State, except that some brackish/freshwater species are likely to return due to the presence of State 2 during November (as for Scenario 1, turnover rates are accommodated within 1 month).	H
2a. Abundance/Biomass	85	Abundance levels are slightly higher than for Scenario 1 because of additional month of State 2.	H
2b. Community composition	20	Remains similar to the Present State, except for limited change due to the return of brackish/freshwater species (presence of State 2 during November). Due to the continued imbalance of the <i>Zostera</i> beds, the community composition change remains significant.	H
Macrocrustaceans (Large crustaceans)			
1. Species richness	65 (80%)	The species richness will remain similar to that of the Present State for most of the year, except that some species that occur in brackish water are likely to occur due to the inflow of freshwater over two consecutive months, which will benefit them (<i>Macrobrachium</i> spp.)	M

2a. Abundance/Biomass	60	Abundance marginally higher than for Scenario 1 due to the return of the freshwater species e.g. <i>Macrobrachium</i> spp. for the 2 months during which State 2 exists.	M
2b. Community composition	65	The mix of species is closer to Reference with the extended period of State 2 (2 months compared to 6 months under the Reference Condition).	M
Invertebrate score	20		

Fish

Variable	Score	Motivation	Confidence
1. Species richness	80 (90%)	Most fish species in the system will persist under this scenario and only a few freshwater species will be lost due to the lack of any REI in the upper reaches for much of the year.	H
2a. Abundance/Biomass	85	Marine fish abundance, especially for the larval component in October and November, is likely to be better than Scenario 1. The abundance of planktivorous fish species is also likely to be better than Scenario 1 due to a lower larval mortality rate associated with increased planktonic food resources.	M
2b. Community composition	65	The composition of the fish community will be very similar to Scenario 1. Increased survival of planktivorous species will move the community closer to the natural state.	M
Fish Score	65		

Birds

Variable	Score	Motivation	Confidence
1. Species richness	85 (90%)	Certain species such as waterfowl may occur more frequently in the Geelhoutboom and Kromme above the confluence.	H
2a. Abundance/Biomass	88	Small increase in abundance of water fowl, piscivores and possibly other marsh users and waders relative to Scenario 4.	M
2b. Community composition	78	A slight change in community composition due to the above.	M
Bird Score	78		

4.2.6 Scenario 6

At the Specialist Workshop in February 2005 scenario 6 was added. Scenario 6 represents a $15.5 \times 10^6 \text{ m}^3$ release into the Kromme Estuary (mainly in the period October to January) while inflow into the Geelhoutboom tributary remains similar to its Present State. Details on the simulation of Scenario 6 are provided in Appendix J.

i. Seasonal variability in river inflow

Monthly simulated runoff data (73-year period) for Scenario 6 into the Kromme Estuary and Geelhoutboom tributary are provided in Tables 4-6 and 3-2, respectively. A summary of the flow distributions (mean monthly flows in m^3/s), derived from the simulated data set, is provided below (green hatched months represent flows where the surface salinities would still be representative of State 2, red hatched months represent flows less than $0.2 \text{ m}^3/\text{s}$ when hypersaline conditions can potentially develop):

Kromme: Summary of flow distributions for Scenario 6 ($15.5 \times 10^6 \text{ m}^3$ release mainly in Oct to Jan)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	14.86	26.47	5.53	5.79	3.49	3.90	4.91	29.21	15.89	19.20	25.78	31.75
90%ile	5.62	2.14	1.11	0.80	0.54	0.60	0.69	2.93	3.13	2.63	6.26	12.01
80%ile	2.81	1.42	0.91	0.72	0.37	0.38	0.40	0.63	0.60	0.79	1.54	3.60
70%ile	2.26	1.36	0.86	0.69	0.30	0.33	0.35	0.36	0.47	0.56	0.84	0.97
60%ile	2.08	1.25	0.81	0.68	0.29	0.26	0.30	0.31	0.33	0.42	0.52	0.79
50%ile	2.02	1.19	0.81	0.66	0.26	0.25	0.27	0.27	0.31	0.36	0.42	0.66
40%ile	1.97	1.16	0.79	0.65	0.24	0.25	0.25	0.25	0.28	0.33	0.37	0.57
30%ile	1.93	1.13	0.77	0.63	0.24	0.23	0.24	0.24	0.26	0.28	0.32	0.52
20%ile	1.85	1.09	0.75	0.47	0.24	0.22	0.22	0.22	0.24	0.25	0.29	0.49
10%ile	0.40	0.42	0.33	0.27	0.23	0.08	0.08	0.08	0.12	0.17	0.25	0.34
1%ile	0.06	0.30	0.26	0.24	0.22	0.02	0.03	0.02	0.03	0.04	0.08	0.12

Geelhoutboom: Summary of flow distributions for Scenario 6 (Present State)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	1.05	1.21	0.34	0.43	0.29	0.32	0.28	1.17	0.90	1.18	1.72	2.09
90%ile	0.37	0.36	0.05	0.00	0.05	0.07	0.08	0.18	0.21	0.18	0.41	0.57
80%ile	0.24	0.11	0.01	0.00	0.00	0.01	0.04	0.07	0.10	0.11	0.17	0.22
70%ile	0.13	0.06	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.07	0.13	0.16
60%ile	0.08	0.03	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.04	0.08	0.09
50%ile	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.05	0.06
40%ile	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.03
30%ile	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02
20%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 4-6 Monthly simulated runoff data in m³/s (73-year period) for Scenario 6 (15.5 x 10⁶ m³ release mainly Oct to Jan) into the Kromme Estuary

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1927	1.87	1.08	0.75	0.63	0.24	1.20	0.69	0.30	0.29	0.27	0.29	0.61
1928	2.02	1.37	0.86	0.66	0.24	0.22	0.22	0.25	0.26	0.39	0.39	0.81
1929	2.08	1.16	0.78	0.63	0.37	0.34	0.30	0.28	0.33	0.33	0.44	0.66
1930	2.06	1.17	0.77	0.68	0.25	0.24	0.25	0.24	0.24	0.32	0.31	0.86
1931	2.96	1.53	1.39	3.24	2.55	0.35	0.30	0.27	0.29	0.34	0.31	31.15
1932	10.34	2.21	0.97	0.68	0.25	0.25	0.28	4.32	2.89	1.12	19.89	4.16
1933	2.05	1.41	0.86	0.68	0.29	0.31	0.28	0.26	0.26	0.42	0.40	0.55
1934	5.87	1.42	0.81	0.64	0.24	0.23	0.28	25.78	8.10	2.36	5.11	2.74
1935	2.22	1.42	0.93	0.69	0.24	0.25	0.25	0.37	0.34	0.35	0.33	0.52
1936	2.04	3.39	1.12	0.69	0.25	0.26	0.25	0.23	0.28	0.32	0.31	0.57
1937	1.93	1.15	0.81	0.68	0.24	0.22	0.25	0.28	0.29	0.28	0.28	0.52
1938	1.92	1.21	0.81	0.64	0.57	0.54	0.39	0.32	0.29	0.32	1.06	0.98
1939	2.10	1.29	0.97	0.79	0.54	0.57	0.41	0.34	0.44	2.04	0.79	1.47
1940	1.97	1.15	0.77	0.65	0.24	0.24	0.27	0.25	0.46	0.37	0.31	0.51
1941	1.96	1.15	1.08	0.84	0.29	0.25	0.25	0.35	0.37	0.35	0.35	0.52
1942	2.00	1.17	0.81	0.72	0.27	0.25	0.25	0.25	0.96	0.69	0.57	0.95
1943	2.10	1.74	1.12	0.72	0.28	0.36	0.35	38.02	9.21	3.04	1.46	3.64
1944	2.26	1.22	0.80	0.65	0.24	0.22	0.22	10.33	11.88	2.43	1.58	0.75
1945	2.47	1.32	0.80	0.65	0.23	0.51	0.37	0.26	0.25	0.40	0.46	0.63
1946	2.05	1.16	0.77	0.63	0.22	0.33	0.32	0.47	0.59	13.83	2.16	0.85
1947	2.01	1.18	0.80	0.65	0.24	0.26	0.63	0.44	0.33	0.32	0.31	0.56
1948	2.56	1.39	0.81	0.65	0.24	0.23	0.23	0.23	0.22	0.22	0.22	0.44
1949	0.03	1.87	0.84	0.25	0.23	0.02	0.03	0.04	0.03	0.17	0.35	0.31
1950	0.38	1.37	0.70	1.16	0.61	0.09	0.05	0.08	0.12	6.75	8.28	6.40
1951	3.13	0.41	0.29	0.27	0.82	0.24	0.07	0.08	0.10	0.10	0.35	19.23
1952	4.01	1.32	0.86	0.66	0.25	0.24	0.23	0.23	0.27	0.37	0.52	1.06
1953	26.47	9.38	0.94	0.69	0.24	0.60	0.44	1.45	3.06	6.51	18.64	6.90
1954	2.08	1.19	0.80	0.66	5.92	8.09	0.68	0.52	0.31	0.32	0.82	0.76
1955	2.00	6.11	5.01	0.68	0.30	0.33	0.29	3.09	3.15	0.74	0.44	11.68
1956	9.74	16.59	3.97	0.81	0.39	0.36	0.34	0.40	0.48	0.46	1.21	6.80
1957	5.71	1.24	0.79	0.63	0.21	0.28	0.26	0.67	0.51	0.36	0.54	0.70
1958	1.99	1.13	0.78	0.86	0.36	0.28	0.36	0.35	0.32	0.34	0.50	0.68
1959	2.07	1.17	0.81	0.83	0.33	0.25	0.25	0.30	0.33	2.32	0.97	1.34
1960	1.93	1.11	0.77	0.65	0.28	0.77	0.56	0.64	0.54	0.50	0.47	0.60
1961	1.94	1.11	0.75	0.63	0.23	0.37	0.38	0.31	0.28	0.28	1.32	1.03
1962	2.31	1.30	0.81	0.79	0.30	1.09	0.97	0.61	0.47	0.44	0.41	0.57
1963	1.90	1.13	0.91	0.78	0.29	0.28	0.27	0.25	0.73	0.56	0.66	17.24
1964	7.43	1.38	0.86	0.66	0.22	0.26	0.28	0.34	0.35	0.34	0.32	0.50
1965	2.30	4.76	0.91	0.71	0.30	0.25	0.24	0.25	0.24	0.24	0.31	0.54
1966	1.90	1.15	0.80	0.65	0.22	0.23	0.98	0.84	0.60	0.55	0.54	0.89
1967	2.11	1.18	0.80	0.64	0.23	0.24	0.38	0.36	26.21	7.87	3.04	26.05
1968	4.61	1.30	0.83	0.66	0.24	0.24	0.24	0.24	0.27	0.28	0.28	0.52
1969	1.96	1.13	0.75	0.63	0.24	0.23	0.22	0.21	0.22	0.21	0.26	0.48
1970	0.14	0.30	0.56	0.36	0.33	0.10	0.76	0.67	0.51	2.96	40.95	12.09
1971	2.54	1.84	0.33	0.25	0.43	0.12	0.15	0.14	0.14	0.17	2.23	0.15
1972	1.87	1.06	0.73	0.62	0.22	0.28	0.30	0.29	0.28	0.25	0.25	0.46
1973	0.07	0.30	0.26	0.38	0.37	0.75	0.40	0.25	0.26	0.17	3.39	14.29
1974	1.09	0.39	0.28	0.26	0.30	0.19	0.12	0.05	0.06	0.09	0.19	0.31
1975	1.98	1.11	0.78	0.65	0.26	0.44	0.49	0.40	0.37	0.62	0.63	0.71
1976	2.58	1.54	0.88	0.68	0.55	0.38	0.31	12.91	4.40	0.69	0.49	0.97
1977	2.16	1.36	0.91	0.69	0.24	0.27	0.34	0.31	0.38	0.38	0.38	0.57
1978	2.16	1.40	0.91	0.76	0.31	0.26	0.25	0.27	0.30	0.54	18.29	14.71
1979	2.27	1.25	0.81	0.68	0.25	0.22	0.25	0.25	0.28	0.28	0.27	0.52
1980	1.94	1.17	0.83	0.97	0.37	2.27	1.13	11.57	10.06	0.88	14.79	9.09
1981	5.96	1.51	0.87	0.68	0.24	0.25	0.90	2.32	0.33	0.57	0.42	0.61
1982	1.92	1.10	0.75	0.62	0.22	0.21	0.22	0.24	0.27	33.01	13.27	0.78
1983	4.30	1.21	0.80	0.64	0.23	0.26	0.24	0.22	0.24	0.29	0.29	0.49
1984	1.84	1.05	0.77	0.72	0.30	0.25	0.27	0.26	0.33	0.34	0.32	0.49
1985	0.17	0.39	0.33	0.30	0.26	0.03	0.03	0.02	0.03	0.04	0.19	0.17
1986	0.69	0.63	0.36	0.27	0.24	0.03	0.12	0.08	0.33	0.22	0.15	0.46
1987	0.27	0.32	0.26	0.23	0.25	0.03	0.07	0.08	0.18	0.16	0.15	0.14
1988	0.13	0.30	0.28	0.25	0.24	0.02	0.10	0.08	0.05	0.08	0.08	0.15
1989	1.44	2.49	0.85	0.31	0.35	0.10	0.16	0.16	0.59	0.39	0.28	0.26
1990	0.49	0.48	0.31	0.25	0.22	0.02	0.02	0.02	0.03	0.03	0.08	0.08
1991	0.16	0.32	0.31	0.26	1.25	0.38	0.08	0.09	0.12	0.23	1.23	0.71
1992	1.37	1.25	0.49	0.36	0.29	0.04	0.10	0.08	1.43	0.71	0.37	33.30
1993	8.14	0.50	1.27	0.35	0.29	0.08	0.07	0.09	0.11	0.82	6.55	3.55
1994	5.24	1.19	4.96	12.34	0.99	0.88	0.90	1.93	1.00	0.68	0.87	0.61
1995	1.98	1.20	1.00	0.75	0.28	0.26	0.25	0.23	0.22	0.26	0.35	0.57
1996	5.14	51.86	6.86	0.73	0.26	0.25	14.63	4.80	3.59	2.68	2.23	0.88
1997	1.96	1.13	0.76	0.66	0.24	0.43	0.33	0.27	0.27	0.27	0.42	0.60
1998	1.91	1.13	0.81	0.66	0.24	0.24	0.25	0.25	0.24	0.45	0.38	0.51
1999	1.84	1.03	0.77	0.70	0.41	0.56	0.42	0.31	0.28	0.25	0.25	0.46
Median	2.02	1.19	0.81	0.66	0.26	0.25	0.27	0.27	0.31	0.36	0.42	0.66
Average	2.86	2.32	1.01	0.81	0.43	0.44	0.52	1.83	1.42	1.49	2.57	3.53

<0.2

0.2-1.0

1.0-8.0

>8.0

ii. Predicted flood regime for Scenario 6

Similar to the Present State

Confidence: High

iii. Predicted sediment processes under Scenario 6

Similar to the Present State

Confidence: High

iv. Occurrence and duration of different abiotic states under Scenario 6

Estimated occurrence and duration of the different Abiotic States in the Kromme Estuary and Geelhoutboom tributary under Scenario 6, based on simulated monthly river inflow into the Kromme Estuary and Geelhoutboom tributary are indicated Tables 4-6 and 3-2, respectively.

To provide a conceptual overview of the annual distribution of Abiotic States under Scenario 6 for the Kromme Estuary and Geelhoutboom tributary, median monthly flows (representative of seasonal conditions) and 10%ile flows (representative of drought conditions) were used to depict the situation for normal and drought periods (Figure 4-6).

Confidence: Medium

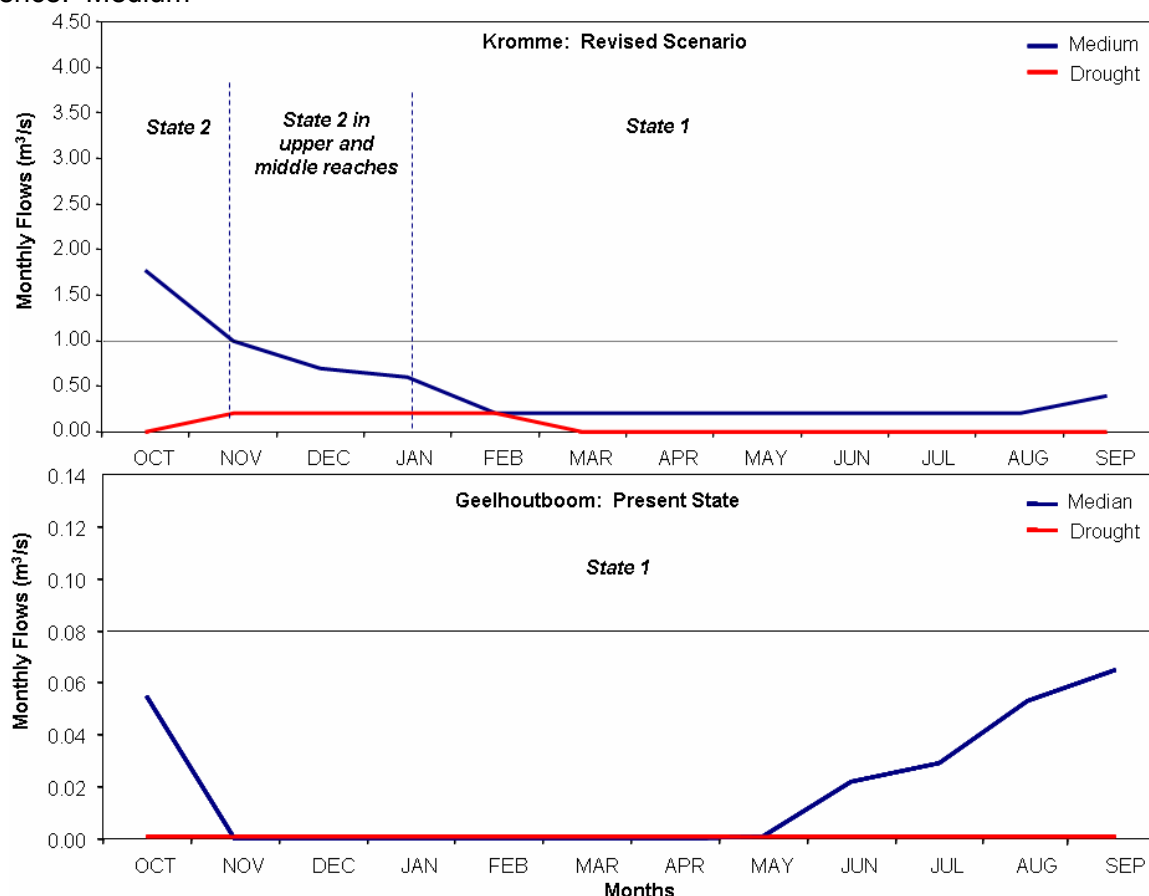


Figure 4-6 Predicted distribution of Abiotic States under Scenario 6 for the Kromme Estuary and Geelhoutboom tributary, based on median monthly flows (representative of seasonal conditions) and 10%ile flows (representative of drought conditions)

v. Predicted change in biotic characteristics under Scenario 6

Microalgae
During medium rainfall conditions there will be a pulse of freshwater in October and this will taper off over the following 4 months, i.e. Abiotic State 3 for 1-2 months, state 2 for 2-3 months and Abiotic State 1 for the remainder of the year. A base flow of ~0.2 m ³ /s will be maintained over the remainder of the year but hypersaline conditions (<40 ppt) can still be expected in the upper reaches during late summer. The freshwater will introduce nutrients and TSS to the estuary, which will maintain a phytoplankton biomass that is only slightly lower than the Reference Condition. Freshwater species of phytoplankton, dominated by diatoms (~50%), will be imported into the estuary during States 2 and 3 but during low flow conditions, flagellates will dominate (~90%) with some dinoflagellates near to the mouth of the estuary. Fine sediments will still be trapped by the dams so sediment dynamics in the estuary, the major driver of benthic microalgal richness, is unlikely to change from the Present State. Benthic microalgal biomass is likely to respond significantly to the pulses in freshwater, with a doubling in intertidal benthic chl a in response to the increased nutrient load in the surface water.
Confidence: Medium
Macrophytes
Under median but not drought conditions there will be a potential salinity gradient in the estuary from October to January. This lower salinity will prevent the formation of hypersaline conditions in the salt marshes. There will be an increase in germination and growth of intertidal salt marsh. Lower water column salinity will influence sediment and groundwater conductivity and promote the growth of supratidal salt marsh as well. The lower salinity will kill the marine macroalgae and prevent them from colonising the middle to upper reaches of the estuary.
Confidence: Medium
Invertebrates (including zooplankton, benthic invertebrates and macrocrustaceans)
Under Scenario 6, reduced salinity conditions extend relatively far downstream and persist for a few months into the summer months. Although not persisting for as long as under natural conditions, these scenarios will benefit all invertebrates as the range of habitats will be greater compared to the Present State and follow natural variation patterns within years. Because of the increased input of nutrients, greater phytoplankton response will benefit filter feeders such as the zooplankton as well as species reliant on zooplankton as a source of food (<i>Gilchristella aestuaria</i>).
Confidence: Medium
Fish
The development of an REI at the head of the estuary during certain times of the year will allow the return of freshwater species to the headwaters of the estuary. Freshwater pulses entering the estuary at the optimum time for breeding and recruitment will enable the fish abundance and biomass to approach that recorded in the Reference Condition. Prolonged riverine inputs at the correct time of the year will enable planktivorous species to increase in abundance and move the fish community towards the Reference Condition.
Confidence: Medium

vi. EHI scoring for Scenario 6

Hydrology

Variable	Score	Motivation	Confidence
a. % similarity in period of low flows OR Present MAR as a % of MAR in the Reference Condition	67	For the Kromme Estuary low flows are defined as flows associated with State 1 (i.e. < 1 m ³ /s). Months with low flows of less than 1 m ³ /s increased from 4 (Jan – Apr) under the Reference Condition to 8 months under Scenario 6 (State 2 in Oct - Nov).	
	58	Same as Present	

b. % similarity in mean annual frequency of floods	20	The major floods (1:20) (magnitude and frequency) have been dramatically modified and most of the smaller floods (1:5 years) do not reach the estuary under the Present State. Allow for a 80% modification from Reference Condition.	H
	80	There are no large impoundments in the Geelhoutboom catchment; therefore most large floods (1:20) from this tributary still reach the estuary. This is also supported by the fact that monthly flows $>1.0 \text{ m}^3/\text{s}$ reach the estuary. They occurred 15% of the years under the Reference Condition and 13% of the years under the Present State.	M
Hydrology Score	51	Kromme - weight 85%; Geelhoutboom - weight 15%	

Hydrodynamics and mouth condition

Variable	Score	Motivation	Confidence
Change in mean duration of closure, e.g. over a 5 or 10 year period	100	Due to tidal flows the estuary mouth remains permanently open.	H
	100	Due to tidal flows the estuary mouth remains permanently open.	H
Hydrodynamic Score	100		

Water quality

Variable	Score	Motivation	Confidence
1. Change in the longitudinal salinity gradient (%) and vertical salinity stratification	55	State 3: Fresh, which used to occur for 1 out of 2 (50%) years for about 1–2 months at a time under the Reference Condition, has been reduced to 1 out of 3 years (34%) under Scenario 6. Furthermore, State 2: Salinity Gradient only occurs for 4 months (Oct - Jan) of the year under Scenario 6, while it used to occur for 8 months (May – Dec) of the year under Reference Condition. Hypersalinity ($<40 \text{ ppt}$) may still develop at the end of summer during drought periods. This signifies modified salinity conditions. Under Reference Condition the estuary fluctuated between a marine dominated and a saline gradient state under its median flow conditions.	H
	45	Under Scenario 6, there is a loss of State 2: Salinity Gradient. This implies that there is no significant gradient in the system and that the homogenous water body takes on the salinity of the Kromme Estuary. Under the Reference Condition this would have varied between 20 to 35 ppt depending on the inflow. Under Scenario 6 the Geelhoutboom tributary would be 35ppt for ~ 8 months of the year under median flow conditions. During the months of the Kromme flow release (Oct - Jan) it would be between 20-25 ppt.	M
Kromme Score (weight 85%)	53.5	Geelhoutboom Score (weight 15%)	6

Variable	Score	Motivation	Confidence
2a. Nitrate/phosphate concentration in the estuary	67	The Kromme system (including Geelhoutboom tributary) receives its inorganic nutrients through river inflow, either the Kromme and/or Geelhoutboom rivers, particularly inorganic nitrogen. State 1 (little to no freshwater inflow) is therefore characteristic of nutrient depleted conditions. During States 2 and 3 river inflow introduced inorganic nutrients to the estuary. In Scenario 6, State 2 only occurs for 2 months (Oct - Nov) compared to 8 months (May – Dec) under the Reference Condition. Freshwater pulses (under which State 3 would have developed) have also been reduced. Under Scenario 6, State 1 now occurs for 8 months (compared to 4 months under the Reference Condition (Jan – Apr)). Using Table 3.2b (DWAF, 2004), which is also used to derive scores for low flow periods, this translates into a score of 67.	L/M
2b. Suspended solids present in inflowing freshwater	67	The Kromme system receives suspended solids through river inflow. States 2 and 3 (both in the Kromme and Geelhoutboom) are therefore characterised by higher suspended solid concentrations (or higher turbidity) than State 1. In Scenario 6, State 2 only occurs for 2 months (Oct - Nov) compared to 8 months (May – Dec) under the Reference Condition. Freshwater pulses (under which State 3 would have developed) have also been reduced. Under Scenario 6, State 1 now occurs for 10 months (compared to 4 months under the Reference Condition (Jan – Apr)). The estuary under Scenario 6 is therefore considered to be less turbid than under the Reference Condition (used to be 'clear' for 4 months (Jan – Apr), now 'clear' for 10 months (Dec - Sep)). Using Table 3.2b (DWAF, 2004), which is also used to derive scores for low flow periods, this translates into a score of 67.	L/M

Variable	Score	Motivation	Confidence
2c. Dissolved oxygen in the estuary	85	The Kromme System is usually well oxygenated, except during prolonged periods of State 1, when a reduction in oxygen has been observed in the deeper areas in the upper reaches of the estuary. After construction of the Impofu Dam this would seldom drop to below 5 mg/l as the dam cutoff significant organic inputs to the upper reaches. Higher organic input during the Reference Condition, however, would have resulted in more severe reductions in DO in this region in the 4 months in which State 1 occurred. Allow for a modification of 10% during those periods. Also, the risk of lower oxygen conditions has been extended from the Reference Condition to Scenario 6 (State 1 occurs for 8 months instead of 4 months) although DO reductions are not severe (i.e. seldom drop below 5 mg/l). Allow for a modification of 5% during those periods.	M
2d. Levels of toxins	100	Similar to Present State	M
Water Quality Score	61.6		

Physical habitat alteration

Variable	Score	Motivation	Confidence
1. Resemblance of <u>intertidal sediment</u> structure and distribution to Reference Condition			
1a % similarity in intertidal area (size) exposed	70	The estuary was probably deeper under the Reference Condition and the sandbanks not as widespread. However, the rate at which sedimentation occurs is slow so the intertidal area will not have changed dramatically yet, but the process is still on a trajectory of change. Losing intertidal areas due to <u>localised</u> sedimentation effects of the bridge.	M
1b % similarity in sand fraction relative to total sand and mud	50	The marine sediment area (sandy habitat) stretches further upstream and in the upper part of the estuary all the fine sediment (muddy habitat) is being flushed away resulting in coarser bed sediment. This process is still on a trajectory of change (predicted that estuary will be mainly sand habitat in 400 years).	M
2. Resemblance of <u>sub-tidal sediment</u> structure and distribution to Reference Condition			
2 Resemblance of subtidal estuary to Reference Condition: depth, bed or channel morphology	80	The estuary is shallower under the Present State and the marine sediment moves slowly upstream. The rate at which sedimentation occurs is, however, slow. Bed sediments are becoming coarser. This process is also still on a trajectory of change (predictions show that if Present State proceeds the estuary will fill up in 2000 years not taking into account sea level rise).	M
Physical habitat Score	70		

Microalgae

Variable	Score	Motivation	Confidence
Phytoplankton			
1. Species richness	65 (80%)	Abiotic State 2 will introduce freshwater species of phytoplankton, which is dominated by diatoms (~50%). This will create a gradient of phytoplankton from diatom dominated freshwater to more saline water dominated by flagellates (~90%) with some dinoflagellates near to the mouth of the estuary.	M
2a. Abundance/Biomass	90	There is only a slight decrease in phytoplankton biomass expected in relation to the Reference Condition due to the pattern and duration of freshwater releases in this scenario. Freshwater inflow introduces nutrients and TSS into the estuary.	M
2b. Community composition	60	The release will introduce freshwater from the Impofu Dam dominated by diatoms (>60% of phytoplankton), flagellates (~30%) and chlorophytes (~5%). This creates a change in community structure from one dominated by diatoms near to the head of the estuary to one dominated by flagellates closer to the mouth. Dinoflagellates will only occur in saline water close to the mouth of the estuary. This dramatic change in community composition will only last while water with a salinity of <4 ppt persists in the estuary. This change is likely to be delayed by the 0.2 m ³ /s baseflow.	M
Benthic microalgae			
1. Species richness	17 (40%)	It is unlikely that there will be a significant change in species richness after the releases because sediment structure is the most important driver.	M
2a. Abundance/Biomass	70	The effects of the freshwater release on the microalgae will only persist for ~2 months after the 4 months of release. The rest of the year will be receiving baseflow, which should maintain a slightly higher biomass than if no flow were present. It is unlikely that the releases of freshwater will erode the benthic sediments so an immediate increase in intertidal benthic chl a is expected over the first week after the start of releases from an average of <40 mg/m ² to ~60 mg/m ² . The mixing of water in the lower reaches of the estuary should result in intertidal and subtidal chl a increasing to >150 and >100 mg/m ² in this region within the first week after each release.	M
2b. Community composition	40	It is unlikely that there will be a significant change in species richness after the releases because sediment structure is the most important driver.	M
Microalgae Score	17		

Macrophytes

Variable	Score	Motivation	Confidence
1. Species richness	73 (85%)	Lower salinity would prevent the formation of hypersaline conditions promoting the establishment of salt marsh species. There would still be a loss of primary colonisers as a result of reduced flooding. 80% of original species probably remain.	M
2a. Abundance/Biomass	65	Lower salinity for a longer period of time would increase the germination and growth of intertidal salt marsh and prevent hypersaline conditions. Lower water column salinity would influence sediment and groundwater conductivity and promote the growth of supratidal salt marsh as well. Marine macroalgae would die and there would be an increase in the abundance of reeds and sedges during the low salinity months.	M
2b. Community composition	70	Lower salinity would cause the die-back of marine macroalgae. However, these will colonise the estuary quickly again. Reed and sedge communities will flourish when salinity is less than 20 ppt.	M.
Macrophyte Score	65		

Invertebrates

Variable	Score	Motivation	Confidence
Zooplankton			
1. Species richness	65 (80)%	Species richness will increase because of the more pronounced salinity gradient along the estuary for 2-3 months of the year.	M
2a. Abundance/Biomass	85	Abundance levels will increase significantly compared to present conditions because of increased food availability (phytoplankton).	M
2b. Community composition	65	Because of the increased salinity gradient for part of the year, community composition will change compared to present day. Zonation of species along the gradient will also follow more natural patterns.	M
Macroinvertebrates			
1. Species richness	57 (75%)	Little change compared to present.	M
2a. Abundance/Biomass	85	Because of increased food availability, abundance levels will increase compared to the Present State.	M
2b. Community composition	60	Composition of the community will begin to change towards more natural conditions, but will not persist for more than a few months.	M
Macrocrustacea			
1. Species richness	65 (80%)	Similar to Scenario 5 with the return of brackish water species.	M
2a. Abundance/Biomass	60	Larger crustaceans will increase in biomass (e.g. <i>Macrobrachium</i>) for a few months when brackish water conditions extend into the middle estuarine reaches.	M
2b. Community composition	65	Composition of the community will begin to change towards more natural conditions, but will not persist for more than a few months.	M
Invertebrate score	57		

Fish

Variable	Score	Motivation	Confidence
1. Species richness	90 (95%)	The development of REI at the head of the estuary during certain times of the year will allow the return of freshwater species to the headwaters of the estuary.	M
2a. Abundance/Biomass	90	Freshwater pulses entering the estuary at the optimum time for breeding and recruitment will enable the fish abundance and biomass to approach that recorded in the Reference Condition.	M
2b. Community composition	85	Prolonged riverine inputs at the correct time of the year will enable planktivorous species to increase in abundance and move the fish community towards the Reference Condition.	M
Fish score	85		

Birds

Variable	Score	Motivation	Confidence
1. Species richness	90 (95%)	Most bird species present in the reference state are expected to be present under this scenario, since physical and biological conditions are similar to present state.	M
2a. Abundance/Biomass	90	The abundance of birds is expected to be similar to reference conditions due to increases in all the food groups, but full recovery is limited by anthropogenic impacts such as recreational disturbance.	M
2b. Community composition	80	Composition will be similar to the reference state, though there may still be a slightly lower proportion of waterfowl, and more sensitive species may be affected by disturbance.	M
Bird score	80		

4.2.7 Ecological reserve categories (ERC) associated with the scenarios

The individual EHI scores, as well as the corresponding ERC for the different scenarios are provided in Table 4-7.

Table 4-7 EHI score and corresponding ERC for the different runoff scenarios

Variable	Weight	Present	Scenarios					
			1	2	3	4	5	6
Hydrology	25	33.7	38	42	35	44	38	51
Hydrodynamics/mouth condition	25	100	100	100	100	100	100	100
Water quality	25	33.2	41	47	35	42	47	62
Physical habitat alteration	25	70	70	70	70	70	70	70
Habitat health score	50	59	62	65	60	64	64	71
Microalgae	20	17	17	17	17	17	17	17
Macrophytes	20	50	52	56	51	54	55	65
Invertebrates	20	20	20	20	20	20	20	57
Fish	20	40	50	55	45	60	65	85
Birds	20	70	75	80	72	77	78	80
Biotic health score	50	39	43	46	41	46	47	61
Estuarine Health Index Score		49	53	55	50	55	55	66
Ecological Reserve Category (ERC)		D	D	D	D	D	D	C

4.3 Recommended Ecological Flow Requirement for the Kromme Estuary

The evaluation of the simulated runoff scenarios is used to derive the recommended Ecological Flow Requirement. The recommended Ecological Flow Requirement is defined as the runoff scenario (or a slight modification thereof) that represents the highest reduction in river inflow that will still protect the aquatic ecosystem of the estuary and keep it in the recommended ERC.

The Kromme Estuary has been targeted as a Desired Protected Area (DWAF, 2004). According to the guidelines for assigning a recommended ERC, the estuary needs to be in a Category A or the Best Attainable State (BAS). However, due to the fact that the changes that are currently largely contributing to the Present State of the estuary (Category D) are related to large dam developments in the catchment (e.g. Impofu Dam) and that it is unlikely that these interferences could be reversed even to get it into a Category B, it was decided to at least recommend that the Kromme Estuary be improved into the minimum ERC for an 'Important estuary' which is a **Category C**.

Therefore, **Scenario 6** is selected as the recommended ecological category (REC) for the Kromme Estuary, with flow distributions as summarised in Table 4-8. Details on the simulation of this Scenario are provided in Appendix J. It should be noted that the final scenario selected will also take into consideration socio-economic factors and thus Scenario 6 is only the scenario that best suits the ecology of the system.

Table 4-8 Summary of the flow distribution for the recommended Ecological Flow Requirement (Scenario) for the Kromme Estuary

Kromme: Summary of flow distributions (15.5 x 10⁶ m³ release mainly Oct to Jan)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	14.86	26.47	5.53	5.79	3.49	3.90	4.91	29.21	15.89	19.20	25.78	31.75
90%ile	5.62	2.14	1.11	0.80	0.54	0.60	0.69	2.93	3.13	2.63	6.26	12.01
80%ile	2.81	1.42	0.91	0.72	0.37	0.38	0.40	0.63	0.60	0.79	1.54	3.60
70%ile	2.26	1.36	0.86	0.69	0.30	0.33	0.35	0.36	0.47	0.56	0.84	0.97
60%ile	2.08	1.25	0.81	0.68	0.29	0.26	0.30	0.31	0.33	0.42	0.52	0.79
50%ile	2.02	1.19	0.81	0.66	0.26	0.25	0.27	0.27	0.31	0.36	0.42	0.66
40%ile	1.97	1.16	0.79	0.65	0.24	0.25	0.25	0.25	0.28	0.33	0.37	0.57
30%ile	1.93	1.13	0.77	0.63	0.24	0.23	0.24	0.24	0.26	0.28	0.32	0.52
20%ile	1.85	1.09	0.75	0.47	0.24	0.22	0.22	0.22	0.24	0.25	0.29	0.49
10%ile	0.40	0.42	0.33	0.27	0.23	0.08	0.08	0.08	0.12	0.17	0.25	0.34
1%ile	0.06	0.30	0.26	0.24	0.22	0.02	0.03	0.02	0.03	0.04	0.08	0.12

Geelhoutboom: Summary of flow distributions (Present State)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	1.05	1.21	0.34	0.43	0.29	0.32	0.28	1.17	0.90	1.18	1.72	2.09
90%ile	0.37	0.36	0.05	0.00	0.05	0.07	0.08	0.18	0.21	0.18	0.41	0.57
80%ile	0.24	0.11	0.01	0.00	0.00	0.01	0.04	0.07	0.10	0.11	0.17	0.22
70%ile	0.13	0.06	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.07	0.13	0.16
60%ile	0.08	0.03	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.04	0.08	0.09
50%ile	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.05	0.06
40%ile	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.03
30%ile	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02
20%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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APPENDIX A

SUMMARY OF AVAILABLE DATA FOR THIS STUDY

(Measured against requirements specified for a comprehensive level determination)

For detail on referencing refer to the corresponding Specialist Report Appendices C to I

Data availability on sediment dynamics, hydrodynamics and water quality

Data Required	Availability	Comment
Simulated monthly runoff data (at the head of the estuary) for Present State, Reference Conditions and the selected future runoff Scenarios over a 50 to 70 year period	Provided by Ninham Shand Consulting Engineers	Provided for 73-year period. Low confidence as runoff data is of low quality.
Simulated flood hydrographs for Present State, Reference Conditions and future runoff Scenarios: • 1:1, 1:2, 1:5 floods (influencing aspects such as floodplain inundation) • 1:20, 1:50, 1:100, 1:200 year floods (influencing sediment dynamics)	Calculated for 11- year period (1993-2004)	
Series of sediment core samples for the analysis of particle size distribution (PSD) and origin (i.e. using microscopic observations) taken every 3 years along the length of an estuary (200 m to 2 km intervals).	Grab samples at 500 to 1000 m intervals	Collected in 2004 as part of this study
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.	CSIR (1991), Reddering (1980), Reddering and Esterhuysen (1983)	Cross sections used from unpublished data set.
Set of cross-section profiles and a set of sediment grab samples for analysis of particle size distribution (PSD) and origin (i.e. using microscopic observations) need to be taken immediately after a major flood.	N/A	
Aerial photographs of estuary (earliest available year as well as most recent)	Some historical photos available	Collected for DEAT
Measured river inflow data (gauging stations) at the head of the estuary over a 5-15 year period	Some data provided by DWAF	No data available on the Reference Conditions
Continuous water level recordings near mouth of the estuary	Installed at bridge near mouth	Data obtained from DWAF
Water level recordings at about 5 locations along the length of the estuary over a spring and a neap tidal cycle (i.e. at least a 14 day period).	CSIR (1991)	Cross sections used from unpublished data set.
Longitudinal salinity and temperature profiles (in situ) collected over a spring and neap tide during high and low tide at: • end of low flow season (i.e. period of maximum seawater intrusion) • peak of high flow season (i.e. period of maximum flushing by river water)	Hecht (1973), Hanekom (1982), Emmerson and Erasmus (1987), Bickerton and Pierce (1988), Wooldridge, UPE (unpublished data) Scharler <i>et al.</i> (1998), Scharler and Baird (2003), Slinger (unpublished data,) CSIR (1999), Snow <i>et al.</i> (2000), Scharler and Baird (2000).	Data often aggregated in a manner which made it impossible to relate to river inflow.
Water quality measurements (i.e. system variables, and nutrients) taken along the length of the estuary (surface and bottom samples) on a spring and neap high tide at: • end of low flow season • peak of high flow season	Hecht (1973), Hanekom (1982), Watling (1982), Emmerson and Erasmus (1987), Bickerton and Pierce (1988), Wooldridge, UPE (unpublished data) Scharler <i>et al.</i> (1998), Scharler and Baird (2003), Slinger (unpublished data),	Data often aggregated in a manner which made it impossible to relate to river inflow.

Data Required	Availability	Comment
	CSIR (1999), Snow <i>et al.</i> (2000), Scharler and Baird (2000).	
Measurements of organic content and toxic substances (e.g. trace metals and hydrocarbons) in sediments along length of the estuary.	Watling and Watling (1982)	No data available on the Reference Conditions
Water quality (e.g. system variables, nutrients and toxic substances) measurements on river water entering at the head of the estuary	Limited data available from DWAF	No data available on the Reference Conditions
Water quality (e.g. system variables, nutrients and toxic substances) measurements on near-shore seawater	DWAF (1995)	Data extracted from South African Water Quality Guidelines for Coastal Marine Waters

Data availability on microalgae

Data Required	Availability	Comment
Chlorophyll a measurements taken at 5 stations at the surface, 0.5 m and 1 m depths. Cell counts of dominant phytoplankton groups i.e. flagellates, dinoflagellates, diatoms and blue-green algae. Measurements must be taken coinciding with typically high and low flow conditions.	Snow <i>et al.</i> (2000), Adams (unpublished data). Scharler, <i>et al.</i> (1998).	Measurements taken during low flow and during the release of $2 \times 10^6 \text{ m}^3$ water from Impofu Dam.
Intertidal and subtidal benthic chlorophyll a measurements taken at 5 stations (at least). Epipellic diatoms need to be collected for identification. These measurements coincide with a typical high and low flow condition (in temporarily closed estuaries measurements must include open as well as closed mouth conditions).	Snow <i>et al.</i> (2000), Adams (unpublished data), Scharler, <i>et al.</i> (1998)	Measurements taken during low flow and during the release of $2 \times 10^6 \text{ m}^3$ water from Impofu Dam. Epipellic diatoms were not collected.
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.	Snow <i>et al.</i> (2000), Adams (unpublished data), Scharler, <i>et al.</i> (1998)	Measurements taken during low flow and during the release of $2 \times 10^6 \text{ m}^3$ water from Impofu Dam.

Data availability on macrophytes

Data Required	Availability	Comment
Aerial photographs of the estuary (ideally 1:5000 scale) reflecting the Present State, as well as the Reference Condition (if available) Available orthophoto maps	1942, 1987, 2000	1942 photograph poor quality.
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.	Adams (1991), Adams and Talbot (1992), Adams <i>et al.</i> (1992), Adams and Bate (1994), Bickerton and Pierce (1988), Hanekom and Baird (1988)	Details on distribution and biomass of macrophytes.
Permanent transects: - Measurements of percentage plant cover along an elevation gradient - Measurements of salinity, water level, sediment moisture content and turbidity	Adams, 1991	Transect data completed in 1990.

Data availability on invertebrates

Data Required	Availability	Comment
Compile a detailed sediment distribution map of the estuary. Obtain a detailed determination of the extent and distribution of shallows and tidally exposed substrates. During each survey, collect sediment samples for analysis of grain size and organic content at the six benthic sites.	Hanekom (1982) Reddering and Esterhuizen (1983).	Some sedimentary data done during a survey of intertidal macroinvertebrates associated with <i>Zostera capensis</i> beds.
Surveys to determine salinity distribution pattern along the length of the estuary, as well as other system variables (e.g. temperature, pH and dissolved oxygen and turbidity) are required for different seasons and for different states of the tide. Seasonal (i.e. quarterly) physico-chemical data are also required for each of the six benthic sampling sites	Numerous studies that include salinity data available – see section on sediment dynamics, hydrodynamics and water quality.	Additional unpublished information collated in the invertebrate section below.
Collect a set of six benthic samples each consisting of five grabs. Collect two each from sand, mud and interface substrates. If possible, spread sites for each between upper and lower reaches of the estuary. One mud sample should be in an organically rich area. Species should be identified to the lowest taxon possible and densities (animal/m ²) must also be determined. Seasonal data sets for at least one year are required, preferably collected at spring tides.	Numerous studies on macro invertebrates – Baird and Heymans (1996), Bickerton and Pierce (1988), Day (1981), Emmerson <i>et al.</i> (1982), Hanekom (1982), Hecht (1973), Winter and Baird (1988).	Information mostly focuses on the intertidal invertebrates that were sampled with relatively coarse sieves.
Collect two sets of beam trawl samples (i.e. mud and sand). Lay two sets of five, baited prawn/crab traps overnight, one each in the upper and lower reaches of the estuary. Species should be identified to the lowest taxon possible and densities (animal/m ²) must also be determined.	Some information on the species, scattered in above references, but using other gear.	

Data Required	Availability	Comment
Survey as much shoreline as possible for signs of crabs and prawns and record observations. Seasonal data sets for at least one year are required, preferably collected at spring tides.		
Additional trip(s) may be required to gather data on the occurrence/recruitment and emigration of key species such as <i>Varuna litterata</i> and <i>Upogebia</i> which require a connection to the marine environment at specific times of the year.	Wooldridge (1999)	No information for the Kromme.
Collect three zooplankton samples, at night, one each from the upper, middle and lower reaches of the estuary. Seasonal data sets for at least one year are required, preferably collected at spring tides.	Baird <i>et al.</i> (1981), Wooldridge (1999), unpublished data.	Good coverage of the zooplankton.

Data availability on fish

Data Required	Availability	Comment
In a small estuary (<5 km) collect at minimum three sets of samples from the lower, middle and upper reaches of the estuary. The samples should be representative of the different estuarine habitat types, e.g. <i>Zostera</i> beds, prawn beds, sand flats. At least one of the sample sets need to be in the 0 to 10 ppt reach of the estuary. Sampling should be representative of small fish (seine nets) and large fish (gill nets).	Not applicable as this is a permanently open estuary.	Not applicable as this is a permanently open estuary.
In a larger estuary (>5 km) sampling can either be at fixed intervals (every 2 km) or have the upper, middle and lower reaches subdivided into at least a further three sections each. The samples should be representative of the different estuarine habitat types, e.g. <i>Zostera</i> beds, prawn beds, sand flats. At least one of the sample sets should be in the 0 to 1 ppt reach of the system. Sampling should be representative of small fish (seine nets) and large fish (gill nets).	Melville-Smith (1981), Marais (1983), Marais (1984), Bickerton and Pierce (1988), Marais (1988), Hanekom and Baird (1984), Harrison <i>et al.</i> (2000), Strydom and Whitfield (2000)	Fish larvae, juveniles and adults sampled with plankton, seine and gill nets. Unfortunately no fish data available for pre-impoundment estuary.
Sampling should be done during both the low and the high flow season for the full extent of the system (as far as tidal variation) to allow for predictive capabilities.	Melville-Smith (1981), Marais (1983), Marais (1984), Bickerton and Pierce (1988), Marais (1988), Hanekom and Baird (1984), Harrison <i>et al.</i> (2000), Strydom and Whitfield (2000)	Beach seine netting not possible in upper reaches of the estuary. Lack of information from high flow seasons due to impoundment of catchment rivers.

Data availability on birds

Data Required	Availability	Comment
Undertake one full count of all water associated birds, covering as much of the estuarine area as possible. All birds should be identified to species level and the total number of each counted.	Four full estuary counts undertaken in 2004-2005, in which estuary subdivided into sections	
Monthly data sets for at least one year are required. If this is not possible, a minimum of four summer months and one winter month will be required (decisions on the extent of effort required will depend largely on the size of the estuary, extent of shallows present, as well as extent of tidally exposed areas).	Count data available for three summer months and one winter month	Mid-summer and mid-winter count data for the whole estuary were obtained for a ten year period

APPENDIX B

Proposed changes to the RDM Methodologies for Estuaries

After each Specialist workshop a list of possible improvements to the Ecological Reserve Determination methodology for estuaries needs to be provided. The following list was recorded at the Kromme/Seekoei Estuary Specialist Workshop in February 2005:

Data Requirements

1. The Methodology should explicitly put forward a requirement related to the archiving (formal archiving procedures) for data collated during ecological reserve determination. It would be preferable for DWAF to have a customised data base available that meet the diverse requirements of estuarine data sets.
2. The inclusion of Particulate Organic Carbon and Nitrogen (organic nutrient supplies) need to be investigated – this related in particular to organic nutrient inputs from catchments which are largely affected by major dam developments (e.g. trapping).

Estuarine Health Index (EHI)

1. The terminology referring to the invertebrate subcategories in the EHI (i.e. zooplankton, benthic invertebrates and macrocrustacean) need to be agreed nationally – these categories were largely included to meet requirements in the Kwazulu-Natal region.
2. The EHI scoring rules related to Species Richness and abundance/biomass needs to be explained more explicitly in the methods to prevent confusion or misinterpretation.
3. The scoring of Species Richness in the EHI is not a linear relationship with % modification. To assist in determining the score of all percentage values, a detailed scoring graph or formula needs to be included in the methods.
4. When the motivations related to modification of abundance/biomass is provided for invertebrates and fish, it is essential that details be included on the type of species and size ranges that are modified. This information is required by the bird specialist to predict avifauna responses (add a specific note in the methods).
5. The templates in the methods needs to be more explicit on the type of information that must be included in the EHI score motivations. It is essential that the modification be described, but also that the cause i.e. describe in terms of the abiotic or biotic change that is the direct cause.

APPENDIX C

HYDRODYNAMICS AND WATER QUALITY

L van Niekerk, S Taljaard, R van Ballegooyen and P Huizinga
CSIR Environmentek

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SCOPE OF WORK

The CSIR was commissioned by Coastal & Environmental Services to provide specialist input on the hydrodynamics and water quality of the Kromme Estuary as part of a Comprehensive Ecological Reserve Determination.

Coastal & Environmental Services will include this assessment into the final product to DWAF as lead Professional Service Provider (PSP).

This report was prepared by Lara van Niekerk, Susan Taljaard, Roy van Ballegooyen and Piet Huizinga.

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Special thanks to Dr Ursula Scharler who made the raw data sets on the physico-chemistry of the Kromme Estuary that were collected as part of her PhD studies and a Water Research Commission Project (related to a freshwater release from the Impofu Dam) available to us.

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1. BRIEF

The CSIR was commissioned by Coastal & Environmental Services to provide specialist input on the hydrodynamics and water quality of the Kromme Estuary as part of a Comprehensive Ecological Reserve Determination.

The brief included:

- During a once-off field survey on the Kromme Estuary (the second set of water quality data was collected by UPE) the following will be collected:
 - Salinity and temperature profiles. Longitudinal and vertical salinity and temperature profiles will be collected along the length of the estuaries.
 - System variables (pH, turbidity/suspended solids and dissolved oxygen) and inorganic nutrients (nitrate and nitrite, total ammonia, reactive phosphate and reactive silicate). Surface and bottom samples will be collected along the length of the estuary and in the river and sea.

The Ecological Reserve protocol specifies that field data on toxic substances (e.g. trace metals) in sediments should be collected where such contaminants are expected to be of concern. The Kromme Estuary does not have major urban or industrial zones in its catchment and such measurements were therefore not included.

- Assessment of hydrodynamic and water quality (specialist report) data comprising of:
 - Mouth dynamics of the Kromme Estuary and the correlation with river inflow will be evaluated.
 - The correlation between river inflow ranges and marine dominance will be evaluated and refined. A three-dimensional model will be established to indicate the influence of freshwater on the salinity distribution and stratification within the estuary.
 - Based on the above refinements, abiotic states will be identified for the Kromme Estuary associated with the typical river inflow ranges.
 - The water quality of the estuary will be described for different river inflow ranges. Typical water quality characteristics will be derived for each of the abiotic states above.
 - Differences in abiotic components between the Present State and Reference Condition will be described, based on simulated runoff data and associated changes in the duration and occurrence of abiotic states.
 - Similarly, changes in abiotic components from the Present State for each of the future Scenarios will be predicted, based on simulated river runoff and associated changes in the duration and occurrence of abiotic states.
- Completion of Ecological Reserve Templates for Abiotic processes and attendance of a 2-day specialist workshop where the following will be determined:
 - Present Ecological Status (PES) using the Ecological Health Index (EHI)
 - Ecological importance of the estuary and recommended Ecological Category (EC)
 - Evaluate the various flow Scenarios.
- Review of Ecological Reserve Report

- Attendance of Specialist Meeting to refine the preliminary Ecospecs for the recommended EC, to link the Ecospecs for the recommended EC to Thresholds of Potential Concern (TPCs), and to describe the monitoring actions for each measure when TPCs are exceeded.
- Specialist input on abiotic component of Ecospecs and monitoring report, which will integrate all the information generated at the specialist meeting.

This study also required specialist input on the hydrodynamics and water quality as part of a Rapid Ecological Reserve Determination on the Seekoei Estuary. The brief for this component included:

- Site visit to the Seekoei Estuary, collecting limited field data
- Preparation of Ecological Reserve Templates as required for an Ecological Reserve Determination on a Rapid Level (including a review of available data)
- Attendance of a 1-day specialist workshop where the following will be determined:
 - Present Ecological Status (PES) using the Ecological Health Index (EHI)
 - Ecological importance of the estuary and recommended Ecological Category (EC)
 - Evaluate the various flow Scenarios.
- Review of Ecological Reserve Report.

This document contains the Specialist Assessment on the Hydrodynamics and Water Quality of the Kromme Estuary. Ecological Reserve Templates for the Kromme and Seekoei estuaries will be produced as separate documents.

2. ASSUMPTIONS AND LIMITATIONS

The brief was undertaken based on the following assumptions:

- Required simulated runoff Scenarios (over 50-80 years) on both the Kromme and Seekoei Estuaries will be provided to the CSIR, including the Reference Condition, the Present State for each of the estuaries, as well as simulated runoff Scenarios representative of future developments and/or Ecological Flow Requirements of the IFR sites just upstream of the estuary. For these simulated runoff Scenarios, the simulations be separate for the Kromme and Geelhoutboom rivers.
- Flood hydrographs on the Kromme and Geelhoutboom Rivers just upstream of the estuary for both the Reference Condition and Present State to be provided to the CSIR (by the University of Stellenbosch).
- Available river inflow data on the Kromme, Geelhoutboom, Seekoei and Swart Rivers, just upstream of the estuaries, as well as all available water level recorder data collected at the Kromme Estuary mouth will be supplied to CSIR by DWAF.
- Water quality specialist on the river component will supply the CSIR with the water quality of the Reference Condition and Present State of river water entering the estuary from the Kromme, Geelhout, Seekoei and Swart Rivers, e.g. as represented by the lowest IFR site on these systems.
- Raw data collected by the University of Port Elizabeth (Prof Dan Baird and Dr Ursula Scharler) as part of a WRC study on the Kromme Estuary will be made available to the CSIR (this data was requested from Ursula Scharler who agreed to make it available, but at this stage we are still waiting for the data - publications on these data sets, however, did provide insight into the major water quality characteristics of the Kromme Estuary).

Limitations of the assessment provided as part of this report include:

- For the purposes of the Ecological Reserve determination, it is important to be able to correlate any measured salinity structure to specific river inflow patterns. Unfortunately such information was not always captured, which makes the interpretation of some of these studies more difficult. Also, in some of the publications longitudinal salinity patterns are reported as depth averaged values which are not always reflecting actual conditions, particularly in the deeper section in the upper estuary, where strong vertical stratification occurs during periods of freshwater inflow.

The historical data sets and measurements taken as part of this study were, however, interpreted as best possible to extract the necessary information to support the predictions on the salinity characteristics of the Kromme Estuary under different river inflow Scenarios.

- Most of the historical data sets on water quality were also presented as average data, either depth averaged or averaged over seasons. For the purposes of the Ecological Reserve determination, it is important to be able to link specific water quality characteristics to corresponding salinity regimes (e.g. through plots of salinity versus nutrient concentration), which was not always possible with the manner in which historical data has been processed as part of publications.

The data sets were, however, interpreted as best possible to extract the necessary information to support the predictions on water quality characteristics of the Kromme Estuary.

3. STUDY AREA

The Kromme River, which is approximately 85 km long, has its origin in the Tsitsikamma Mountains and drains a catchment area of approximately 936 km².

The mean annual precipitation in the Kromme catchment ranges from 700 mm to 1 200 mm (Reddering and Esterhuyzen, 1983). Pitman *et al.* (1981) give the mean annual precipitation for the upper catchment of the Kromme as 764 mm and that of the lower catchment as 636 mm. The Mean Annual runoff of the Kromme is estimated to be $105 \times 10^6 \text{ m}^3$.

The Kromme Estuary, located on the east coast of South Africa approximately 80 km west of Port Elizabeth, is a permanently open system discharging into St Francis Bay (Figure C-1). The head of the estuary (i.e. the upstream limit to tidal influence) is located at a rocky sill some 14 km upstream of the permanently open river mouth. A major tributary of the estuary is the Geelhoutboom, which enters the estuary some 7 km upstream of the mouth of the estuary. There are a number of smaller tributaries, the most significant of these being the Sand River that drains part of a by-pass dunefield and joins the estuary approximately 1.3 km upstream of the estuary mouth (Bickerton and Pierce, 1988). Both of these tributaries contribute very little freshwater inflow into the Kromme Estuary¹.

Over a distance of 5 km from the mouth, the estuary is characterised by channel depths of 1.5 m and a sandy bottom substrate. Upstream of this, the estuary deepens to between 3 m and 5 m and current velocities generally are lower than 0.3 m/s (values of the order of 1 m/s are common in the mouth area). Extensive salt marshes cover the banks of the estuary in the middle and lower reaches, while the channel meanders between vegetated cliffs in the upper reaches. A marina has been developed on the west bank near the mouth.

¹ Under natural conditions the Geelhoutboom, on average, is estimated to have contributed less than 5% of the freshwater inflow into the estuary throughout the year while under current conditions this contribution is less than 1% in mid- to late summer but typically between 10 to 30% during the remainder of the year (i.e. the peak contribution is during the early part of the wet season). Under current conditions, during dry years the Geelhoutboom contributes as little as 0% of the freshwater inflow to the Kromme Estuary in the dry summer months but typically 15 to 20% during the remainder of the year, while during wet years the freshwater contribution from the Geelhoutboom ranges between 5 to 10% during the rainy season in late winter to early spring to approximately 20% during the dry months in mid- to late summer. (The Geelhoutboom thus provided a significant percentage of the freshwater inflow required in September to October to potentially raise the estuary a "class" in terms of its ecology). The contribution from the Sand River is considered to be negligible.

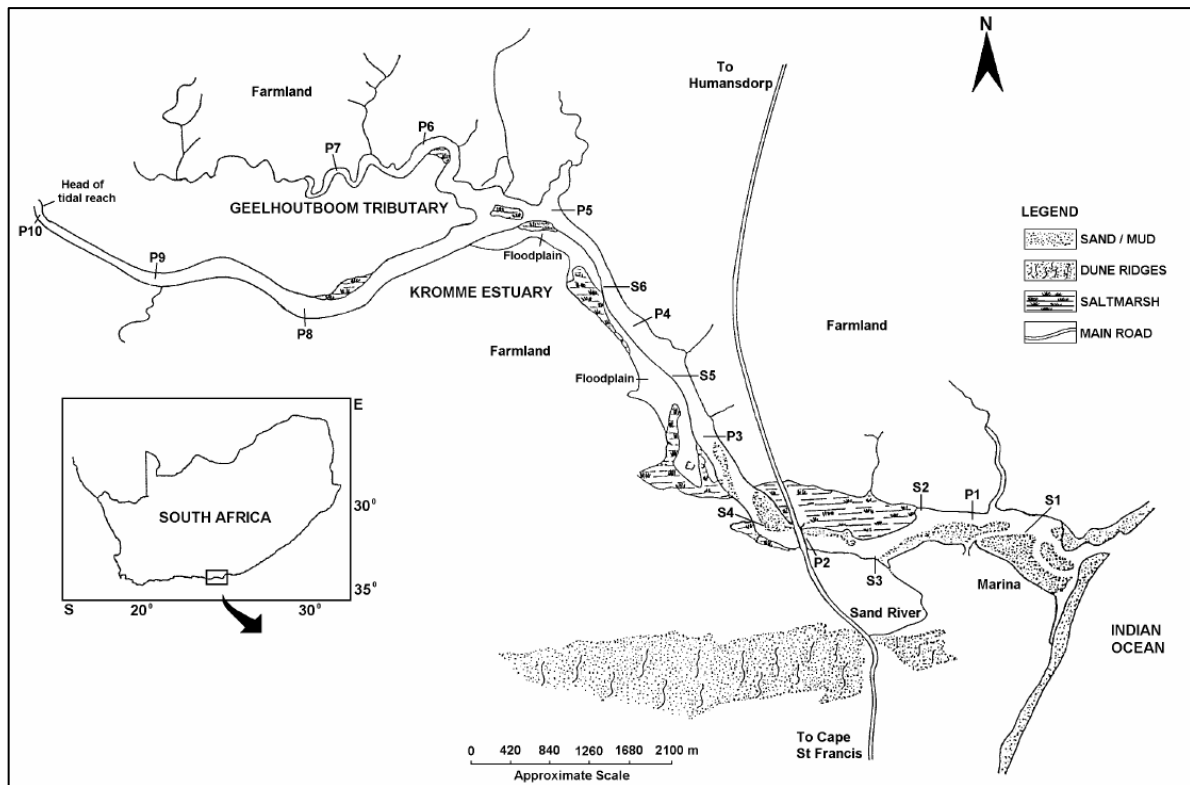


Figure C-1 Major features of the Kromme Estuary (after Wooldridge and Callahan, 2000)

The Kromme Estuary receives water from a catchment where there is little agriculture other than grazing (Reddering and Esterhuyzen, 1983; Bickerton and Pierce, 1988; Bate and Adams, 2000). Natural vegetation occurs along the upper reaches of the estuary, as well as along the banks of the Geelhoutboom tributary (Bate and Adams, 2000).

The Kromme Estuary has been severely impacted by the building of two dams (Churchill and Impofu dams, which between them have a storage capacity of approximately 133% of the estimated mean annual runoff (MAR) of the Kromme Estuary of $100 \times 10^6 \text{ m}^3$ (Bate and Adams, 2000; Scharler and Baird, 2000). The Churchill Dam (built in 1943), situated some 35 km upstream of the head of the estuary, has a storage capacity of $33.3 \times 10^6 \text{ m}^3$ while the Impofu Dam, situated approximately 4 km upstream of the head of the estuary, has a storage capacity of approximately $107 \times 10^6 \text{ m}^3$. This has led to a situation where, apart from dam overflows during floods, the only freshwater supplied to the Kromme Estuary, is the $2 \times 10^6 \text{ m}^3$ allocated to the estuary for ecological purposes (i.e. only floods and controlled releases of freshwater reach the estuary). The dams in the catchment are considered to attenuate all floods less than the 1 in 30 year floods (Bickerton and Pierce, 1988). The magnitude of large floods can also be substantially reduced depending on the volume of water in the dam when these floods occur.

The $2 \times 10^6 \text{ m}^3$ allocated to the estuary for ecological purposes is significantly less than the freshwater requirements of the estuary estimated by Jezewski and Roberts (1986) to be approximately $11 \times 10^6 \text{ m}^3$ or approximately 8.9% of the MAR. Of this total $2 \times 10^6 \text{ m}^3$ was to compensate for evaporative losses while approximately $9 \times 10^6 \text{ m}^3$ was set aside for flooding requirements.

4. AVAILABLE FIELD DATA

A number of research studies have been conducted on the hydrodynamics and water quality aspects of the Kromme Estuary over the past years. These are summarised in Table C-1.

Table C-1 Summary of water quality related studies conducted on the Kromme Estuary

Reference	Period	Parameters	Details
Hecht (1973)	Sept 1972 – Aug 1973	Salinity Temperature pH Dissolved oxygen Secchi disc	Monthly sampling of surface and bottom waters along estuary at spring high and low tides
Hanekom (1982)	Mar 1979 – Jul 1981	Temperature Salinity Secchi disc	Monthly sampling of surface water along estuary (tide not specified), including Geelhoutboom
Watling (1982)	18 Jun & 16 Sept 1981	(No salinity data) Inorganic Nitrogen Phosphate-P Total P Silicate-Si	Once-off sampling in surface and bottom waters along the estuary
Watling and Watling (1982)	Aug 1979	Trace metals	Once-off survey of trace metal concentrations in water column and sediment
Emmerson & Erasmus (1987)	Jun 1979 - Sep 1981	Temperature Salinity pH Dissolved oxygen Inorganic Nitrogen Phosphate-P Total P Silicate-Si	Bi-monthly sampling (surface and bottom samples)
Bickerton & Pierce (1988)	20 Nov 1984	Temperature Salinity pH Dissolved oxygen Secchi disc	Once-off sampling survey along estuary (surface and bottom samples)
Wooldrige, UPE (unpublished data)	Apr 1988- Mar 1991	Temperature Salinity	Monthly profile data collected in the middle and upper reaches
Scharler <i>et al.</i> (1998) Scharler and Baird (2003)	Apr 1993 – Jun 1994 Sept 1994 – Mar 1995	Temperature Salinity pH Dissolved oxygen Secchi disc Inorganic Nitrogen Phosphate-P Total Particulate Nitrogen	Bi-monthly profiles sampling at 0.5 m depth intervals collected during spring low tides Latter survey coincided with overflow from the Impofu Dam (i.e. wet period)
Slinger (unpublished data)	1988 and 1990	Temperature Salinity	
CSIR (1999)	16 Nov 1989 – 14 Dec 998	Temperature Salinity	Study coinciding with a release from Impofu Dam. Samples collected at low tide
Snow <i>et al.</i> (2000)	16 Nov 1998 – 5 Jan 1999	Temperature Salinity (Nitrate-N)	Study coinciding with a release from Impofu Dam. Sampling done at spring high tide. Nitrate samples collected in surface and bottom waters and S&T at 0.5 – 1 m depth intervals
Scharler & Baird	6 – 23 Nov 1998	Temperature	Study coinciding with a release

Reference	Period	Parameters	Details
(2000)		Salinity pH Dissolved oxygen Secchi disc Inorganic Nitrogen Phosphate-P	from Impofu Dam - sampling done at 0.5 to 1.0 m depth intervals during low water slack tide
Present Study	18-19 Feb 2004	Temperature Salinity pH	Once-off survey surface and bottom sampling along estuary
Present Study	30 Jul 2004	Dissolved oxygen Turbidity	Once-off survey surface and bottom sampling along estuary
Present Study	6 Dec 2004 18 Jan 2005	Inorganic Nitrogen Phosphate-P Silicate-Si	Once-off profiles sampling in the Impofu Dam

For this study salinity and temperature profiles as well as other water quality data (refer to Table C-1) were collected from the Kromme Estuary at 13 stations along the estuary (Figure C-2a) on 18 and 19 February 2004 and 29 July 2004, respectively.

Water quality measurements were also taken at the Impofu Dam on 6 December 2004 to provide some indication of the variation in water quality with depth (water can be released from the dam at different levels) (Figure C-2b).

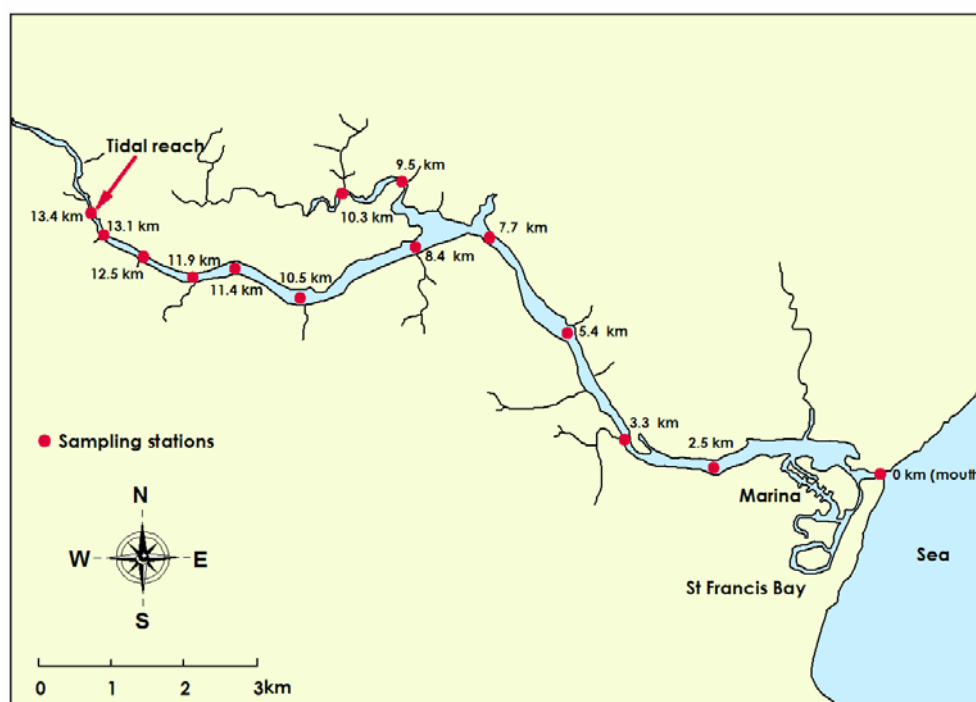


Figure C-2a Map of the Kromme Estuary, showing sampling stations for the 2004 surveys



Figure C-2b The Impofu Dam, showing sampling points for this study (ME – at outlet, MF – 1 km upstream of outlet)

5. HYDRODYNAMIC CHARACTERISTICS

The Kromme Estuary, located on the east coast of South Africa approximately 80 km west of Port Elizabeth, is a permanently open system discharging into St Francis Bay. The head of the estuary (i.e. the upstream limit to tidal influence) is located at a rocky sill some 14 km upstream of the river mouth that opens into St Francis Bay.

A major tributary of the estuary is the Geelhoutboom, which enters the estuary some 7 km upstream of the mouth of the estuary. There are a number of smaller tributaries, the most significant of these being the Sand River that drains part of a by-pass dunefield and joins the estuary approximately 1.3 km upstream of the estuary mouth (Bickerton and Pierce, 1988). A number of significant sand-flat regions exist in the Kromme Estuary as well as fairly extensive sand/mud flats in the lower reaches of the estuary (Figure C-1).

The mouth region is typically highly variable. A massive sandspit of about half a kilometre long extends from the south bank of the estuary mouth and tends to push the mouth channel northwards.

5.1 Bathymetry

The mouth of the Kromme Estuary is flood tide dominated resulting in the ingress of marine sediment in its lower reaches. The bathymetry in the mouth region is highly variable but is reported to be typically 80 m wide on average and has an average depth of approximately 2.5 m at low water ordinary springs (Bickerton and Pierce, 1988). However the bathymetry surveys used in the modelling study indicated depths of less than -2 m MSL. Smith *et al.* (1991) state that flood and ebb channels of maximum depth of 1.5 m MSL meander between sand bars within the main river bed for the lower 6 km of the estuary. This is consistent with the bathymetric data used in the modelling study that indicated depths of less than -2 m MSL in the mouth region.

A marina has been developed on the western bank adjacent to the mouth. The narrow marina channels with depths ranging between -1 and -2 m MSL are connected to the estuary by two access channels (Smith *et al.*, 1991). The eastern channel connects to the estuary in the highly dynamic mouth region and is consequently prone to sedimentation and constriction.

For a distance of approximately 5 km from the mouth, the estuary is characterised by relatively shallow channel depths of 1.5 m and a sandy bottom substrate (Figure C-3). Upstream of this, the estuary deepens to between 3 m and 4 m until the region of confluence of the Geelhoutboom and the Kromme River where the water shallows to between -2 and -3 m MSL. The water depth in the Geelhoutboom is shallow and does not exceed a depth of -2 m MSL at its confluence with the Kromme River and shallowing rapidly on moving upstream in the Geelhoutboom. Upstream of the confluence of the Geelhoutboom and the Kromme, the water depth in the Kromme increases to -4 to -5 m MSL in a reach of approximately 9 to 10.5 km of the estuary mouth. There is a short stretch of shallower water (i.e. -3 m MSL) centred in a region approximately 11 km upstream of the

river mouth. Upstream of this shallow region the channel deepens rapidly forming a deep basin that stretches from approximately 11.5 km upstream to the head of tidal influence where the depth exceeds 5 m MSL.

The sediment distribution in the estuary (Reddering and Esterhuyzen, 1983) shows a gradation in substrate particle size from medium sand in the lowest 5 km to more angular fluvial sand particles with smaller grain sizes and higher organic content upstream of 5 km of the mouth. The muds start to predominate at approximately 5 km upstream of the mouth where the water deepens and where, under average flow conditions, the tidal incursion of seawater occurs with each tidal cycle during spring tides. This is not unexpected as the conditions of mud flocculation governing the deposition behaviour of muds is a subtle function of both salinity and water column turbulence, both of which change substantially approximately 5 km upstream of the mouth.

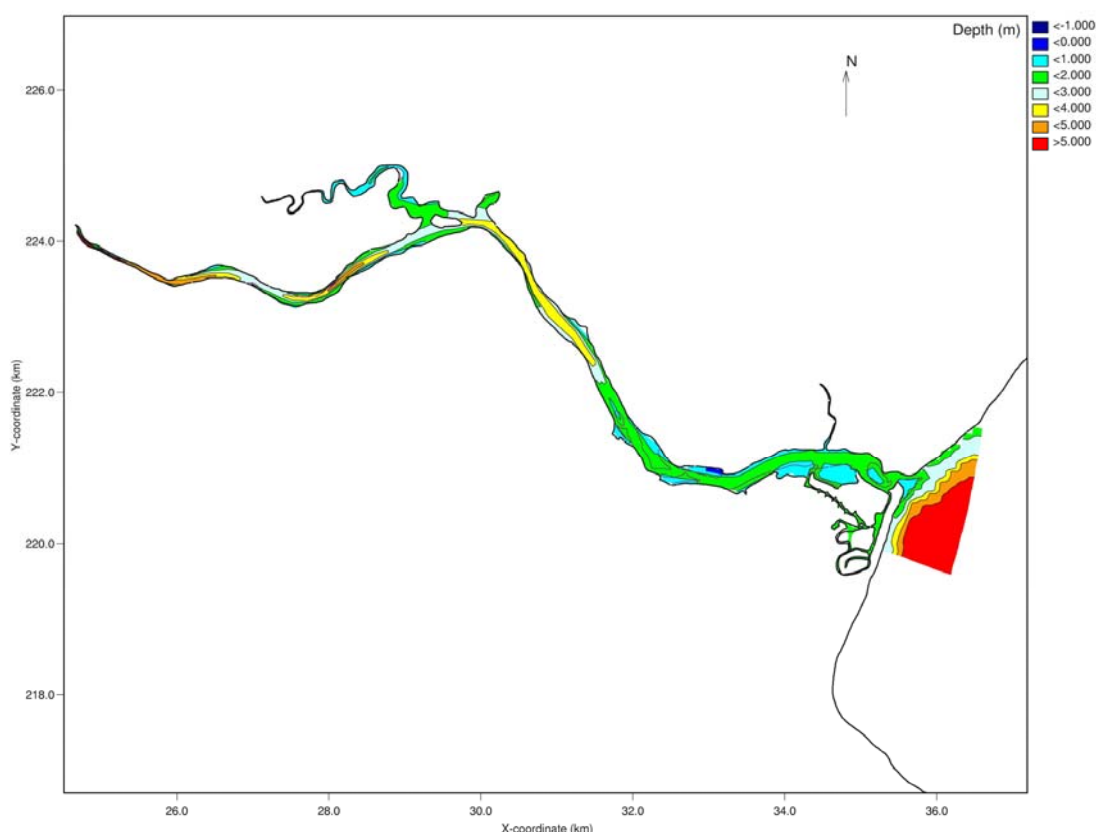


Figure C-3 Bathymetry of the Kromme Estuary as reported in Smith *et al.* (1991)

The bathymetry of the Kromme Estuary plays a large role in determining the unique hydrodynamic regime characteristic of this estuary. A description of the hydrodynamic regime of relevance to this study is given below.

5.2 Circulation processes

For the purposes of this investigation, the hydrodynamics of the Kromme Estuary can be adequately described in terms of mouth dynamics, water level variations, tidal prism, water column stratification, currents, water column turbulence and residence time of estuarine waters.

i. Mouth dynamics

The mouth of the estuary is permanently open. Historical maps and cartographic evidence suggest that the mouth has never closed (Bickerton and Pierce, 1988). The alongshore sediment transport has resulted in a massive sandspit of about half a kilometre long, which extends from the south bank of the estuary mouth and tends to push the mouth channel northwards.

Reddering and Esterhuyzen (1983) state that moderate sedimentation of the lower reaches of the estuary is taking place caused mainly by the influx of marine sediments through the constricted and permanently open mouth that results in a flood tide dominated mouth. This results in a net deposition of marine sand as far as 5 km upstream of the mouth. The terrestrial yield of sediment is considered negligible except for the Sand River, which constitutes a minor sand source and the Geelhoutboom River, which allows mud and, to a lesser extent, sand to enter the estuary. The Sand River, periodically fed by erratic river outbreak, deposits a small delta of sand that is spread up- and downstream by tidal currents.

ii. Water levels

Water level variation is primarily determined by tides but significant changes will result with strong freshwater inflows. This is also due to large scale fluctuations in water levels in the ocean caused by wind-driven set-up or set-down.

Tidal measurements have been made along the length of the estuary during a low freshwater inflow period (Smith *et al.*, 1991), comprising 5 water level measurement sites along the length of the estuary (as well as two in the marina). The location of the water level recorders in the river is given in Figure C-4. The water levels were measured from 11 August 1988 to 24 August 1988, including the spring tide on 14 August and neap tide on 22 August 1988. Dam releases during this period were limited. The Department of Water Affairs and Forestry released 22 158 m³ and 22 432 m³ from the Impofu Dam on 9 and 16 August 1998 respectively. However, not all of this water reached the estuary due to an unknown volume that filled the “hippo pools” and was extracted by local farmers. These volumes, intended to balance evaporative losses in the estuary are negligible compared to the estuarine volumes.

The tidal wave propagates upstream at an average speed of 5-7 m/s during both spring and neap tides. The shallowness of the lower estuary results in this low propagation speed in the lower reaches of the estuary and the deformation of the tidal wave form. Interestingly, there are significant lags between the lower three water level stations (WL1, WL2, and WL3). However, the lags in water level between Stations WL3 to WL5 are negligible.

The 1988 water level measurements indicate a tidal range at WL1 (located just inside the mouth of the estuary) of 55% of that in the open ocean during spring tides compared to those predicted for the open ocean. Further upstream (WL3 to WL5) there is an additional 5 (neap) to 10% (spring) reduction in tidal amplitudes, resulting in a tidal amplitude upstream that is approximately 45 to 50% of that measured in the ocean. During neap tides the tidal range at WL1 is approximately 82% of that in the open ocean and at the upstream end the tidal range is approximately 78% of that in the open ocean. The greater reduction in tidal amplitudes during spring tides can largely be attributed to the constricted mouth conditions.

The tidal asymmetry is clearly evident in both the measured and simulated water level time series, resulting in flood flows of approximately 5 hours in duration and ebb flows of approximately 7.5 hours in the estuary.

During spring tides the tidal delays between the open ocean and WL1 (just upstream of the estuary mouth) were observed to be approximately 30 minutes at high water and approximately 2 hours and 10 minutes at low water. At the upstream end of the estuary high water occurs approximately 1.5 hours to 2 hours after predicted high water at sea and low water occurs approximately 3.5 to 4 hours after predicted low water at sea. During neap tides the tidal delays between the open ocean and WL1 (just upstream of the estuary mouth) were observed to be approximately 30 to 40 minutes at high water and approximately 1.5 to 2 hours at low water. At the upstream end of the estuary high water occurs approximately 0.5 to 1 hour after predicted high water at sea and low water occurs approximately 2.5 to 3 hours after predicted low water at sea.

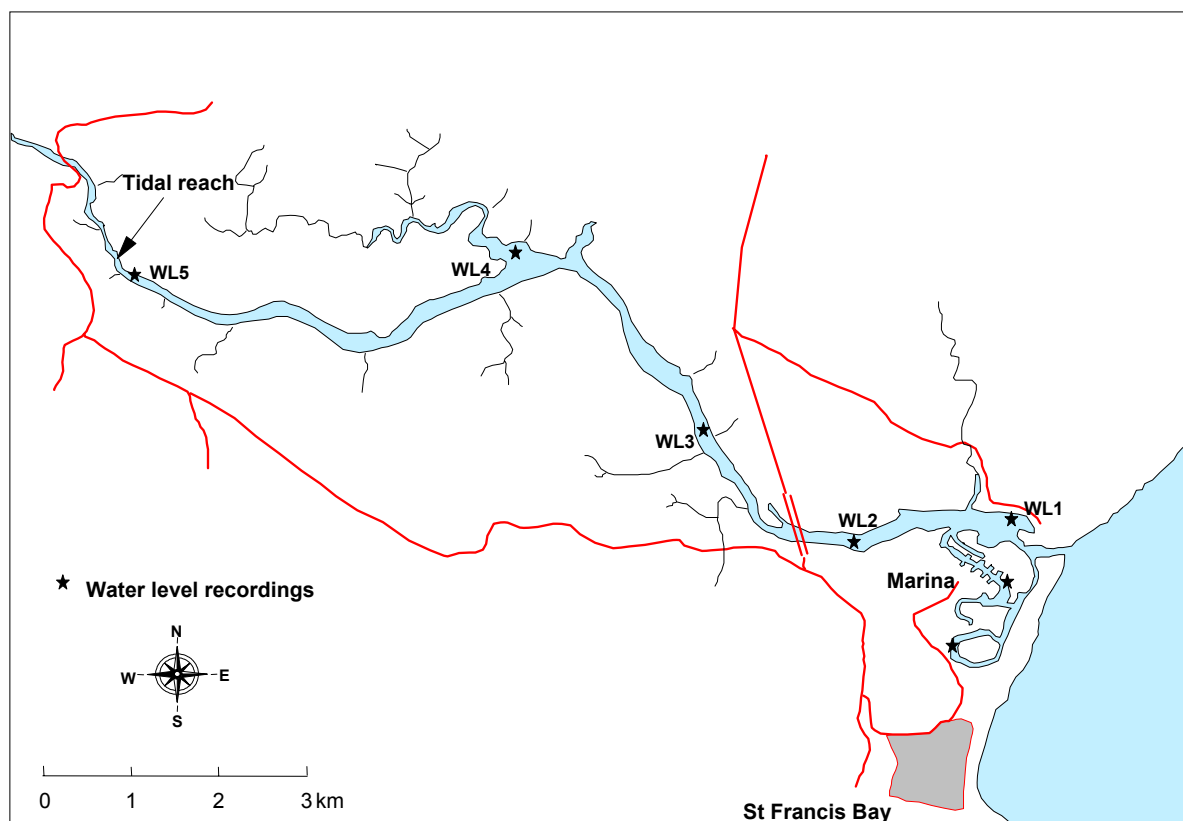


Figure C-4 Location of water level recorders in the Kromme Estuary (August 1988)

iii. Tidal prism

The tidal area of the Kromme Estuary is about 3 km² (Bickerton and Pierce, 1988). Smith *et al.* (1988) estimated the spring tide prism to be $1.61 \times 10^6 \text{ m}^3$ (approximately 14.5% of the low tide volume). This is 2.14 times greater than the neap tidal prism of approximately $7.54 \times 10^5 \text{ m}^3$ (approximately 6.8% of the low water volume). The present modelling results indicated an approximate spring tidal prism of $1.9 \times 10^6 \text{ m}^3$ and a neap tidal prism of $7.8 \times 10^5 \text{ m}^3$ for the limited period modelled.

Model simulations for a number of freshwater inflow scenarios indicates a tidal prism for the Geelhoutboom, upper Kromme and the Kromme estuarine system as a whole (see Figure C-3 for the location of the cross-section for which the tidal prism has been simulated) of $1.9 \times 10^6 \text{ m}^3$, $3.8 \times 10^6 \text{ m}^3$, and $1.3 \times 10^6 \text{ m}^3$ during spring tides and $7.8 \times 10^5 \text{ m}^3$, $1.6 \times 10^6 \text{ m}^3$, and $0.55 \times 10^5 \text{ m}^3$ during neap tides, respectively. (See Figure C-5 for the location of the cross-section for which the various representative tidal prisms have been simulated.)

iv. Water column stratification

Water column stratification in the estuary is generally limited due to the low freshwater inflows and the shallow lower reaches of the estuary where turbulence due to strong tidal flows mixes the water column.

Under low or no freshwater inflow conditions (Abiotic State 1) the water column is well-mixed and has a largely marine character (i.e. the salinity is close to 35 ppt), however hypersalinities may develop in the upper reaches of the Kromme Estuary. Under these hypersaline conditions the water column is typically well-mixed in the vertical with a reverse longitudinal salinity gradient from the head of the estuary towards the estuary mouth. Under these conditions salinities at the head of the estuary may reach up to 39 ppt while those further downstream are more typical of the seawater entering the mouth of the estuary.

Under intermediate flows a salinity gradient develops in the estuary (Abiotic State 2) whereby there is a relative strong water column stratification in the estuary 5 km upstream of the mouth. In the shallow waters 5 km from the mouth and downstream, the high degree of turbulence from the tidal flows typically result in well-mixed waters. However, vertical salinity gradients may occur in these shallower waters and the mouth region during outgoing tides. The strength and depth of this vertical salinity gradient depends on the nature (flow rate and variability in flow rate) and duration of freshwater inflows. In addition, at any particular depth, there exists a salinity gradient along the axis of the estuary that also depends on the nature and duration of freshwater inflows to the estuary. Under these freshwater inflows, the tidal excursion of seawater up the estuary during spring tides is sufficient to inject higher salinity water into the deeper basins upstream of 5 km from the estuary mouth. The implication of this is that the salinities at a location 5 km upstream of the mouth will not consistently remain below 20 ppt for these intermediate freshwater inflows.

Under sustained high flow conditions (Abiotic State 3), salinities in the estuary are typically < 2 ppt and fairly well-mixed in the vertical, except for the very upper reaches where some higher salinity bottom waters may remain depending on the duration of the high freshwater inflows. The freshwater inflows are sufficiently strong to prevent the ingress of higher salinity seawater into the deeper basins 5 km upstream from the mouth.

It should be noted that due to the shallowness of the Geelhoutboom tributary, should a surface layer of freshwater reach the confluence it would be rapidly flushed. This would freshen the total water column in the Geelhoutboom tributary even if the freshwater flows into the upstream section of the tributary are limited or non-existent. Conversely, should there be no freshwater inflows into the Kromme Estuary but a reasonably strong freshwater flow into the Geelhoutboom tributary, not only will the waters of the tributary be freshened but there will be a surface inflow of freshwater into the Kromme Estuary that is likely to result in stratified conditions in the vicinity of the confluence.

Although there are at times significant cross-channel temperature differences and temperature stratification due to diurnal heating and cooling of the surface waters, in terms of density stratification and modification of flow velocities with depth, these temperature variations are usually negligible compared to the influence of changes in salinity on density stratification of the water column. The only time such temperature fluctuations are likely to be of relevance is when the water column salinities are uniform and even then these temperature differences are likely only to play a minor role in determining the hydrodynamics of the estuary.

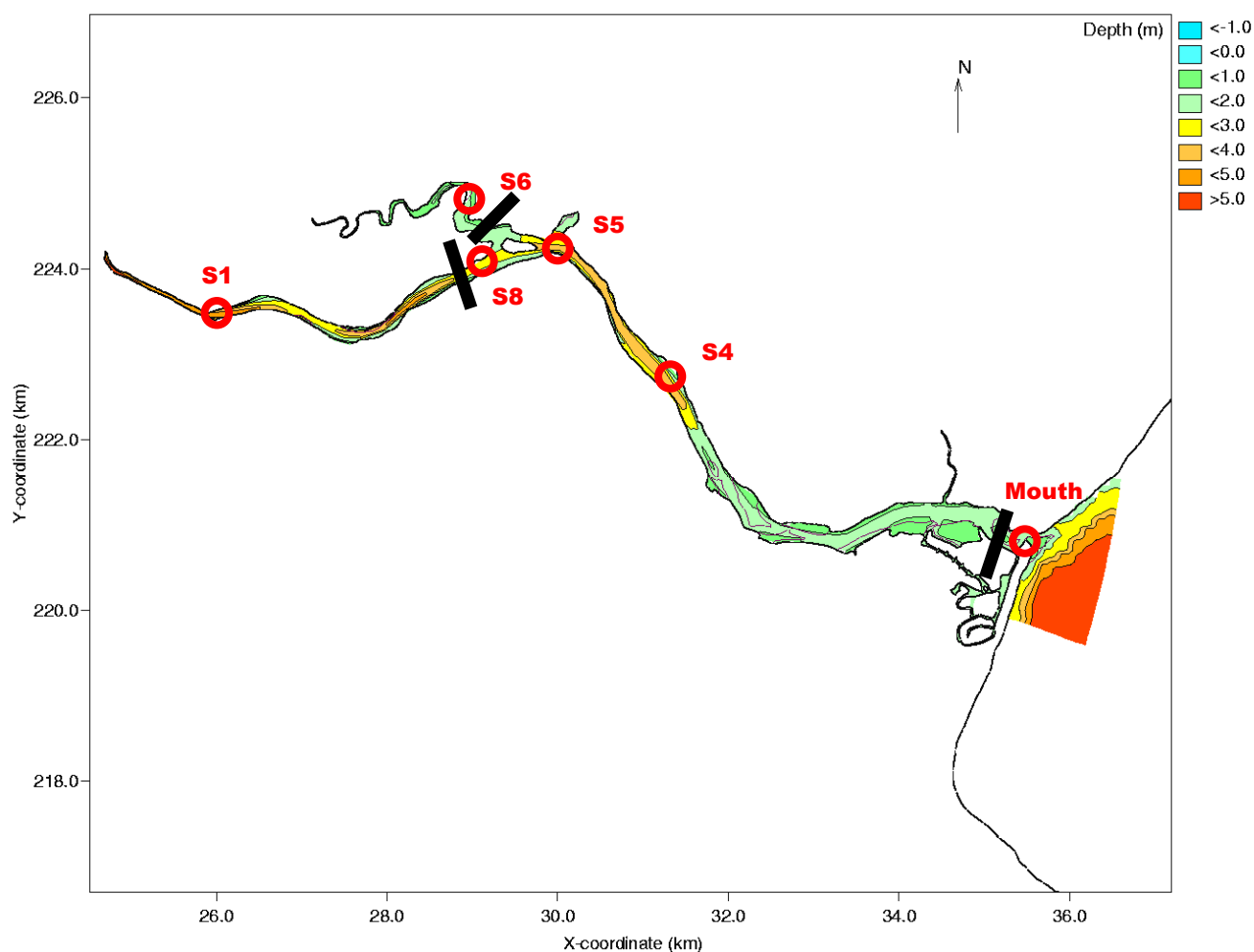


Figure C-5 Locations of monitoring locations (○) and cross sections for which the tidal prism has been calculated

v. Currents and water column turbulence

The maximum mid-channel, depth averaged, surface and bottom currents at selected locations along the axis of the estuary are tabulated below (Table C-2). The locations referred to are as indicated in Figure C-5.

Even when the water column is not stratified, there will be higher flows at the surface than near the bottom due to the effects of friction. However during periods of strong freshwater inflow the surface currents are likely to be much stronger than those at depth and also will display a residual downstream flow. The strength of these flows are determined by the rate of inflow of freshwater into the estuary.

Table C-2 Maximum tidal currents at various locations along the axis of the Kromme Estuary

Station D	Tide	Mouth	S4	S5	S6	S8	S1
Max depth-averaged current (m/s)	Spring	1.00	0.25	0.28	0.08	0.20	< 0.02
	Neap	0.40	0.06	0.07	0.03	0.05	< 0.01
Maximum surface current (m/s)	Spring	1.20	0.30	0.33	0.12	0.27	0.06
	Neap	0.50	0.10	0.10	0.06	0.14	< 0.02
Maximum bottom current (m/s)	Spring	0.50	0.10	0.10	0.02	0.08	< 0.01
	Neap	0.20	0.04	0.03	0.01	0.02	< 0.01

vi. Residence time

Based on the tidal prism method of Dyer (1973), the mean flushing times were estimated to be 98 hours at spring tide and 197 hours for neap tides (Smith *et al.*, 1991). However, due to the assumption that all water entering the estuary is mixed throughout the estuary, the method of Dyer significantly underestimates the flushing times in the estuary.

In the absence of multiple simulations to characterise the flushing times for various regions of the estuary, a set of simulations is useful to characterise the residence time of a “particle” in the various reaches of the estuary for various freshwater inflows. We have undertaken a number of surface drogue simulations for each of the Scenarios modelled. These provide a rough indication of the residence times of surface waters in the various reaches of the estuary. Unfortunately the DELFT3D-FLOW software does not allow for similar drogue simulations at various water depths. In a stratified system, as in the Kromme Estuary, this could be considered to be a serious limitation. However, determining the residence time of fresh surface waters is more important as they contain nutrients. If the water column becomes mixed and the freshwater and associated nutrients are mixed throughout, then the current will become vertically more uniform and the surface currents can be considered a reasonable proxy for estimating the residence time of the bottom waters. Drogues were placed in the estuary every 5 days at the locations indicated in Figure C-5. The results of the flushing rates for the different reaches of the Kromme Estuary based on the drogue simulations are summarised in Table C-3.

Table C-3 Flushing rates for the different reaches of the Kromme Estuary based on drogue simulations

Flushing rates of freshwater inflows into the Kromme Estuary								
Section of estuary		Tidal state	Water column location	Freshwater inflow into the Kromme Estuary (m ³ /s)				
				0.3	0.5	1	2	5
Kromme Upstream 4 000 m	Spring	Surface	7– 21d*	1w*	2-5 d*	2d*	<2d*	<1 d*
		Bottom	3 – 6w	> 30d	30d	3w	2w	1 - 2 w
	Neap	Surface	7-21d*	1w*	2-5 d*	2d*	1d*	<1 d*
		Bottom	3 – 6w	> 30d	30d	3w	2w	1 - 2 w
Kromme middle reaches 4 000 m	Spring	Surface	1.5-2w*	7-10*	5 – 7d*	3d*	1 – 2d*	<1 d*
		Bottom	2 – 4w	2-3w	2w	< 2w	1w	<1w
	Neap	Surface	1.5-2w *	7-10d*	5 – 7d*	2.5d*	1 – 2d*	<1 d*
		Bottom	2 – 4w	2-3w	2w	< 2w	1w	<1w
Kromme Lower reaches 3 250	Spring	Surface	1 - 2w	2 – 4d	2-3 d	2d	1 – 2d	<1 d
		Bottom	1 - 2w	2 – 4d	2-3 d	2d	1 – 2d	<1 d
	Neap	Surface	1 - 2w	2 – 4d	2-3 d	2d	1 – 2d	<1 d
		Bottom	1 - 2w	2 – 4d	2-3 d	2d	1 – 2d	<1 d
Geelhoutboom 2 800 m	Spring	Surface	2 – 4w	2 – 4w	2-3 d	14 - 21d	14 - 21d	14d
		Bottom	2 - 4 w	2 – 4w	2-3 d	14 - 21d	14 - 21d	14d
	Neap	Surface	2 – 4w	2 – 4w	2-3 d	7 - 14d	7 - 14d	7 - 14d
		Bottom	2 – 4w	2 – 4w	2-3 d	7 - 14d	7 - 14d	7 - 14d
Section of estuary		Water column location	Freshwater inflow into the Kromme Estuary (m ³ /s)					
			0.3	0.5	1	2	5	10
Total	Kromme	Surface	3.5–7w	2.5–3w	1.5 – 2w	7 d	3 – 6 d	1 day
		Bottom	6 - 12 w	6 – 8 w	5 – 6w	5 w	3 – 3.5 w	1.5-2.5w
	Geelhoutboom	Mixed	2 – 4 w	2 – 4w	2-3d	7 – 21d	7 – 21d	14d

* May be significantly longer if drogue enters Geelhoutboom (this is most likely to occur during spring tides). However the drogue is then located in the Geelhoutboom for this additional period. This implies that the greatest retention is likely in the Geelhoutboom (flow vs retention time)

5.3 River inflow versus salinity distribution

In addition to the salinity data that were recorded as part of this study, the longitudinal salinity structure of the Kromme Estuary has been investigated extensively over the past years (Table C-1).

For the purposes of the Ecological Reserve determination, it is important to be able to correlate any measured salinity structure to specific river inflow patterns. Unfortunately such information was not always captured, which makes the interpretation of some of these studies more difficult. Also, in some of the publications longitudinal salinity pattern is reported as depth averaged values which do not always reflect actual conditions, particularly in the deeper section in the upper estuary, where strong vertical stratification occurs during periods of freshwater inflow.

The historical data sets and measurements taken as part of this study were, however, interpreted as best possible to extract the necessary information to support the predictions on the salinity characteristics of the Kromme Estuary under different river inflow Scenarios.

No salinity data could be located for the Kromme Estuary prior to the commissioning of the Churchill Dam, constructed in 1943 (the dam is situated about 50 km upstream of the mouth and has a capacity of $33.3 \times 10^6 \text{ m}^3$).

The earliest salinity data for the Kromme Estuary appears to be that collected by Hecht (1973) for the period September 1972 to August 1973, prior to the commissioning of the Impofu Dam in 1982 (the dam is situated 4 km above the tidal reach of the estuary and has a capacity of $100 \times 10^6 \text{ m}^3$). Surface and bottom water salinity measurements were collected from 12 stations in the estuary on a monthly basis during spring high and low tides. Results from this study depict the salinity profiles measured during the two extremes, i.e. when salinities were lowest (September 1972) and when salinities was highest (February 1973) (Figure C-6a).

Although river inflow data was not provided, simulated runoff data (prior to the commissioning of the Impofu Dam) suggest that during September 1972 the mean monthly river inflow was around $2\text{--}3 \text{ m}^3/\text{s}$. Salinity data from this period, therefore, indicates that flows in this range do create a salinity gradient in the estuary, but due to strong vertical stratification in the upper reaches of the estuary, freshwater conditions are limited to the surface waters. Further downstream vertical mixing and strong tidal influence results in marine dominated conditions.

Simulated river inflows for February 1973, when salinity in the estuary was at its highest (even hypersaline), were around $0.1\text{--}0.2 \text{ m}^3/\text{s}$. The hypersaline conditions, however, suggest that no riverwater probably reached the estuary, the likely reason being (illegal) water abstraction. From these results it can be concluded that the Kromme Estuary probably encountered hypersaline conditions during drier years, even prior to the commissioning of the Impofu Dam.

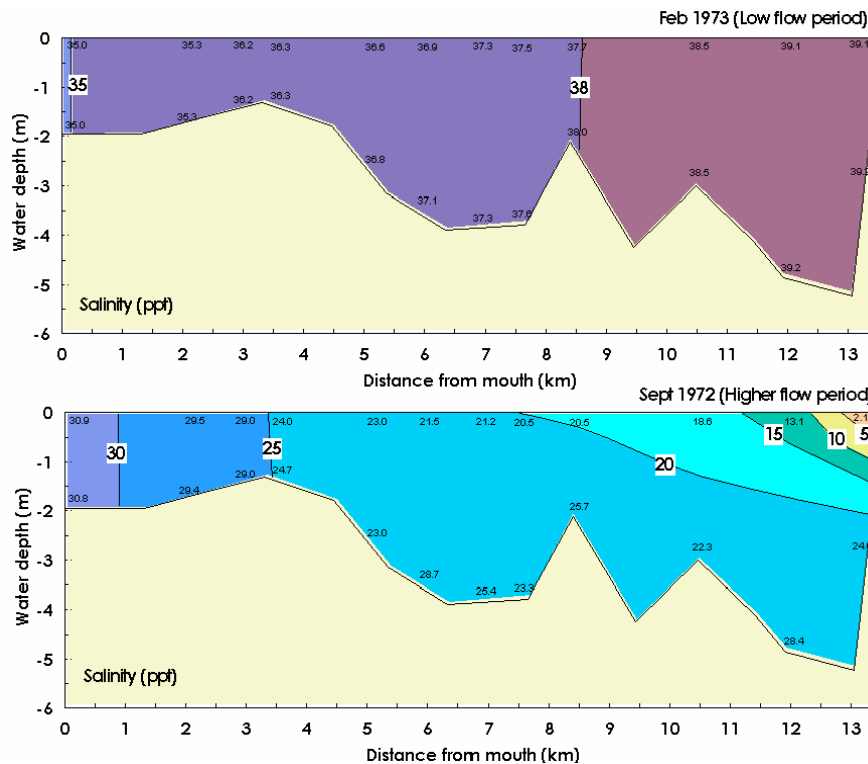


Figure C-6a Extreme salinity distribution patterns measured in the Kromme Estuary for the period September 1972 to August 1973

Another study was performed prior to the commissioning of the Impofu Dam by Emmerson and Erasmus (1987) from July 1979 to October 1981. During this period bi-monthly surface and bottom water measurements were taken during spring low tides at 7 stations in the estuary. During both winter (usually higher flow periods) and summer (usually the lower flow period) a salinity gradient was found down the estuary which indicated a continuous freshwater input. In the upper reaches of the estuary near the head, vertical salinity gradients were always present. No reverse salinity gradient, reflecting hypersaline conditions was recorded. Horizontal salinity gradients, representative of summer and winter conditions during the study period are provided in Figure C-6b. Unfortunately the data has been depth averaged and therefore does not properly resolve the situation for the upper reaches in the estuary.

Simulated river inflow for this period indicates that it was an above average flow period. A number of monthly river inflows exceeding $10.0 \text{ m}^3/\text{s}$ were simulated for this period. This synopsis of salinity data suggest that under these flow conditions, the Kromme Estuary remains mainly a marine dominated system, although slightly less saline during winter (usually months with higher river inflow).

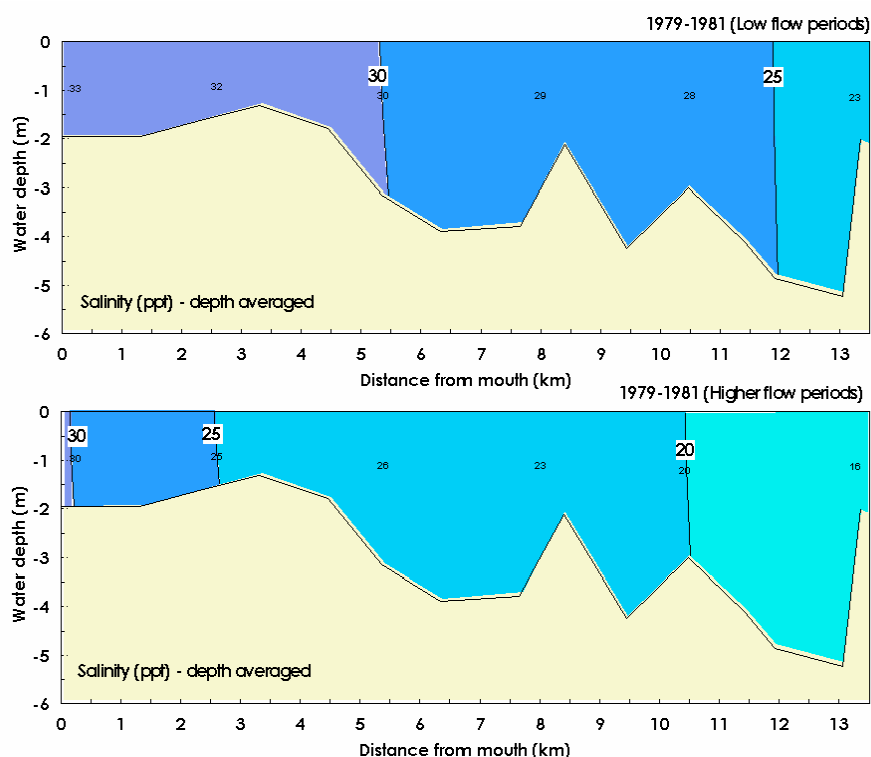


Figure C-6b Synopsis of salinity distribution patterns measured in the Kromme Estuary for the period July 1979 to October 1981

Although Hanekom (1982) also collected bi-monthly salinity data for the period March 1979 to August 1981, it was difficult to interpret results for the purposes of an Ecological Reserve study as only surface salinity measurements were taken, which do not truly reflect actual conditions in the upper reaches of the estuary. Strong vertical stratification is known to occur during periods of freshwater inflow in the upper reaches – a condition which prevailed at the time (Emmerson and Erasmus, 1987).

A once-off survey conducted by the CSIR in November 1994 (Bickerton and Pierce, 1987) showed high salinities throughout the estuary ranging between 35 to 38 ppt. These high values are probably indicative of low to no freshwater inflow into the estuary at the time.

Monthly salinity profile data were collected from the middle and upper reaches of the Kromme Estuary (including 2 stations in the Geelhoutboom tributary during the period March 1988 to March 1991 (Wooldridge, UPE, unpublished data). Results from this study depict the salinity profiles measured during the two extremes, i.e. when salinities were highest (April 1989) and when salinities were lowest (November 1989) (Figure C-6c).

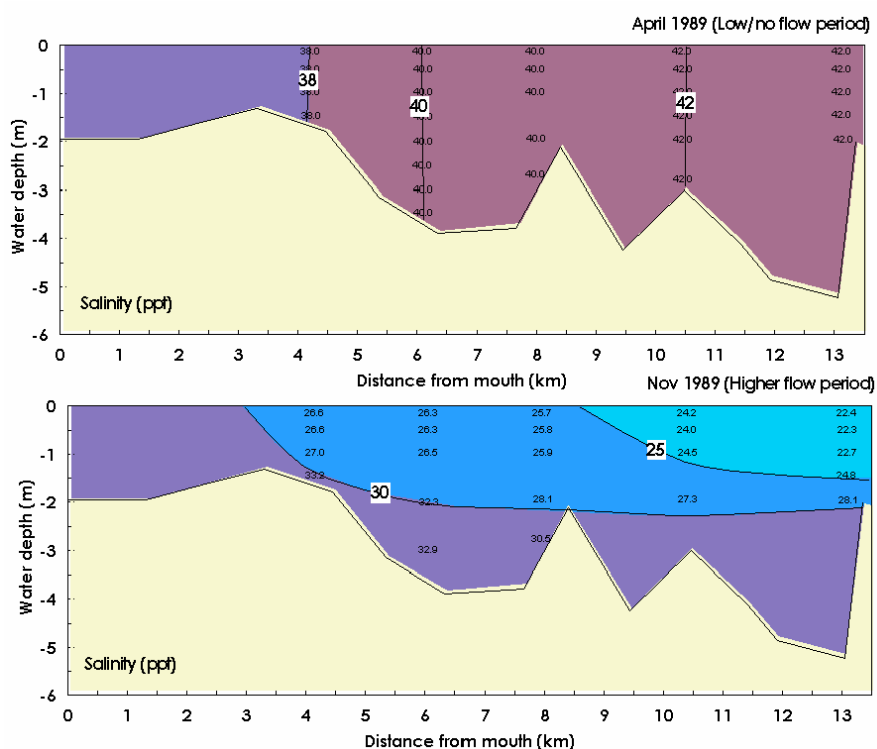


Figure C-6c Extreme salinity distribution patterns measured in the Kromme Estuary for the period April 1988 to March 1991

A comprehensive survey conducted after commissioning of the Impofu Dam took place in 1993 and 1994 (Scharler *et al.* 1998; Scharler and Baird, 2003). Bi-monthly measurements were taken along the estuary (surface and 0.5 m intervals thereafter) on spring low tides for the period of July 1993 to June 1994. River inflow was recorded during each sampling survey. Horizontal salinity gradients, representative of summer and winter conditions during the study period are provided in Figure C-6d. Data has been depth averaged and therefore does not always resolve the situation for the upper reaches in the estuary.

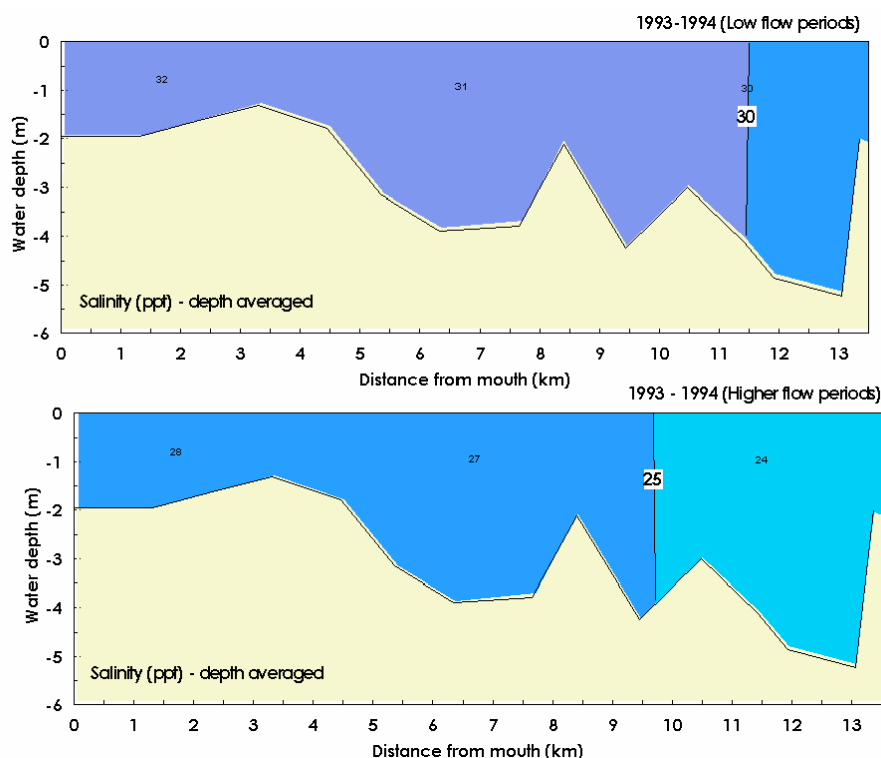


Figure C-6d Synopsis of salinity distribution patterns measured in the Kromme Estuary for the period April 1993 to June 1994

Although river inflow data were recorded during each sampling survey, these can only be used for the purposes of an Ecological Reserve study when compared with corresponding salinity data sets. To provide an indication of mean runoff conditions at the time, simulated runoff data were therefore used. Simulated runoff data for this period suggested that the measurement period started during low flow conditions (flows of less than $0.2\text{m}^3/\text{s}$ since Feb 1993) which increase to a maximum flow of $24\text{m}^3/\text{s}$ in September 1993, before decreasing to below $0.2\text{m}^3/\text{s}$ again by February the following year. This is similar to the conditions in 1979-1981 (Emmerson and Erasmus, 1978) thus a synopsis of salinity data suggests that under such flow conditions, the Kromme Estuary remains mainly a marine dominated system, although slightly less saline during winter.

In November 1998, a project was undertaken at the Kromme Estuary to investigate the effect of a single freshwater release from the Impofu Dam on the salinity distribution pattern of the Kromme Estuary, amongst other aspects (CSIR, 1999; Scharler and Baird, 2000). Two million cubic metres of water were released from the Impofu Dam over a period of 3 days, at a flow rate of about $15\text{m}^3/\text{s}$. Prior to the release salinities in the estuary was high, around 34 ppt throughout the estuary (Figure C-6e). After the release, salinities in the estuary reached its lowest levels on Day 3. Strong vertical stratification persisted in the upper and middle reaches of the estuary, where fresh conditions were limited to the surface waters. In the lower reaches vertical mixing and strong tidal influence resulted in the break-down of stratification, creating a well-mixed water body that was still largely marine dominated. Approximately 8 days after the release, salinities in the estuary were virtually the same as before (i.e. around 34 ppt throughout).

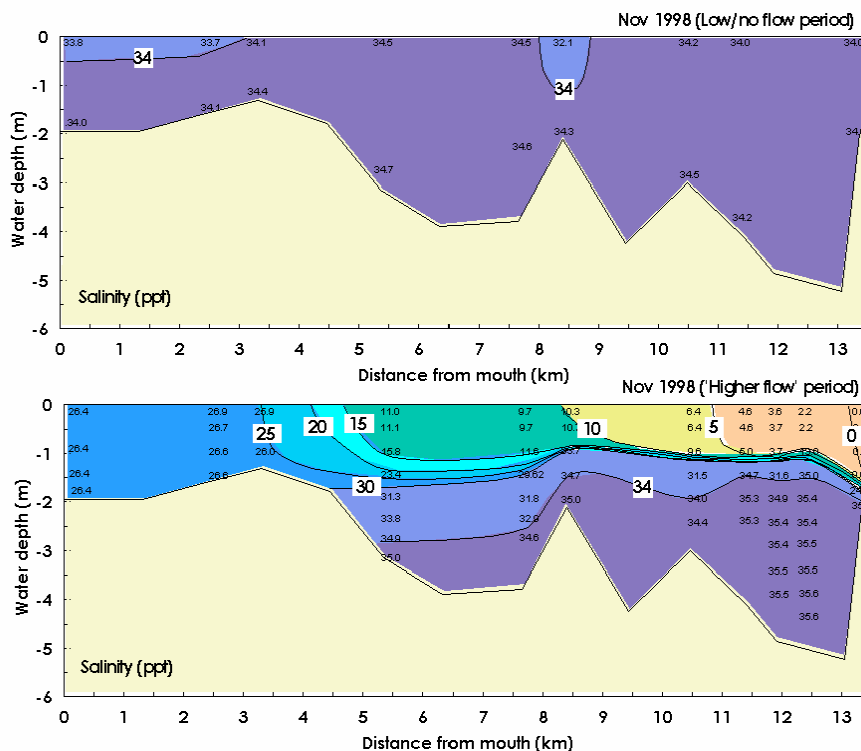


Figure C-6e Salinity distribution patterns measured in the Kromme Estuary on 16 November 1998, prior to the once-off release of freshwater from the Impofu Dam and 3 days after the release commenced, i.e. when salinities in the estuary reached its lowest levels

The study illustrated that the bathymetry of the Kromme Estuary (i.e. deep upper reaches becoming shallower towards the middle and lower reaches) largely influenced the effect of river inflow into the system. This is further affected by the salinity distribution patterns within the estuary at the time of release. Also, strong tidal flushing reduces the residence time of any freshwater entering the system, particularly in the lower and middle reaches.

Therefore, for a salinity gradient to prevail in the Kromme Estuary, a significant 'pulse of freshwater' will have to be followed by 'maintenance inflow'.

Salinity measurements taken in the Kromme Estuary as part of this Ecological Reserve determination study are provided in Figure C-6f.

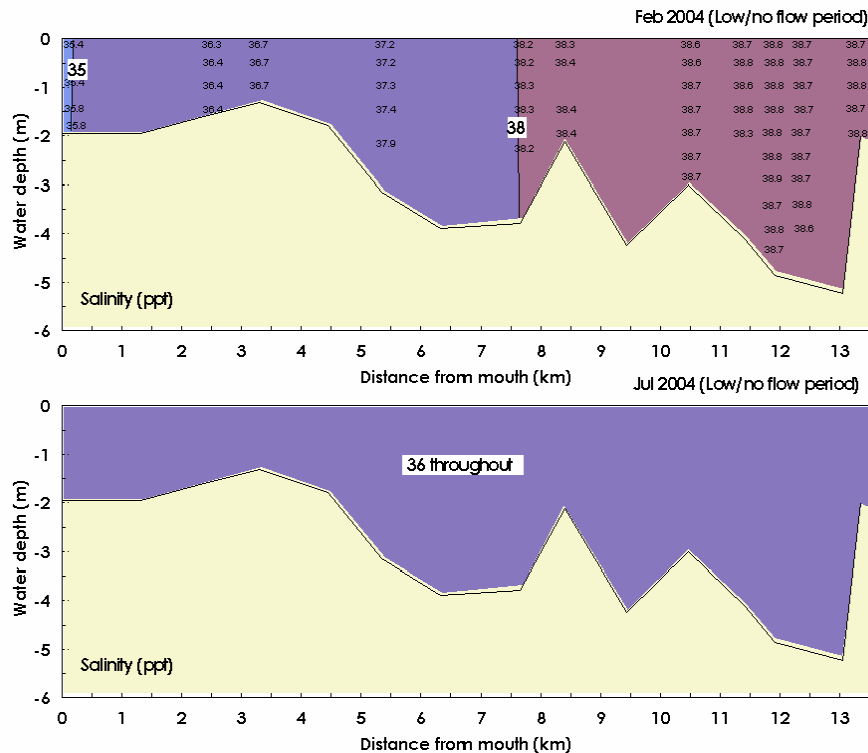


Figure C-6f Salinity distribution patterns measured in the Kromme Estuary on 18/19 February 2004 and 30 July 2004

During the February 2004 survey there was no freshwater inflow into the Kromme Estuary with hypersaline conditions developing during February 2004, the result of evaporation during warmer summer months. During the February 2004 survey salinity measurements in the Geelhoutboom tributary also reflected hypersaline conditions with salinities around 39 ppt.

During the winter survey in July 2004, a lack of freshwater inflow also resulted in the system being saline throughout (36 ppt). This was also the case for salinities in the Geelhoutboom tributary.

6. WATER QUALITY CHARACTERISTICS

The water quality assessment considered the following variables:

- System variables (temperature, pH, dissolved oxygen and transparency/turbidity)
- Inorganic nutrients (inorganic nitrogen, reactive phosphate and reactive silicate)
- Organic nutrients (although organic nutrients are currently not explicitly included in the Ecological Reserve protocols, a brief overview on organic (nitrogen) nutrient characteristics of the Kromme Estuary is also provided, based on historical data)

The Ecological Reserve protocol specifies that toxic substances (e.g. trace metals) in sediments should also be assessed where such contaminants are expected to be of concern. The Kromme Estuary does not have any major urban or industrial zones in its catchment or along its banks and it was therefore agreed with DWAF not to include toxic substances as part of this water quality assessment. Studies conducted on trace metal distribution patterns in the Kromme Estuary (Watling and Watling, 1982) also concluded that trace metals did not present a hazard due to the absence of urbanisation and industrialisation in the area.

6.1 Temperature

Most of the water quality studies on the Kromme Estuary included temperature measurements (Table C-4). The most distinct pattern observed in the temperature regime of the Kromme Estuary is the strong seasonal signal, largely following trends in atmospheric temperature (Table C-4).

Summer temperatures typically range between 20–25°C, with temperatures in winter dropping down to around 13–16°C. Although the temperature gradients within seasons were observed to be small, the lower reaches tended to be slightly lower compared with the upper reaches (Emmerson and Erasmus, 1987; Scharler *et al.*, 1998). This can probably be attributed to seawater having lower ambient temperature than resident water in the estuary during these warmer months. The reverse applies in winter, where the temperature in the upper reaches was usually higher than in the lower reaches (Emmerson and Erasmus, 1987).

Table C-4 Summary of temperature ranges measured in the Kromme Estuary during summer and winter

Period	Temperature Range (°C)	
	Summer	Winter
September 1972 to August 1973	24.3 – 27.8	12.0 – 14.0
July 1979 to October 1981	19.5 – 25.2	15.5 – 16.0
April 1988 to March 1991	18 – 28.5	12.4 – 19.7
April 1993 to Jun 1994	20.0 – 23.0	16.0 – 18.0
Nov 1984	17.0 – 23.0	-
Nov 1998	18.0 – 24.5	-
February/July 2004 (this study)	21.6 – 25.8	13 – 14.5

Temperature profile measurement taken in the Impofu Dam during January 2005 (summer period), showed a marked decrease in temperature from surface to bottom waters (about 10°C difference, with a strong thermocline at about 15 m (Figure C-7a). This change was much less during November 1998 and December 2004 where the difference was about 2–3°C.

Based on the above, the temperature regime of the Kromme Estuary (including the Geelhoutboom tributary) is expected to show a strong seasonal pattern, with summer temperatures ranging between 20–25°C and winter temperatures between 13 and 16°C. Bottom releases from the dam during summer months may result in lower temperatures in the upper reaches of the estuary (14–18°C) unless the retention time between the dam and the head of the estuary is long enough for these waters to warm.

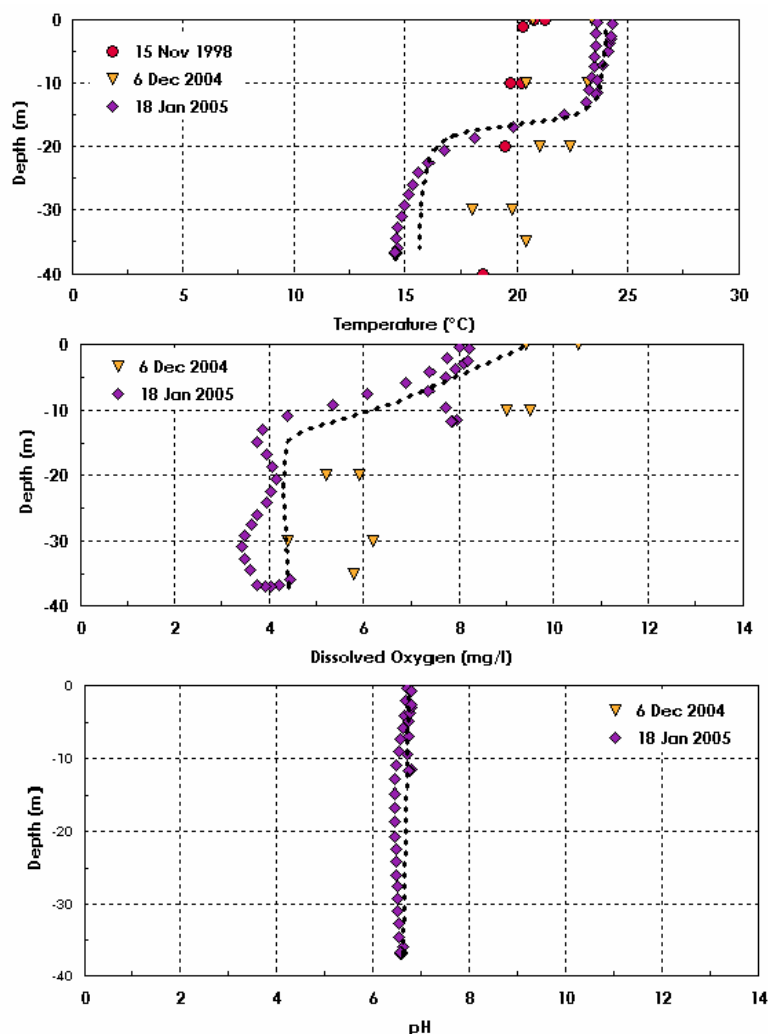


Figure C-7a Temperature, Dissolved oxygen and pH profile data collected from the Impofu Dam at the outlet (ME) about 1 km upstream (MF) – refer to Figure C-2b for sampling locations

6.2 pH

Historical data sets on the pH characteristics of the Kromme Estuary, as well as data collected as part of this study, revealed no distinct patterns or trends (Table C-5).

Table C-5 Summary of pH levels measured in the Kromme Estuary

Period	pH
September 1972 to August 1973	7.95 – 8.4
July 1979 to October 1981	7.1 – 9.2
April 1993 to June 1994	7.9 ± 0.2
Nov 1984	7.85 – 8.25
Nov 1998	Around 8.0
February/July 2004 (this study)	7.81 – 8.04

Values reflect the strong marine influence in the Kromme Estuary, being close to that of seawater (~8.2). During periods of higher freshwater inflow it is expected for pH values in the surface water of the upper reaches to drop (~7), reflecting the pH of inflowing river water. However, these lower pH values will be localised – mixing with even the smallest amount of saline water should return levels to around 8.0, as a result of seawater's strong buffering capacity.

pH profile measurements collected from the Impofu Dam in January 2005 did not show any variation with depth and values ranged between 6 and 7 (Figure C-7a).

pH values in the Kromme Estuary (and the Geelhoutboom tributary) are expected to remain within the range 7 to 8.5, with the lower range being associated with the fresher (upper) reaches and the higher range within the more saline (middle and lower) reaches.

6.3 Dissolved oxygen

Historical data sets on the dissolved oxygen levels in the Kromme Estuary, as well as data collected as part of this study, revealed no distinct patterns or trends (Table C-6).

Table C-6 Summary of dissolved oxygen concentrations measured in the Kromme Estuary

Period	Dissolved oxygen (mg/l)
September 1972 to August 1973	6.5 ± 0.7
July 1979 to October 1981	7.4 (mean)
April 1993 to June 1994	6.9 – 7.9
Nov 1984	6.7 – 6.9
Nov 1998	7.8 – 8.2
February/July 2004 (this study)	5.7 – 7.5

The estuary is generally well-oxygenated although it has been reported that oxygen concentrations in deeper water (e.g. upper reaches) do show lower dissolved oxygen concentrations, particularly during the warmer summer months, suggesting a degree of organic decay (Emmerson and Erasmus, 1987).

Although results from the February 2004 survey do show a tendency for dissolved oxygen concentrations to decrease with depth (Figure C-7b), this was not considered to be significant. Concentrations throughout the estuary seldom dropped below 5 mg/l.

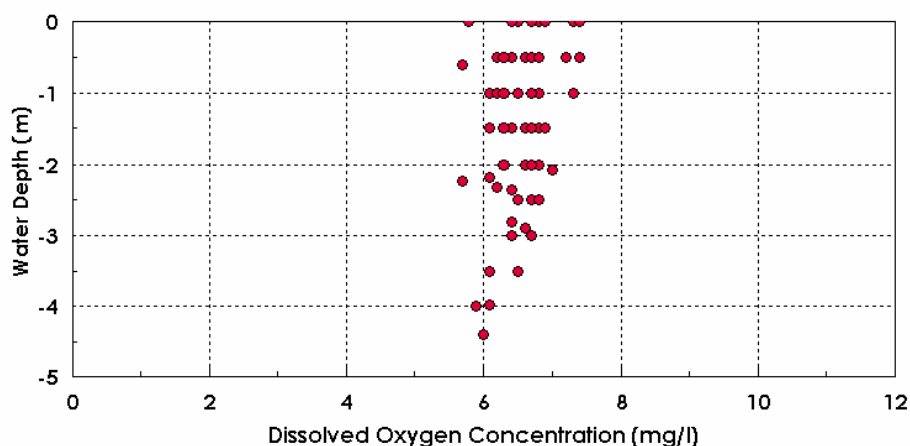


Figure C-7b Change in dissolved oxygen concentrations with water depth as measured on 18 February 2004 in the Kromme Estuary (salinity range: 35–39 ppt; temperature range 21.6–25.8 °C)

It is important to note that dissolved oxygen levels are also dependent on the prevailing salinity and temperature regime. Under saturated or near-saturated conditions dissolved oxygen concentrations are higher in fresh and/or colder waters compared with saline and/or warmer waters.

Dissolved oxygen profile measurements taken in the Impofu Dam showed a clear trend (Figure C-7a). Surface waters were well-oxygenated (8–10 mg/l), but around 15 m water depth levels dropped to between 4–6 mg/l.

Based on the available information, the Kromme Estuary (and the Geelhoutboom tributary) should generally be well-oxygenated. Concentrations in the deeper water (e.g. in the upper reaches) can drop during the drier summer periods, as a result of long residence times and organic decay, but levels are not expected to drop below 5 mg/l. Results from the Impofu Dam suggest that releases from the bottom waters of the dam may result in inflow to the estuary being less oxygenated (~4 mg/l) than from a surface release (8–10 mg/l), unless sufficient aeration occurs between the dam and the estuary.

6.4 Transparency/turbidity

Available data on secchi disc readings are summarised in Table C-7.

Table C-7 Summary of secchi disc readings measured in the Kromme Estuary

Period	Secchi disc reading (m)
September 1972 to August 1973	0.97 ± 0.19 (ebb tides) 1.08 ± 0.18 (flood tides)
March 1979 to July 1981 (excluding Geelhoutboom data)	0.88 ± 0.38 (ebb tides)
Nov 1984	0.52 – 1.82
Nov 1998 (during release from Impofu Dam)	0.3 – 2.0

Hanekom (1982) reported that runoff from the Geelhoutboom tributary was consistently more turbid than waters in the Kromme Estuary. During ebb tides, inflow from the Geelhoutboom therefore resulted in more turbid conditions in the middle reaches of the estuary, resulting in lower secchi disc readings compared with flood tides. During flood tides, tidal flushing introduced less turbid seawater into the estuary.

During the November 1988 survey, the lowest secchi disc readings coincided with peak freshwater inflows, suggesting the water released from the Impofu Dam introduced more turbid conditions, particularly to the upper reaches of the estuary. At the time the secchi disc reading from the Impofu Dam was 0.45 m (Gavin Snow, UPE, personal communication). Turbidity profile measurements taken in the Impofu Dam on 6 December 2004 ranged between 10 and 50 NTU. Although results did not show a clear vertical trend, surface waters (up to about 2 m water depth) appeared to be clearer than the deeper waters (Gavin Snow, UPE, personal communication).

Turbidity concentrations measured in the Impofu Dam during December 2004 and January 2005 were considered to be relatively low in the upper 20 m of the dam (below 5 NTU), but increased with depth (~80 NTU at 35 m water depth) (Figure C-7c). A similar trend was observed for suspended solid concentrations measured during December 2004, with low values in the upper 20 m (below 3 mg/l), and higher in bottom waters below 10 m (~ 11 mg/l).

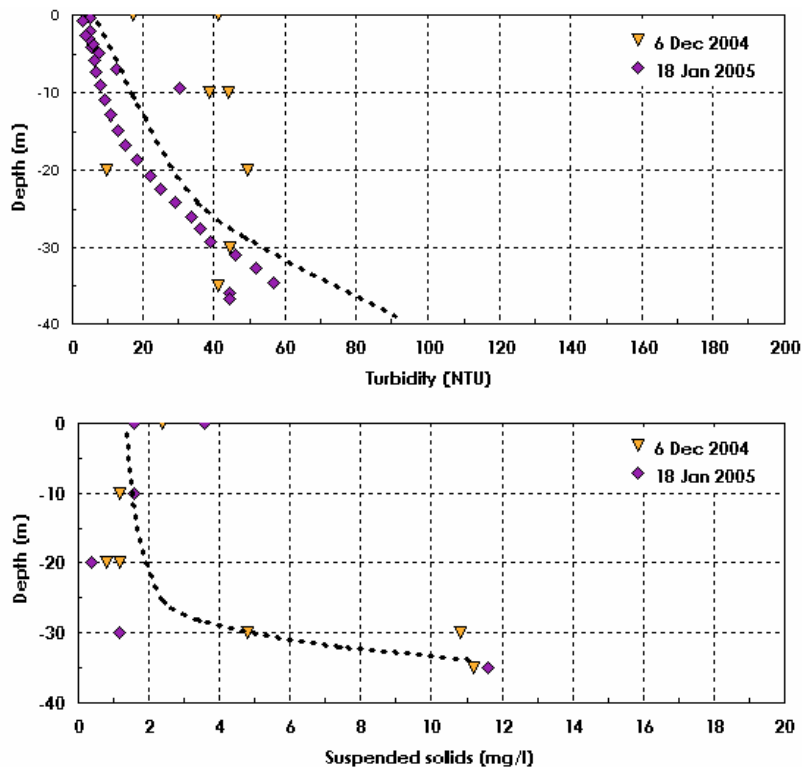


Figure C-7c Turbidity and suspended solid concentrations measured data in the Impofu Dam at the outlet (ME) about 1 km upstream (MF) – refer to Figure C-2b for sampling locations

It is expected that during periods of no or very low river inflow, secchi disc readings for the estuary should be around 1 m, based on data collected from the estuary prior to the freshwater release in November 1998 (Scharler and Baird, 2000).

During once-off surveys in February 2004 and July 2004, turbidity levels measured in surface and bottom waters of the Kromme Estuary were low, as would be expected under conditions of no river inflow. There was also no distinct trend and concentrations ranged between 0.1 and 0.38 NTU in February 2004 and between 0.4 and 0.9 NTU in July 2004.

Based on the above, turbidity concentrations in the Kromme Estuary are generally expected to be low. However, during periods of higher freshwater inflow (either from the Geelhoutboom tributary or through releases from the Impofu Dam), turbidity levels can be expected to increase, especially in the upper and middle reaches. Although turbidity data were not available under freshwater inflow conditions, secchi disc readings reflected a decrease in visibility from about 1 m down to about 0.3 m during periods of significant inflow (see above).

6.5 Inorganic nutrients

The inorganic nutrient concentrations in the Kromme Estuary are largely a function of the concentrations in the source waters, i.e. the river and the sea. In the case of the Kromme and Geelhoutboom rivers, the major source of nutrients is considered to be the Kromme River (Scharler *et al.*, 1998; Scharler and Baird, 2000; Scharler and Baird, 2003).

Even so, much of the Kromme River catchment consists of Table Mountain sandstone, resulting in relatively little nutrient enrichment of the river water (Reddering, 1980). There are also no major anthropogenic sources of nutrients in the catchment, comprising largely undisturbed rural areas

and limited agriculture development (stock raising and grain cultivation). There are also no major urban or industrial development zones in the catchment (Scharler *et al.*, 1998).

Compared to other river systems in the area, inorganic nutrient concentrations in the Kromme River are therefore considered to be relatively low (Table C-8).

Table C-8 Estimated inorganic nutrient concentrations for the Kromme River compared with other river systems in the area (Data collected as part of this study; DWAF Eastern Cape, personal communication; Scharler *et al.*, 1998; Scharler and Baird, 2000), as well as typical concentration measured in seawater along the south coast (DWAF, 1995)

River	Average nutrient concentrations (µg/ℓ)				
	NO _x -N	NH ₄ -N	Total Dissolved Inorganic N	PO ₄ -P	SiO ₄ -Si
Kromme (Impofu Dam ≡ release)**	260	30	290	<10	2030
Kromme (overtopping)*	230	130	360	20	-
Kromme (high flows)*	500	100	600	100	-
Geelhoutboom	1400***	500*	-	660***	-
Swartkops	340	100	440	210	-
Sundays	940	80	1 020	20	-
Seawater along south coast****	83	-	-	37	146

* Derived from raw data collected from 1993 – 1995 (Scharler, unpublished data, pers.comm.)

** Referring to Figure C-8a

*** Data collected in Geelhoutboom River (Oyster Bay Road) from July – December 2004: 6 samples (DWAF Water Quality Management, Eastern Cape, pers. comm.)

**** Derived from South African Water Quality Guidelines for Coastal Marine Waters (DWAF, 1995)

Table C-8 indicates dissolved inorganic nitrogen (DIN) (i.e. NO_x-N and NH₄-N) and PO₄-P concentrations in inflow from the Geelhoutboom River are typically higher than in the Kromme River, as has been documented elsewhere (Scharler *et al.*, 2000). However, the influence of the Geelhoutboom River is usually limited to the estuarine section of that tributary and is not considered a vital nutrient supplier to the larger Kromme Estuary. For example, during November 1998, when there was some river flow into the Geelhoutboom tributary, the higher nutrient concentrations measured in the tributary did not seem to influence the main Kromme Estuary to a great extent (Scharler *et al.*, 2000). However, during periods of high river flow from the Geelhoutboom tributary it can be expected to introduce higher nutrients to the Kromme Estuary, albeit limited to the middle reaches.

Also, based on the above, it is important to note that even though major reductions in freshwater inflow to the estuary is likely to have markedly reduced inorganic nutrient inputs to the system, the Kromme Estuary probably always received river inflow that contained lower inorganic nutrient concentrations compared with systems such as the Swartkops and Sundays.

Low inorganic nutrient concentrations typically measured in marine waters off the south coast of South Africa, suggests that the sea is probably not a major source of inorganic nutrients to the Kromme system, i.e. confirming that the rivers are the main source (Table C-8).

To establish whether inorganic nutrients show variation with depth in the Impofu Dam, nutrient profiles were measured during November 1998, December 2004 and January 2005 (such information could be important for decision-making related to the depth of water releases) (Figure C-8a).

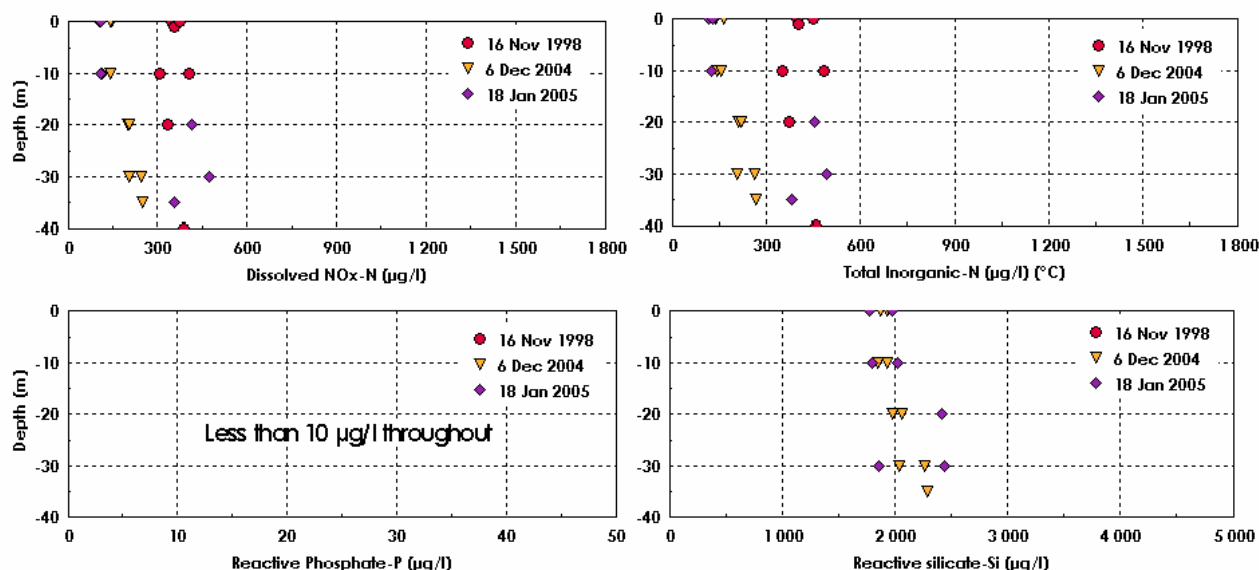


Figure C-8a Inorganic nutrient data collected from the Impofu Dam at the outlet (ME) about 1 km upstream (MF) – refer to Figure C-2b for sampling locations

In terms of NO_x-N and Total Inorganic N (DIN) results show no marked trends. This is similar to data collected from the Impofu Dam by DWAF (Figure C-8b), averaged concentrations from NO_x-N and DIN were around 260 and 290, respectively.

PO₄-P concentrations were depleted in waters from the Impofu Dam (Figure C-8a) which suggest that during a release the estuary will receive little if any PO₄-P from this source. These low concentrations are also reflected in the DWAF data set (Figure C-8b). 'Normal' concentrations in river inflow (as suggested by concentrations measured during overtopping) (Table C-8), were probably always low in PO₄-P concentrations – a function of the geological character of the catchment (mainly Table Mountain sandstone).

SiO₄-Si concentrations measured in the Impofu Dam during December 2004 and January 2005 increased slightly with depth, with average concentrations around 2000 µg/l (Figure C-8a). Although there were no measurements available on SiO₄-Si concentrations for 'normal' inflow (as mimicked by an overtopping event), it is expected for those concentrations to have been within the same order of magnitude as measured in the Impofu Dam.

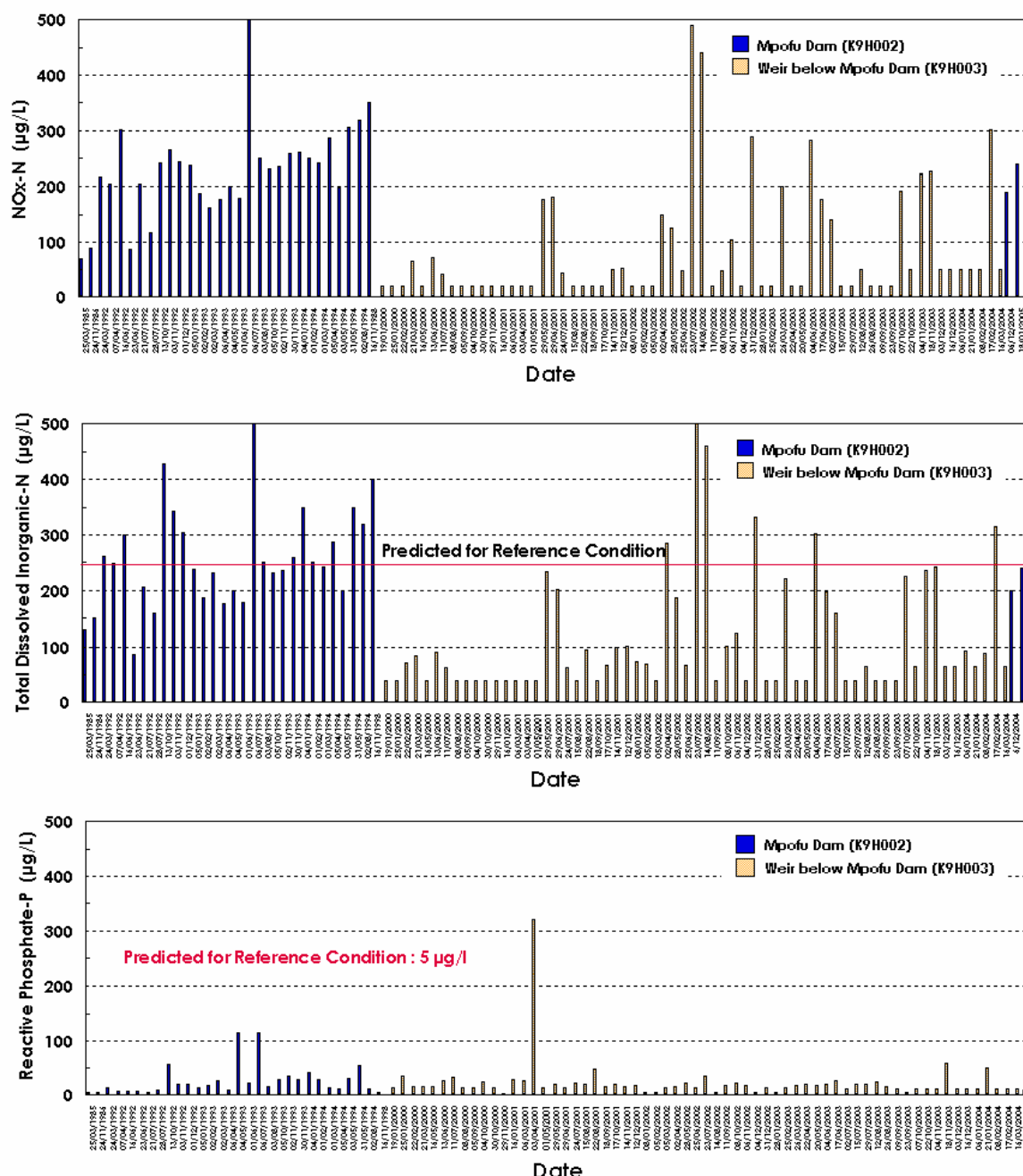


Figure C-8b Inorganic nutrient data collected by DWAF in the Impofu Dam (K9H002) and at the weir downstream of the Impofu Dam (K9H003) from 1985 to 2004. Also indicated are measurements collected as part of this study

To assess spatial and temporal variations in the nutrient distribution patterns in Kromme Estuary, the relationship between nutrient concentrations versus salinity was used. As salinity is usually a conservative parameter, the relationship between this and nutrient concentrations can be used as a means of characterising the distribution, transport and fate of other chemical variables within an estuary. The Kromme Estuary does, at times, experience hypersaline conditions, in which case salinity no longer behaves conservatively as a result of evaporation.

Nutrient concentrations versus salinity plots, measured during various studies on the Kromme Estuary are provided in Figure C-9a to C-9c.

Inorganic nutrient versus salinity plots derived for various studies conducted in the Kromme Estuary, showed a distinct difference in the distribution of inorganic nutrients during periods of no

(or very low) river inflow versus periods of river inflow, distinguishing between normal and high inflow (Figures C-9a – C-9c).

During periods of no (or very low) river inflow the estuary develops into a near homogenous water body, where salinities typically range between 35 and 39 ppt (Abiotic State 1 – refer to section 7). Depending on the duration of low/no flow conditions and evaporation rates, hypersaline conditions can develop in the middle and upper reaches. During such periods the dissolved inorganic nitrogen (DIN), $\text{PO}_4\text{-P}$ and SiO_4 concentrations are either low or depleted (Figure C-9a – C-9c).

These low (or depleted) inorganic nutrient concentrations also support the suggestion by Scharler and Baird (2000) that during periods when the main nutrient supplier (i.e. the Kromme River) is 'switched off', the standing stock of bacteria and micro-zooplankton in the estuary is probably too low to account for any efficient recycling in this system. Low primary productivity during such periods also confirms the latter.

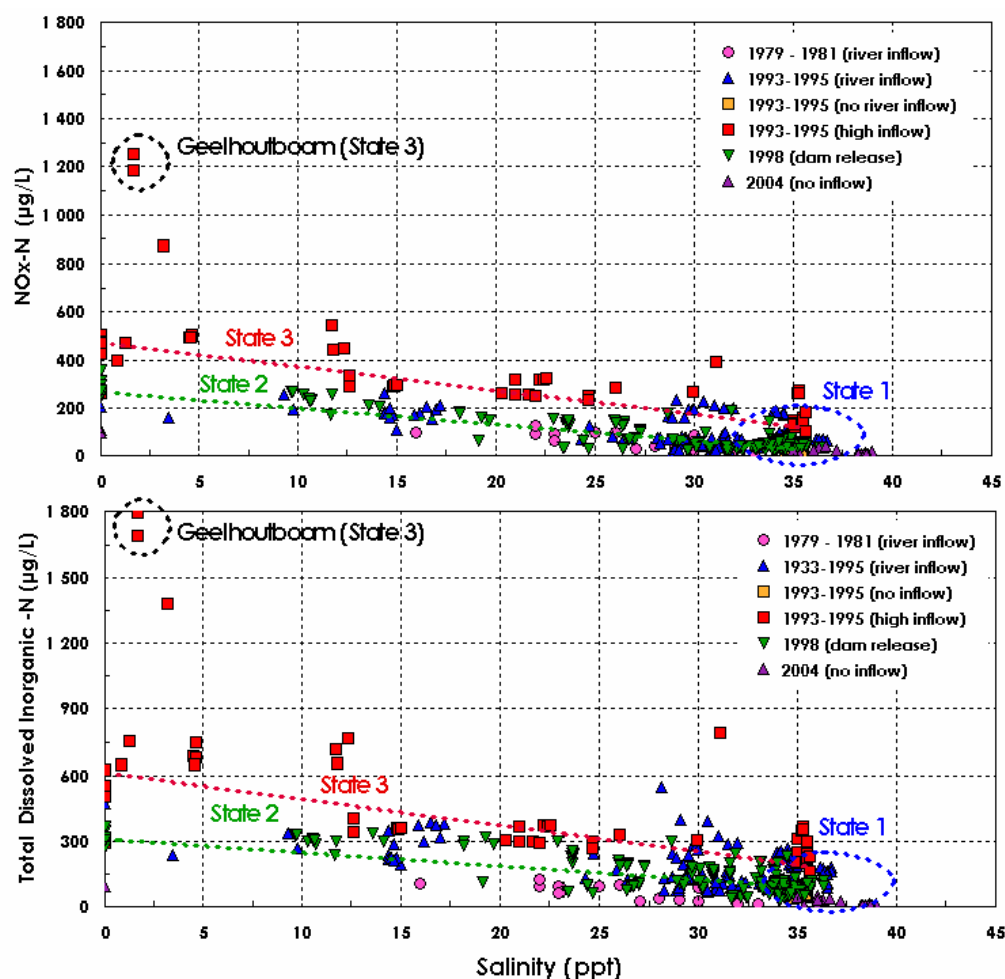


Figure C-9a Relationship between $\text{NO}_x\text{-N}$ and DIN concentrations versus salinity measured in the Kromme Estuary

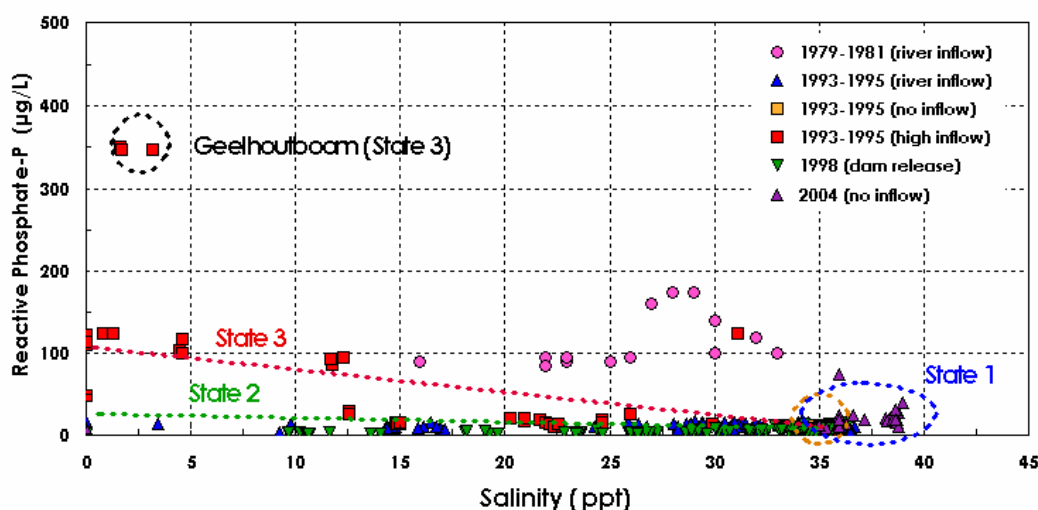


Figure C-9b Relationship between $\text{PO}_4\text{-P}$ (DIP) concentrations versus salinity measured in the Kromme Estuary

NOTE:

$\text{PO}_4\text{-P}$ concentrations in river inflow appeared to have decreased from early 1980s to late 1990s. These contradicting changes could not be explained – increase in inorganic nutrient concentrations would typically be associated with increased agricultural and urban (sewage discharges) developments in a catchment, which is not the case in this instance (Figure C-9b).

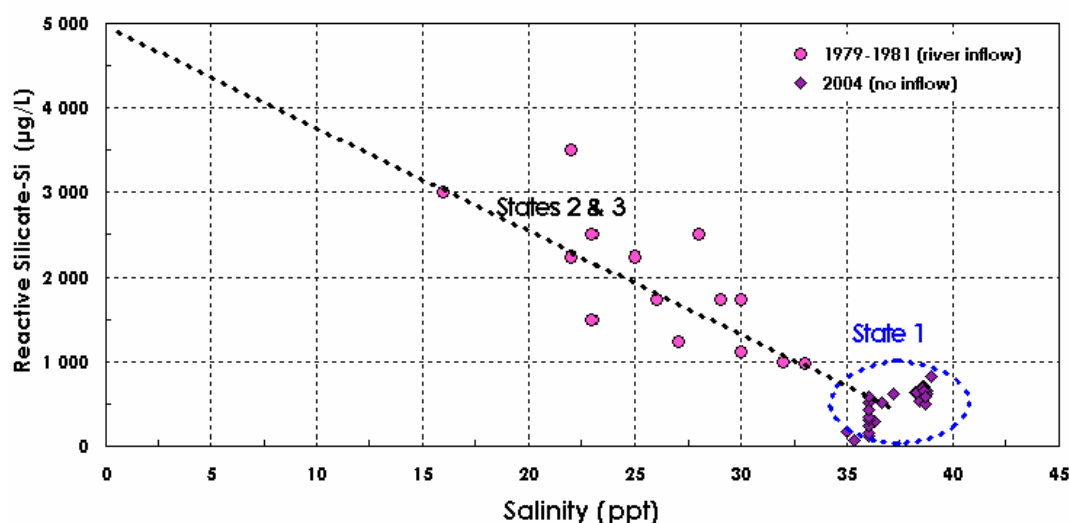


Figure C-9c Relationship between $\text{SiO}_4\text{-Si}$ concentrations versus salinity measured in the Kromme Estuary

For the purposes of this Ecological Reserve Study, the inorganic nutrient concentrations in the Kromme Estuary during extended periods of no (or very low) river inflow (Abiotic State 1), is estimated to be as follows:

Dissolved Inorganic Nitrogen (DIN)	<50 $\mu\text{g/l}$, however during the initial stages of this state concentrations can be higher, between 100-200 $\mu\text{g/l}$
Dissolved Reactive Phosphate-P ($\text{PO}_4\text{-P}$)	<10 $\mu\text{g/l}$
Dissolved Reactive Silicate ($\text{SiO}_4\text{-Si}$)	200 – 900 $\mu\text{g/l}$

During periods of normal (seasonal) river inflow, a salinity gradient develops in the estuary, albeit strongly stratified in the upper reaches (Abiotic State 2 – refer to section 7). During these periods, a good linear relationship exists between inorganic nutrient concentrations and salinity (Figure C-9a – C-9c) (Scharler and Baird, 2000). Such linear relationships indicate that the inorganic concentrations along the estuary are largely a function of the extent of mixing between river and seawater, as well as the concentration of a particular nutrient in the two sources.

A once-off set of inorganic nitrogen and $\text{PO}_4\text{-P}$ data collected from the Kromme Estuary at a time when the estuary was almost completed fresh (salinities at the mouth down to 11 ppt) (Scharler, unpublished data), were markedly higher than what was measured under normal (seasonal) inflow conditions (Figure C-9a and C-9b) (Scharler, unpublished data). The condition measured was considered to be representative of Abiotic State 3 (refer to Chapter 7). It therefore appears that during periods of high inflow e.g. flows occurring at intervals of between 5 and 7 years, inorganic N and $\text{PO}_4\text{-P}$ concentrations in river inflow to the estuary is markedly higher compared with normal (seasonal) inflow conditions.

Considering that inorganic nutrient concentrations and salinities in the Kromme Estuary usually show strong linear correlations, during periods of river inflow concentrations of inorganic nutrients at a particular reach of the estuary can be estimated from the salinity at that location, as well as the concentration in the source waters.

For the purposes of this Ecological Reserve Study and based on the above assessment, the relationship between inorganic nutrient concentrations versus salinity for Abiotic State 2 and Abiotic State 3, respectively, are estimated to be as follows:

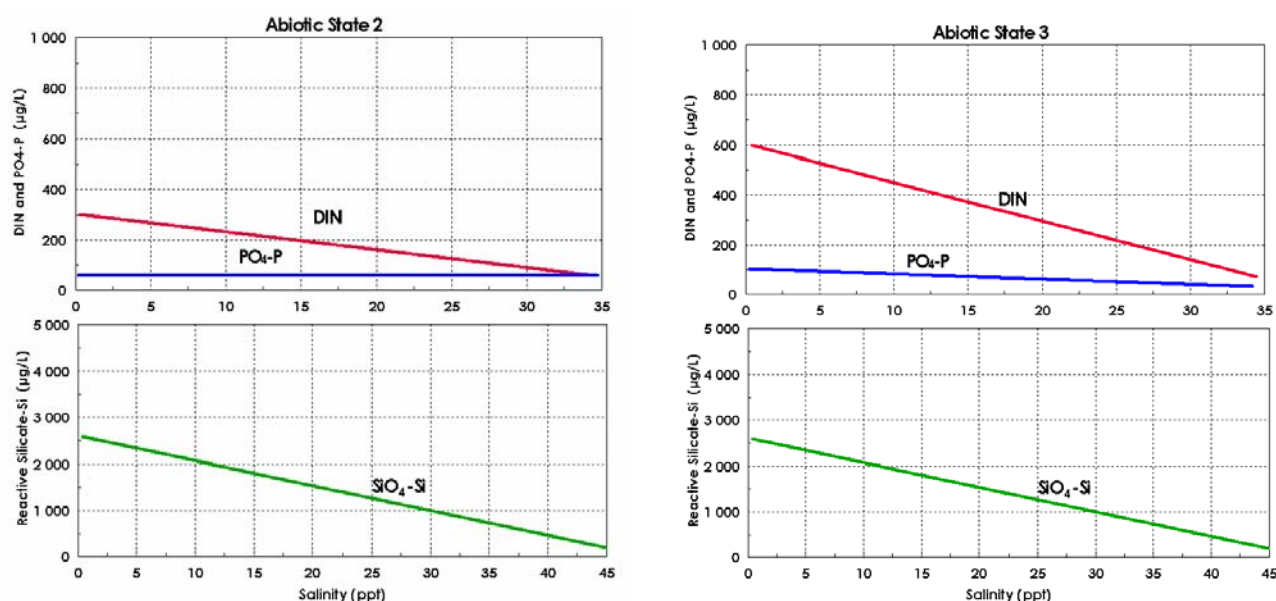


Figure C-9d Relationship between inorganic nutrient concentrations versus salinity for Abiotic State 2 and Abiotic State 3

To orientate oneself in terms of the spatial distribution of nutrient concentrations along the estuary during periods of river inflow, the nutrient versus salinity plots should be compared with corresponding longitudinal salinity profiles.

6.6 Organic nutrients

The only available data on organic nutrients for the Kromme Estuary, was the data on particulate organic carbon and nitrogen (POC and PON) collected during 1993-1995 (Scharler *et al.*, 1998; Scharler and Baird, 2003) and 1998 (Scharler, unpublished data) (Figure C-10a). Concentrations measured in the Impofu Dam during 1998 are illustrated in Figure C-10b.

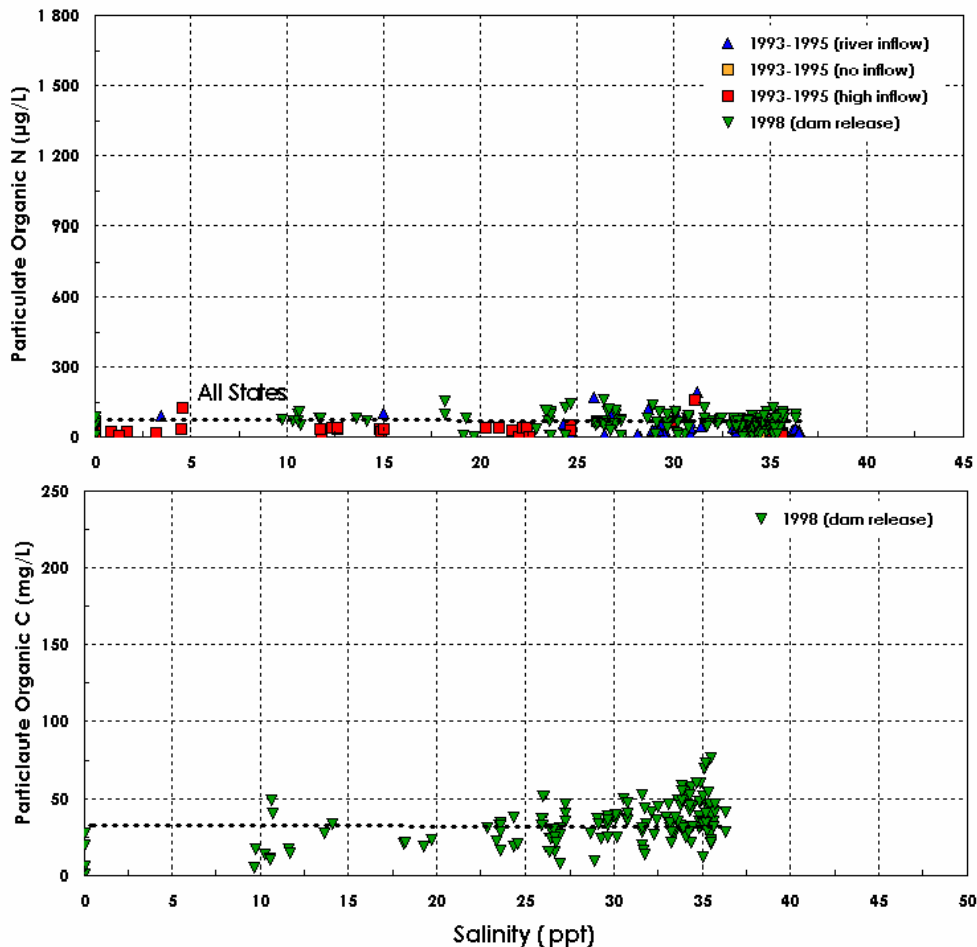


Figure C-10a Relationship between particulate organic nitrogen (PON) and particulate organic carbon (POC) concentrations versus salinity measured in the Kromme Estuary

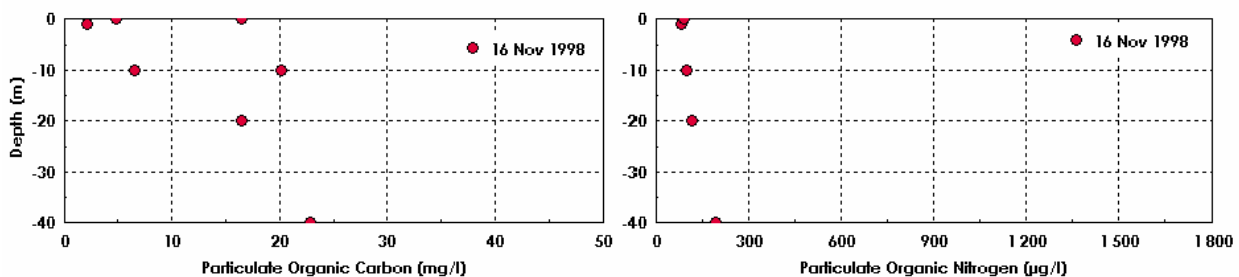


Figure C-10b Relationship between particulate organic nitrogen (PON) and particulate organic carbon (POC) concentrations versus water depth measured in the Impofu Dam in November 1998

Results indicate that both PON and POC concentrations in the estuary appear to be relatively uniform through the system and different Abiotic States. PON concentrations were generally $<100 \mu\text{g/l}$, while POC were below 50 mg/l . Concentrations measured in the Impofu Dam during a once-off survey in November 1998 reflected these ranges.

It is however, expected that the dams on the Kromme River are currently trapping a significant component of PON and POC (either decomposed or settling to the bottom of the dam). Therefore, in the pre-dam situation (Reference Condition) it is expected that PON and POC loading from the

Kromme catchment into the Kromme Estuary would have been markedly higher compared to the Present State, particularly during Abiotic State 3.

7. ABIOTIC STATES OF KROMME ESTUARY AND GEELHOUTBOOM

7.1 Kromme Estuary

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

State	River inflow
State 1: Marine	< 1 m ³ /s
State 2: Salinity Gradient	1 – 8 m ³ /s
State 3: Fresh	> 8 m ³ /s

The transitions between the different states will not be instantaneous, but will gradually take place and time delays will play a role. The estimated occurrences of the different states by direct correlation with river flow will nevertheless be reasonably accurate and can be used to assess the ecological consequences of different Scenarios.

7.1.1 State 1: Marine

Typical flow patterns: Flow rates are usually less than 1 m³/s. At present, measured flows during this state are often less than 0.2 m³/s, which could potentially result in the hypersaline conditions.

State of the mouth: The mouth is permanently open.

Flood plain inundation patterns: This state does not result in inundation of the flood plain in the lower reaches.

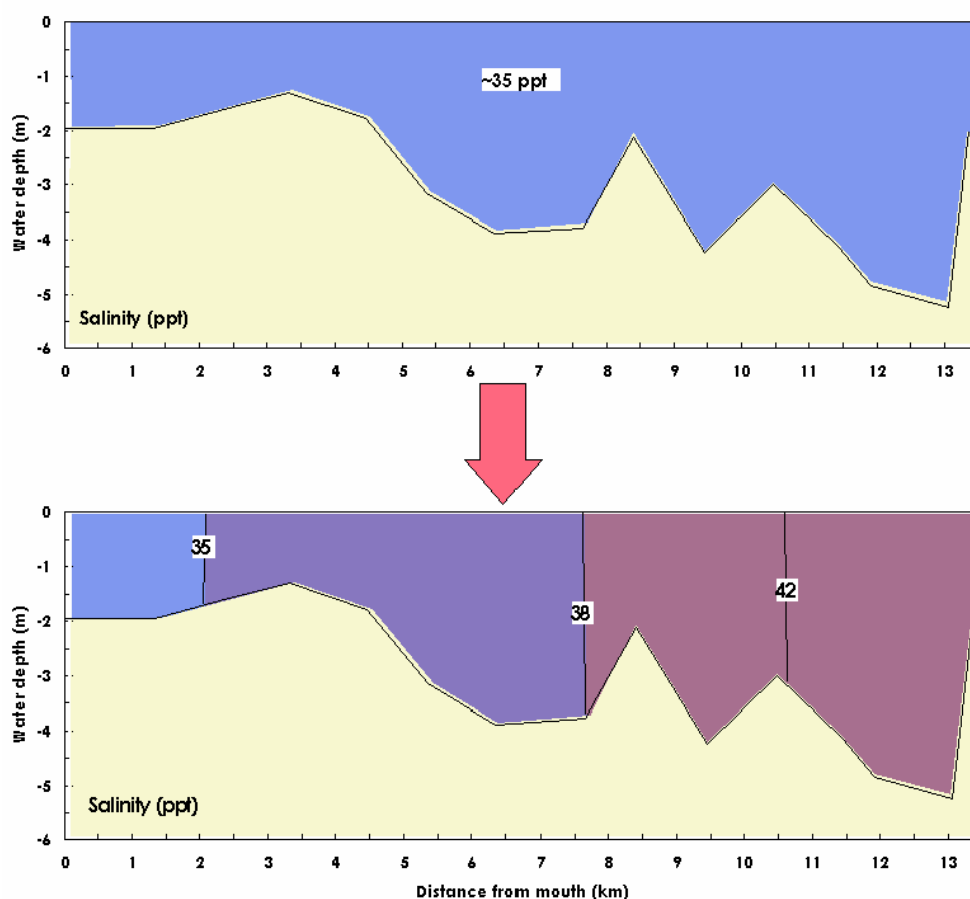
Amplitude of tidal variation: Tidal variation could typically range between 0.3 m (neap tide) and 1.5 m (spring tide).

Retention times of water masses: There will be high retention time of the deep water areas upstream of the confluence with the Geelhoutboom tributary. In the lower reaches, strong tidal flushing will result in much shorter residence times, typically one to two tidal cycles.

Total volume: The total volume on average tide is estimated at 3 x 10⁶ m³.

Salinity distributions in the estuary: During the marine state the estuary becomes a near homogenous water body with salinities close to that of seawater (~ 35 ppt). When river inflow into the estuary drops to below 0.2 m³/s for more than 2 consecutive months during summer, hypersaline conditions start to develop in the middle and upper reach. Salinities in the lower reaches, however, still remain similar to seawater due to tidal flushing.

The range of salinity distribution patterns under the Marine State is illustrated as follows:



System variables: Levels of system variables in the Kromme Estuary under State 1, Marine are estimated as follows:

Variable	Estimated concentration
Temperature (°C)	Temperatures in the Kromme Estuary are expected to show a strong seasonal pattern, with summer temperatures ranging between 20–25 °C and winter temperatures between 13 and 16 °C.
pH	pH values in the Kromme Estuary are expected to remain within the range of seawater (~8).
Turbidity (NTU)	Turbidity levels are expected to be low in the Kromme Estuary. Secchi disc readings ~ 1 m.
Dissolved oxygen (mg/l)	The Kromme Estuary should generally be well-oxygenated. Concentrations in the deeper water (e.g. in the upper reaches) may drop due to long residence times and organic decay, but levels are not expected to drop below 5 mg/l.

Inorganic Nutrients: Concentration in the Kromme Estuary during extended periods of no (or very low) river inflows are estimated to be as follows:

Dissolved Inorganic Nitrogen (DIN)	<50 µg/l, during the initial stages of this state concentrations can be slightly higher, between 100 - 200 µg/l
Dissolved Reactive Phosphate-P (PO ₄ -P)	<10 µg/l
Dissolved Reactive Silicate (SiO ₄ -Si)	200 – 900 µg/l

7.1.2 State 2: Salinity Gradient

Typical flow patterns: River inflow rates are usually between 1 and 8 m³/s.

State of the mouth: The mouth is permanently open.

Flood plain inundation patterns: This state does not result in inundation of the flood plain in the lower reaches.

Amplitude of tidal variation: Tidal variation could typically range between 0.3 m (neap tide) and 1.5 m (spring tide).

Retention times of water masses: Under the higher flow range of this State (4-8 m³/s), the retention time of water throughout the estuary is expected to be low, about 1-3 days. However, bottom waters in the deeper section of the upper reaches may still be subject to longer residence times. Should the higher inflow rates persist for longer than a few weeks these bottom waters will also be flushed, resulting in short residence times.

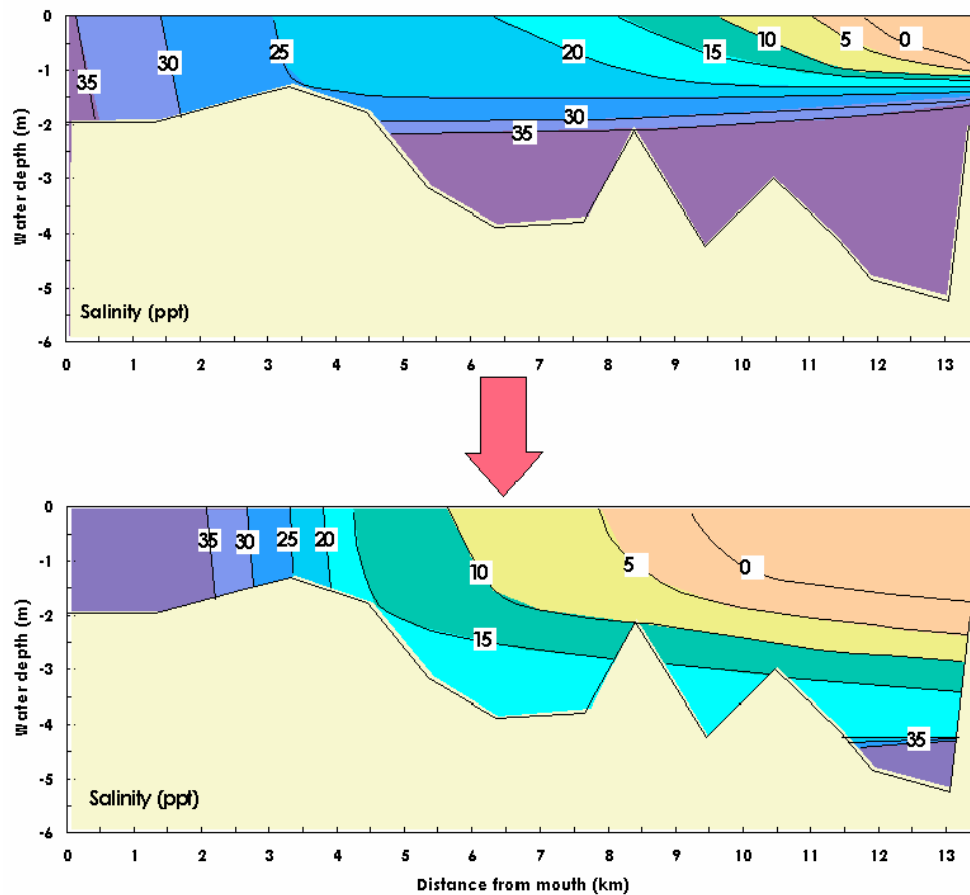
Under the lower flow range of this State (1-3 m³/s), the retention time of surface waters in the middle and upper reaches may still be around 3–7 days, while the bottom water in the deeper section of these reaches will tend to still be long, similar to that of State 1: Marine State. In the lower reaches, strong tidal flushing will result in much shorter residence times, typically one to two tidal cycles.

Total volume: The total volume is 3 x10⁶ m³.

Salinity distributions in the estuary: A salinity gradient exists in the estuary during this State, the extent depends on the flow rate within the range and the duration. Due to the bathymetry of the estuary, the salinity distribution patterns is characterised by strong vertical stratification in the deeper areas of the middle and upper reaches.

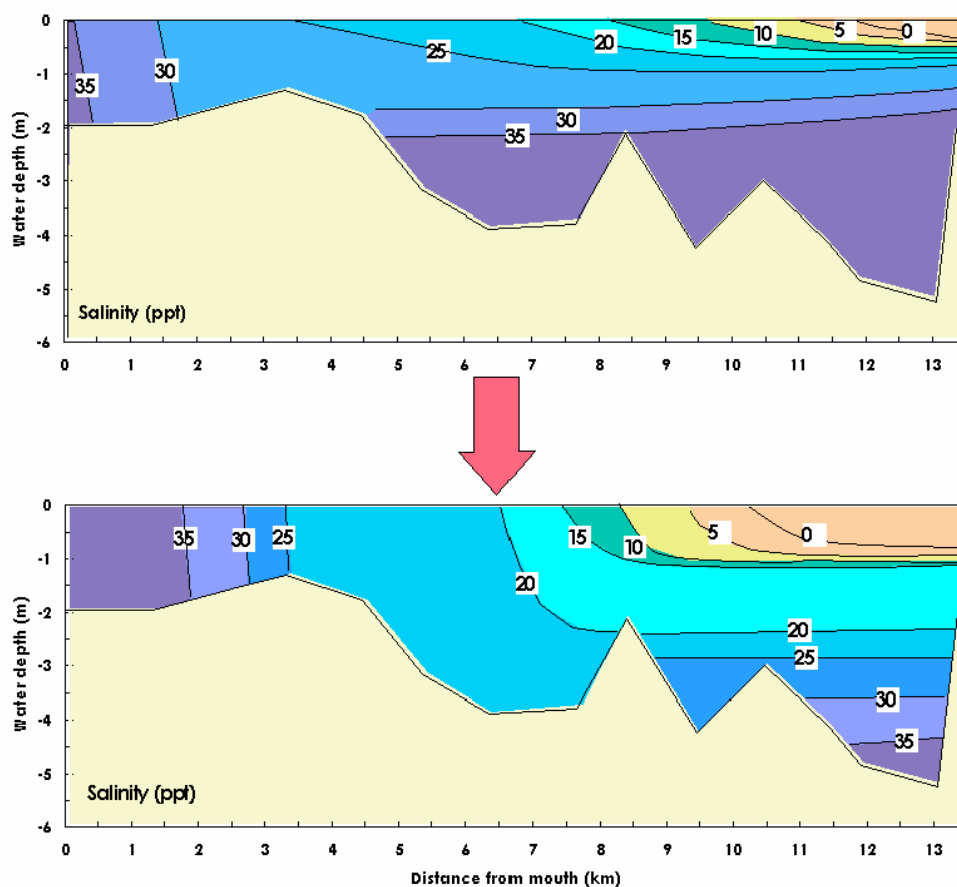
Under the higher flow range of this State (4-8 m³/s), strong vertical stratification in the middle and upper reaches will initially maintain high salinities in bottom waters. However, as higher flows persist, most of the saline waters from the deeper areas will also be removed (through scouring). Due to strong tidal flushing (especially during spring tides), a distinct horizontal salinity gradient also develops in the estuary, concentrated in the lower to middle reaches.

The range of salinity distribution patterns under higher flow ranges of State 2: Salinity Gradient is illustrated as follows:



Under the lower flow range of this State ($1-3 \text{ m}^3/\text{s}$), strong vertical stratification in the upper to middle reaches will maintain high salinities in bottom waters. Freshwater conditions are limited largely to the surface waters of the upper to middle reaches. Strong tidal flushing maintains well-mixed saline conditions in the lower to middle reaches of the estuary.

The range of salinity distribution patterns under higher flow ranges of State 2: Salinity Gradient is illustrated as follows:

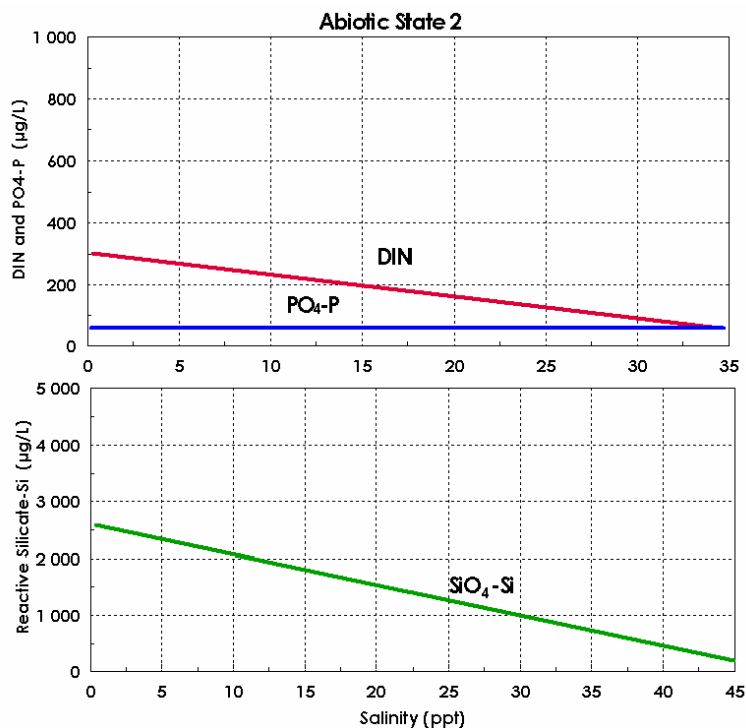


System variables: Levels of system variables in the Kromme Estuary under State 2, Salinity Gradient, are estimated as follows:

Variable	Estimated concentration
Temperature (°C)	The temperature regime of the Kromme Estuary is expected to show a strong seasonal pattern, with summer temperatures ranging between 20–25 °C and winter temperatures between 13 and 16 °C. Bottom releases from the Dam during summer months, may result in lower temperatures in the upper reaches of the estuary (14-18°C) unless the retention time between the dam and the head of the estuary is long enough for these waters to warm.
pH	pH values in the Kromme Estuary are expected to remain within the range 7 to 8.5, with the lower ranges being associated with fresher (upper) reaches, and with the higher range in the more saline (middle and lower) reaches.
Turbidity (NTU)	Turbidity concentrations in the Kromme Estuary are generally expected to be low. However, during periods of higher freshwater inflow (either from the Geelhoutboom tributary or through releases from the Impofu Dam), turbidity levels can be expected to increase, especially in the upper and middle reaches. Although turbidity data were not available under freshwater inflow conditions, secchi disc readings reflected a decrease in visibility from about 1 m down to about 0.3 m during periods of significant inflow.

Variable	Estimated concentration
Dissolved oxygen (mg/l)	The Kromme Estuary should generally be well-oxygenated. Concentrations in the deeper water (e.g. in the upper reaches) can drop during the drier summer periods, as a result of long residence times and organic decay, but levels are not expected to drop below 5 mg/l. Results from the Impofu Dam suggest that releases from the bottom waters of the dam may result in the inflow to the estuary being slightly less oxygenated (6–4 mg/l) than from a surface release (8–10 mg/l), unless sufficient aeration occurs between the dam and the estuary.

Inorganic Nutrients: The relationship between inorganic nutrient concentrations versus salinity is estimated to be as follows during State 2, Salinity Gradient:



To orientate oneself in terms of the spatial distribution of nutrient concentrations along the estuary during periods of river inflow, the nutrient versus salinity plots should be compared with corresponding longitudinal salinity profiles.

7.1.3 State 3: Fresh

Typical flow patterns: River inflow rates are usually greater than 8 m³/s.

State of the mouth: The mouth is wide open.

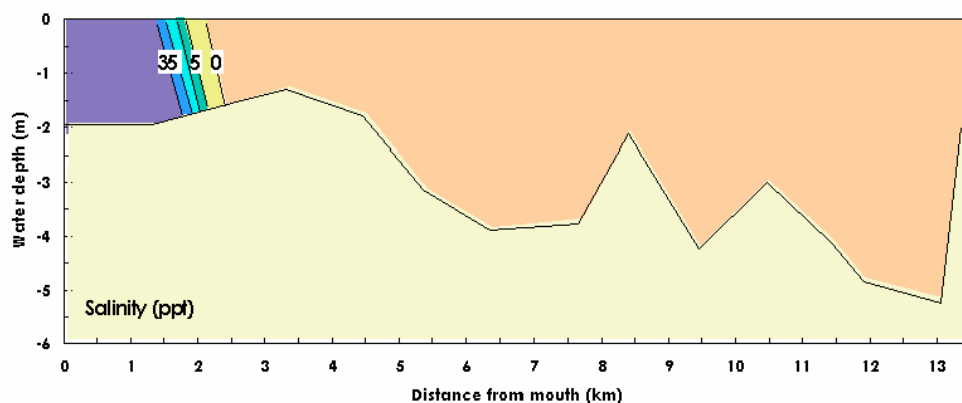
Flood plain inundation patterns: Inundation of the flood plain in the lower reaches of the Kromme Estuary and Geelhoutboom tributary, particularly during flood events.

Amplitude of tidal variation: Tidal variation could typically range between 0.3 m (neap tide) and 1.5 m (spring tide).

Retention times of water masses: Under this State the retention time of water will be low, about 1-2 days. In the lower reaches, strong tidal flushing will result in much shorter residence times, typically one to two tidal cycles.

Total volume: The total volume is $3 \times 10^6 \text{ m}^3$.

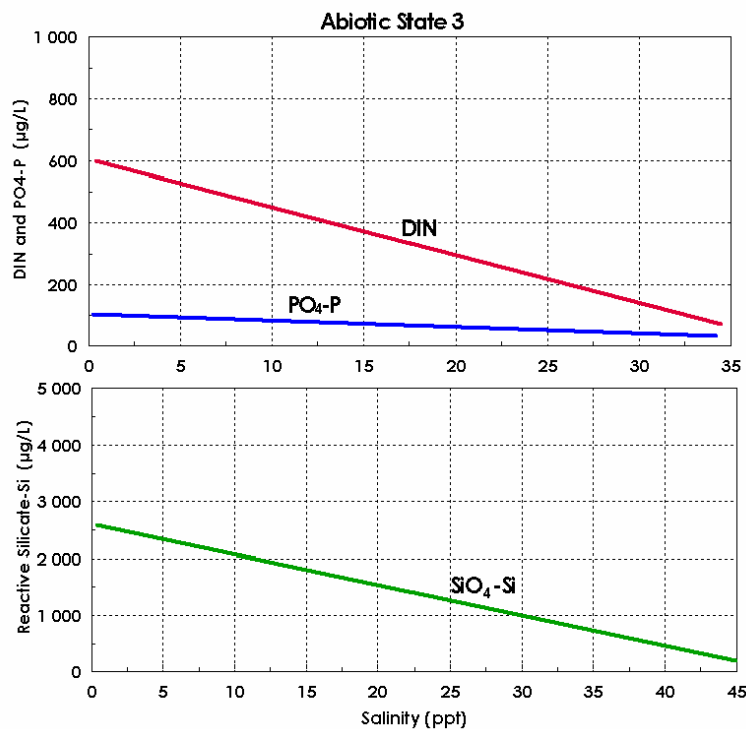
Salinity distributions in the estuary: The estuary is fresh throughout with a small horizontal salinity gradient near the mouth due to intrusion of saline water, particularly during spring high tides. A typical salinity distribution pattern during State 3 is illustrated as follows:



System variables: Levels of system variables in the Kromme Estuary under the State 3, Salinity Gradient, are estimated as follows:

Variable	Estimated concentration
Temperature (°C)	The temperature regime of the Kromme Estuary is expected to show a strong seasonal pattern, with summer temperatures ranging between 20–25 °C and winter temperatures between 13 and 16 °C. Bottom releases from the Dam during summer months, may result in lower temperatures in the upper reaches of the estuary (14–18°C) unless the retention time between the dam and the head of the estuary is long enough for these waters to warm.
pH	pH values in the Kromme Estuary are expected to remain within the range 7 to 8.5, with the lower range being associated with fresher (upper) reaches and the higher range within the more saline (middle and lower) reaches.
Turbidity (NTU)	Turbidity concentrations in the Kromme Estuary are generally expected to be low. However, during periods of higher freshwater inflow (either from the Geelhoutboom tributary or through releases from the Impofu Dam), turbidity levels can be expected to increase, especially in the upper and middle reaches. Although turbidity data were not available under freshwater inflow conditions, secchi disc readings reflected a decrease in visibility from about 1 m down to about 0.3 m during periods of significant inflow.
Dissolved oxygen (mg/l)	The Kromme Estuary should generally be well-oxygenated. Concentrations in the deeper water (e.g. in the upper reaches) can drop during the drier summer periods, as a result of long residence times and organic decay, but levels are not expected to drop below 5 mg/l. Results from the Impofu Dam suggest that releases from the bottom waters of the dam may result in inflow to the estuary being slightly less oxygenated (6–4 mg/l) than from a surface release (8–10 mg/l), unless sufficient aeration occurs between the dam and the estuary.

Inorganic Nutrients: The relationship between inorganic nutrient concentrations versus salinity is estimated to be as follows during State 3, Fresh:



To orientate oneself in terms of the spatial distribution of nutrient concentrations along the estuary during periods of river inflow, the nutrient versus salinity plots should be compared with corresponding longitudinal salinity profiles.

7.2 Geelhoutboom Tributary

Based on the assessments and evaluations conducted for this specialist report, three Abiotic States were derived for the Geelhoutboom Tributary, of which the occurrence and duration varies depending on river inflow rate:

	River inflow
State 1: Homogenous water body, similar to middle reaches of Kromme	< 0.08 m ³ /s
State 2: Salinity Gradient	0.08 - 1 m ³ /s
State 3: Fresh	> 1 m ³ /s

The transitions between the different states will not be instantaneous, as the resultant salinity is both dependent on a flow rate and duration of the flows. Nonetheless, the estimate of the occurrences of the different states by direct correlation with river flow will be reasonably accurate and can be used to assess the ecological consequences of different Scenarios.

7.2.1 State 1: Homogenous water body, similar to middle reaches of Kromme

Typical flow patterns: River inflow rates usually less than 0.08 m³/s.

Salinity distributions in the estuary: During this state the Geelhoutboom becomes a near-homogenous water body (i.e. no significant salinity gradients). The salinities in the Geelhoutboom are driven by that of the middle reaches of the Kromme Estuary. Salinities can vary, depending on conditions (i.e. the Abiotic State) in the Kromme Estuary. For example when the Kromme is in State 1, salinities in the Geelhoutboom will be around 35 ppt, while if the Kromme Estuary is in State 3, it will be near fresh.

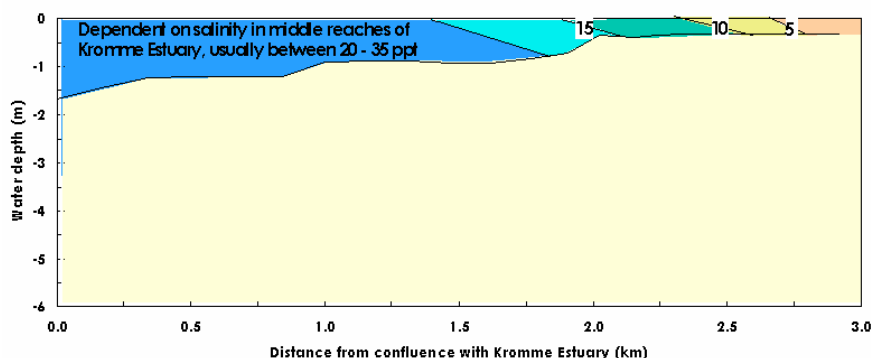
System variables: Similar to that of the middle reaches of the Kromme Estuary which, in turn, will depend on the Abiotic State in the Kromme at any one time.

Inorganic Nutrients: Similar to that of the middle reaches of the Kromme Estuary which, in turn, will depend on the Abiotic State in the Kromme at any one time.

7.2.2 State 2: Salinity Gradient

Typical flow patterns: Flow rates range between 0.08–1.0 m³/s

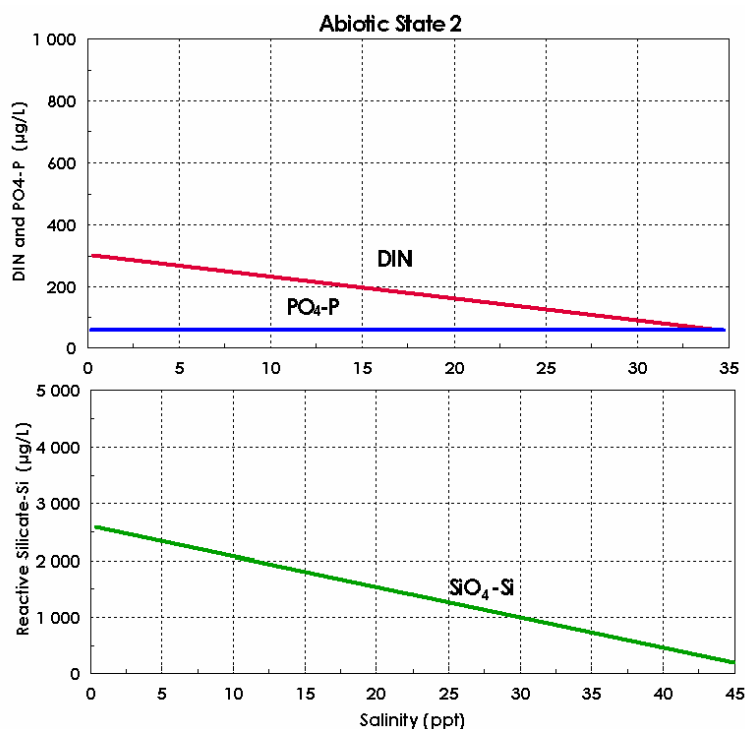
Salinity distributions in the estuary: During this state a salinity gradient develops in the Geelhoutboom tributary as illustrated below:



System variables: Levels of system variables in the Geelhoutboom Tributary under the State 2, Salinity Gradient, is estimated as follows:

Variable	Estimated concentration
Temperature (°C)	The temperature regime of the Geelhoutboom tributary is expected to show a strong seasonal pattern, with summer temperatures ranging between 20–25°C and winter temperatures between 13 and 16°C.
pH	pH values are expected to remain within the range 7 to 8.5, with the lower range being associated with fresher (upper) reaches and higher range with more saline (middle and lower) reaches.
Turbidity (NTU)	Higher freshwater inflow is expected to result in increased turbidity levels, especially in the upper and middle reaches. Although turbidity data were not available under freshwater inflow conditions, secchi disc readings indicate a decrease in visibility from about 1 m down to about 0.3 m during periods of significant inflow (i.e. in the fresher area).
Dissolved oxygen (mg/l)	Should generally be well-oxygenated, being a shallow system.

Inorganic Nutrients: No data is available for the Geelhoutboom Tributary for this State, but it is estimated to be similar to that for State 2 of the Kromme Estuary:



7.2.3 State 3: Fresh

Typical flow patterns: Flow rates usually greater than 1.0 m³/s.

Salinity distributions in the estuary: During this state the Geelhoutboom tributary is largely fresh, with limited or no penetration of saline water at the confluence with the Kromme Estuary. Where waters do penetrate at the Kromme confluence, the salinity (and abiotic) characteristics will depend the State of the Kromme at the time.

System variables: Levels of system variables in the Geelhoutboom tributary under State 3, Fresh, is estimated as follows:

Variable	Estimated concentration
Temperature (°C)	The temperature regime of the Geelhoutboom tributary is expected to show a strong seasonal pattern, with summer temperatures ranging between 20–25 °C and winter temperatures between 13 and 16 °C.
pH	pH values in the Geelhoutboom tributary are expected to remain within the range 7 to 8.5, with the lower range being associated with fresher (upper) reaches and higher range with more saline (middle and lower) reaches.
Turbidity (NTU)	High freshwater inflow is expected to result in increased turbidity levels through the Geelhoutboom tributary. Secchi disc readings are expected to be < 0.3 m.
Dissolved oxygen (mg/l)	Should generally be well-oxygenated, being a shallow system.

Inorganic Nutrients: Concentration in the Geelhoutboom Tributary during high river inflow is estimated as follows:

Dissolved Inorganic Nitrogen (DIN)	1700 µg/l
Dissolved Reactive Phosphate-P (PO ₄ -P)	300 µg/l
Dissolved Reactive Silicate (SiO ₄ -Si)	2000 - 3000 µg/l

8. OCCURRENCE AND DURATION OF ABIOTIC STATES FOR SELECTED SCENARIOS

8.1 Description of Scenarios

A precursory screening of the Kromme Estuary indicated that it is currently functioning as an “arm of the sea” and therefore likely to be of a low Present Ecological Health Status. As the water supply from Port Elizabeth comes from its catchment, it was deemed unlikely that enough freshwater would be allocated to the system to restore it to a near natural state.

A study approach (refer to Attachment B^C for further details) was therefore followed:

- Describe the abiotic conditions (focusing on salinity as a conservative indicator) that would improve the Kromme Estuary’s health significantly. This was done for the various biotic components looking at aspects such as increased species diversity and changes in abundance and community composition. For example, the majority of the biological components required a salinity of ~20 ppt for a month (October or November) in the middle to upper reach of the estuary. Potential additional benefits to the ecology could be gained by increasing the period from one to two months or pulsing the system in October and January.
- Three-dimensional numerical modelling was then used to select the most efficient flows to create the desired habitat conditions required by the biota. For example, a freshwater inflow of 5m³/s for ~6 days, followed by a maintenance flow of 1m³/s was the most efficient flow to generate the above stated criteria.
- The optimum flow ranges were used in turn to develop the different simulated monthly runoff Scenarios evaluated in the Ecological Reserve Study, e.g. Scenario 1, 2 and 5.
- Simulated Monthly Runoff Scenarios were also developed to evaluate the roll and contribution of the Geelhoutboom Tributary to the overall health status of the Kromme Estuary. For example, looking at the Geelhoutboom River Class C/B release to the system (Scenario 3 and 4).

Simulated monthly runoff was supplied to the estuarine team by Mr A Sparks, Ninham Shand Consulting Engineers. A summary of the various simulated monthly runoff Scenarios is provided Table C-9. Note that there are a number of iterations around the Present State flows for both the Kromme Estuary and the Geelhoutboom tributary.

Table C-9 A summary of the various simulated monthly runoff Scenarios used in this Ecological Reserve Study

Name	Kromme Estuary	Geelhoutboom	Volume (10 ⁶ m ³ /year)
Reference	Reference	Reference	97
Present	Present Flows (2 million m ³ release)	Present	35
Scenario 1	5 Million m ³ flow release (Nov)	Present	38
Scenario 2	10 Million m ³ flow release (Oct and Jan)	Present	43
Scenario 3	Present Flows (2 million m ³ release)	Inflow for River Class C/D	35
Scenario 4	5 Million m ³ flow release (Nov)	Inflow for River Class C/D	38
Scenario 5	7.5 Million m ³ flow release (Oct - Nov)	Present	41

Due to the complexity of the abiotic drivers it was deemed necessary to separate the evaluation for the main Kromme Estuary and the Geelhoutboom tributary. This separation is not necessary from a biotic perspective, as the biotic components of the estuary function as a holistic system.

The overall confidence in the hydrology is **Low** as limited accurate runoff data was available to base the hydrological assessment on.

To assess the occurrence and duration of the different Abiotic States selected for the estuary during the different Scenarios, a number of techniques were used, including:

- Colour coding was used for the full tables of simulated monthly river flow reaching the estuary for each scenario to highlight the occurrences of the different States related to the different flow ranges. The median and 10%ile low flows for each month are summarised on the bottom of each table, as well as the occurrences of the four states for each month for the 73-year period.
- Summary tables of the occurrences of different flows at increments of 10%ile are listed separately to provide a quick comprehensive overview.
- Separate graphs are added to highlight the occurrences of the different states for each Scenario for median flows and for 10%ile low flows reflecting drought conditions.

8.2 Present State

i. Seasonal variability in river inflow

Monthly simulated runoff data (73-year period) for the Present State of the Kromme Estuary and Geelhoutboom tributary are provided in Tables C-10 and C-11 respectively. A summary of the flow distributions (mean monthly flows in m³/s), derived from the simulated data set, is provided below (hatched months represent flows less than 0.2 m³/s when hypersaline conditions can potentially develop):

Kromme: Summary of flow distributions for Present State

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	13.60	25.85	5.08	4.70	2.48	3.67	4.41	26.39	14.37	16.56	22.96	25.98
90%ile	4.50	1.72	0.56	0.28	0.40	0.45	0.48	1.48	2.66	1.97	2.98	10.39
80%ile	1.79	0.82	0.35	0.23	0.24	0.31	0.25	0.49	0.56	0.44	1.09	3.08
70%ile	0.76	0.48	0.28	0.19	0.18	0.22	0.21	0.22	0.32	0.31	0.43	0.61
60%ile	0.47	0.39	0.23	0.16	0.16	0.17	0.17	0.18	0.21	0.26	0.36	0.41
50%ile	0.36	0.30	0.19	0.15	0.13	0.14	0.14	0.15	0.18	0.22	0.29	0.35
40%ile	0.31	0.27	0.18	0.14	0.11	0.13	0.13	0.14	0.15	0.20	0.25	0.26
30%ile	0.25	0.24	0.17	0.13	0.11	0.12	0.11	0.11	0.13	0.17	0.20	0.22
20%ile	0.22	0.22	0.15	0.12	0.11	0.11	0.10	0.10	0.11	0.13	0.17	0.17
10%ile	0.19	0.19	0.14	0.11	0.10	0.10	0.09	0.09	0.08	0.11	0.14	0.16
1%ile	0.11	0.13	0.11	0.09	0.07	0.03	0.07	0.06	0.06	0.05	0.09	0.10

Table C-10 Monthly simulated runoff data in m³/s (73-year period) for the Present State into the Kromme Estuary

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1927	0.15	0.17	0.13	0.10	0.11	1.08	0.54	0.16	0.13	0.11	0.15	0.26
1928	0.31	0.46	0.24	0.14	0.11	0.10	0.07	0.10	0.11	0.24	0.25	0.46
1929	0.36	0.25	0.15	0.11	0.25	0.22	0.16	0.14	0.18	0.18	0.29	0.31
1930	0.35	0.25	0.14	0.15	0.12	0.12	0.10	0.09	0.08	0.16	0.17	0.51
1931	1.24	0.62	0.77	1.97	0.82	0.23	0.15	0.12	0.13	0.18	0.17	27.14
1932	9.73	1.59	0.35	0.15	0.12	0.13	0.13	2.67	2.45	0.68	19.44	3.63
1933	0.33	0.71	0.24	0.16	0.16	0.19	0.13	0.12	0.11	0.27	0.26	0.20
1934	3.87	0.51	0.18	0.11	0.11	0.11	0.13	24.40	7.66	1.92	4.67	2.21
1935	0.66	1.07	0.30	0.17	0.11	0.12	0.10	0.23	0.18	0.19	0.19	0.17
1936	0.33	1.98	0.50	0.17	0.12	0.14	0.10	0.09	0.13	0.16	0.17	0.22
1937	0.22	0.23	0.19	0.15	0.11	0.09	0.11	0.14	0.13	0.13	0.13	0.17
1938	0.21	0.30	0.18	0.12	0.45	0.41	0.24	0.17	0.14	0.16	0.92	0.63
1939	0.39	0.38	0.34	0.26	0.41	0.44	0.26	0.19	0.28	0.32	0.25	0.35
1940	0.26	0.23	0.14	0.12	0.11	0.11	0.12	0.11	0.31	0.22	0.17	0.17
1941	0.25	0.23	0.45	0.32	0.16	0.12	0.10	0.21	0.21	0.20	0.20	0.17
1942	0.28	0.25	0.18	0.19	0.15	0.12	0.11	0.10	0.81	0.54	0.43	0.60
1943	0.39	0.83	0.49	0.20	0.15	0.23	0.21	31.51	8.77	2.59	1.02	3.11
1944	0.77	0.31	0.17	0.12	0.11	0.09	0.07	9.81	11.44	1.99	1.14	0.41
1945	1.58	0.41	0.18	0.12	0.11	0.38	0.22	0.12	0.10	0.25	0.31	0.28
1946	0.34	0.25	0.14	0.11	0.09	0.20	0.18	0.33	0.43	10.84	1.72	0.39
1947	0.29	0.27	0.17	0.12	0.11	0.14	0.48	0.29	0.17	0.16	0.17	0.22
1948	0.84	0.48	0.19	0.13	0.11	0.10	0.08	0.09	0.07	0.06	0.08	0.09
1949	0.09	1.76	0.72	0.13	0.11	0.09	0.09	0.10	0.08	0.22	0.40	0.37
1950	0.44	1.26	0.57	1.04	0.48	0.17	0.11	0.13	0.17	0.71	0.57	5.83
1951	2.51	0.29	0.17	0.14	0.69	0.32	0.13	0.14	0.15	0.15	0.41	13.59
1952	3.40	0.41	0.23	0.14	0.13	0.11	0.09	0.09	0.11	0.22	0.37	0.71
1953	23.58	8.77	0.32	0.17	0.11	0.48	0.30	1.31	1.05	6.07	18.20	6.38
1954	0.36	0.99	0.18	0.14	5.97	7.56	0.24	0.16	0.16	0.17	0.54	0.42
1955	0.28	5.62	4.39	0.16	0.17	0.20	0.14	1.42	2.71	0.30	0.30	10.85
1956	9.13	15.98	3.36	0.28	0.27	0.24	0.20	0.25	0.33	0.31	0.36	4.54
1957	5.09	0.32	0.17	0.11	0.09	0.16	0.12	0.52	0.36	0.21	0.39	0.36
1958	0.27	0.21	0.15	0.34	0.23	0.15	0.21	0.20	0.17	0.18	0.36	0.33
1959	0.36	0.25	0.19	0.31	0.20	0.12	0.10	0.16	0.18	0.29	0.29	0.31
1960	0.22	0.20	0.14	0.13	0.15	0.65	0.41	0.50	0.39	0.34	0.33	0.26
1961	0.23	0.20	0.13	0.11	0.11	0.25	0.23	0.17	0.13	0.12	1.18	0.69
1962	0.60	0.39	0.19	0.27	0.18	0.96	0.82	0.46	0.32	0.28	0.27	0.23
1963	0.19	0.22	0.28	0.25	0.16	0.15	0.12	0.11	0.57	0.41	0.52	10.84
1964	6.82	0.47	0.23	0.14	0.10	0.14	0.14	0.20	0.20	0.18	0.17	0.16
1965	0.58	2.95	0.29	0.19	0.17	0.13	0.09	0.10	0.09	0.08	0.17	0.19
1966	0.19	0.24	0.17	0.12	0.10	0.10	0.83	0.70	0.45	0.40	0.40	0.54
1967	0.39	0.27	0.17	0.12	0.10	0.11	0.23	0.21	21.89	7.43	2.60	25.52
1968	3.99	0.38	0.20	0.14	0.11	0.12	0.09	0.09	0.11	0.12	0.14	0.17
1969	0.24	0.21	0.13	0.11	0.11	0.10	0.07	0.07	0.06	0.06	0.12	0.13
1970	0.20	0.19	0.44	0.24	0.20	0.18	0.81	0.73	0.55	3.01	32.01	11.56
1971	1.93	1.22	0.21	0.12	0.30	0.19	0.20	0.19	0.18	0.21	0.27	0.21
1972	0.15	0.15	0.11	0.09	0.10	0.15	0.16	0.15	0.12	0.10	0.11	0.12
1973	0.13	0.19	0.14	0.25	0.24	0.83	0.45	0.31	0.31	0.22	1.34	6.04
1974	0.69	0.27	0.15	0.14	0.17	0.27	0.17	0.11	0.11	0.14	0.24	0.37
1975	0.27	0.20	0.15	0.12	0.13	0.32	0.34	0.25	0.22	0.46	0.49	0.36
1976	0.87	0.62	0.26	0.15	0.42	0.25	0.16	6.03	3.96	0.37	0.34	0.62
1977	0.45	0.45	0.28	0.17	0.11	0.14	0.19	0.17	0.23	0.23	0.24	0.23
1978	0.45	0.49	0.29	0.23	0.18	0.14	0.10	0.12	0.15	0.38	15.38	14.19
1979	0.56	0.34	0.19	0.15	0.12	0.09	0.11	0.10	0.12	0.12	0.12	0.17
1980	0.22	0.26	0.20	0.44	0.25	2.15	0.99	10.10	9.62	0.44	14.35	8.56
1981	5.34	0.79	0.25	0.15	0.11	0.12	0.76	0.76	0.18	0.23	0.28	0.26
1982	0.21	0.19	0.12	0.09	0.09	0.09	0.07	0.09	0.11	31.29	12.83	0.44
1983	3.52	0.30	0.18	0.12	0.10	0.14	0.10	0.08	0.08	0.14	0.15	0.14
1984	0.13	0.14	0.14	0.20	0.18	0.13	0.13	0.12	0.18	0.19	0.18	0.14
1985	0.23	0.27	0.21	0.18	0.13	0.11	0.08	0.07	0.08	0.09	0.25	0.22
1986	0.75	0.52	0.23	0.14	0.11	0.11	0.17	0.14	0.38	0.26	0.21	0.52
1987	0.33	0.21	0.14	0.10	0.12	0.03	0.13	0.10	0.22	0.21	0.20	0.19
1988	0.19	0.19	0.10	0.08	0.04	0.02	0.16	0.08	0.10	0.13	0.13	0.17
1989	1.50	2.38	0.72	0.19	0.22	0.18	0.21	0.21	0.64	0.44	0.33	0.31
1990	0.55	0.37	0.18	0.12	0.10	0.09	0.06	0.02	0.05	0.04	0.14	0.10
1991	0.22	0.21	0.16	0.13	1.12	0.46	0.14	0.14	0.17	0.27	1.29	0.76
1992	1.43	1.14	0.36	0.23	0.16	0.12	0.15	0.14	1.47	0.76	0.43	24.38
1993	7.52	0.38	0.34	0.22	0.16	0.15	0.13	0.15	0.15	0.26	3.07	3.03
1994	4.63	0.27	4.63	11.73	0.37	0.36	0.46	1.49	0.56	0.24	0.43	0.23
1995	0.26	0.29	0.37	0.22	0.15	0.14	0.10	0.09	0.07	0.11	0.20	0.23
1996	3.19	51.25	6.25	0.20	0.13	0.13	13.22	4.35	3.15	2.24	1.78	0.35
1997	0.24	0.22	0.14	0.14	0.11	0.30	0.18	0.13	0.11	0.11	0.28	0.26
1998	0.19	0.22	0.19	0.14	0.11	0.11	0.10	0.10	0.08	0.30	0.23	0.16
1999	0.12	0.11	0.14	0.18	0.27	0.43	0.28	0.17	0.13	0.10	0.10	0.12

1 <0.2 1 0.2-1.0 2 1.0-8.0 3 >8.0

Table C-11 Monthly simulated runoff data in m³/s (73-year period) for the Present State into the Geelhoutboom tributary

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1927	0.00	0.00	0.00	0.00	0.00	0.19	0.11	0.00	0.01	0.00	0.02	0.07
1928	0.06	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.08
1929	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.02	0.05	0.04
1930	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10
1931	0.34	0.07	0.23	0.67	0.16	0.00	0.00	0.00	0.00	0.04	0.00	1.95
1932	0.76	0.25	0.00	0.00	0.00	0.00	0.00	0.08	0.07	0.04	0.57	0.27
1933	0.01	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.00
1934	0.23	0.08	0.00	0.00	0.00	0.00	0.00	0.99	0.55	0.17	0.20	0.19
1935	0.12	0.11	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.03	0.00	0.00
1936	0.05	0.35	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.03
1937	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
1938	0.01	0.02	0.00	0.00	0.05	0.07	0.03	0.01	0.00	0.02	0.26	0.17
1939	0.08	0.05	0.03	0.00	0.05	0.12	0.04	0.03	0.08	0.09	0.01	0.11
1940	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.01	0.00
1941	0.03	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.01	0.00
1942	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.14	0.13	0.19
1943	0.03	0.26	0.08	0.00	0.00	0.00	0.02	1.64	0.69	0.18	0.10	0.23
1944	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.34	0.15	0.15	0.08
1945	0.25	0.00	0.00	0.00	0.00	0.04	0.01	0.00	0.00	0.03	0.05	0.03
1946	0.07	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.08	0.39	0.17	0.09
1947	0.03	0.00	0.00	0.00	0.00	0.00	0.06	0.02	0.02	0.01	0.01	0.03
1948	0.27	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1949	0.00	0.38	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.08	0.06
1950	0.09	0.42	0.08	0.33	0.05	0.00	0.00	0.00	0.01	0.22	0.17	0.28
1951	0.10	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.02	0.01	0.13	0.89
1952	0.33	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.07	0.16
1953	1.82	0.70	0.00	0.00	0.00	0.06	0.04	0.42	0.26	0.23	1.19	0.47
1954	0.03	0.00	0.00	0.00	0.53	0.22	0.00	0.01	0.02	0.04	0.17	0.10
1955	0.02	0.36	0.02	0.00	0.00	0.00	0.00	0.28	0.18	0.07	0.08	0.38
1956	0.72	0.36	0.17	0.00	0.00	0.00	0.02	0.06	0.10	0.08	0.11	0.26
1957	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.06	0.01	0.07	0.06
1958	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.03	0.10	0.06
1959	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.05	0.03	0.07
1960	0.00	0.00	0.00	0.00	0.00	0.09	0.08	0.16	0.10	0.10	0.08	0.02
1961	0.01	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.01	0.31	0.17
1962	0.19	0.03	0.00	0.00	0.00	0.21	0.27	0.14	0.06	0.08	0.06	0.01
1963	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.10	0.17	2.04
1964	0.67	0.09	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.02	0.00	0.00
1965	0.11	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
1966	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.15	0.13	0.12	0.11	0.17
1967	0.05	0.00	0.00	0.00	0.00	0.00	0.01	0.03	1.43	0.61	0.19	1.00
1968	0.36	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
1969	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1970	0.00	0.00	0.04	0.00	0.00	0.00	0.13	0.17	0.18	1.05	2.92	0.93
1971	0.05	0.06	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.04	0.05	0.00
1972	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1973	0.00	0.00	0.00	0.00	0.00	0.13	0.07	0.06	0.08	0.02	0.46	0.60
1974	0.13	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.04	0.07
1975	0.00	0.00	0.00	0.00	0.00	0.02	0.06	0.03	0.03	0.13	0.14	0.06
1976	0.29	0.15	0.00	0.00	0.04	0.00	0.01	0.65	0.33	0.08	0.09	0.20
1977	0.08	0.09	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.03	0.03	0.01
1978	0.13	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	1.26	0.61
1979	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1980	0.02	0.01	0.00	0.02	0.00	0.59	0.30	0.28	0.20	0.10	0.88	0.34
1981	0.32	0.11	0.00	0.00	0.00	0.00	0.12	0.05	0.03	0.07	0.07	0.04
1982	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.50	0.68	0.10
1983	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1984	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00
1985	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02
1986	0.15	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.02	0.03	0.12
1987	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.02	0.02	0.01
1988	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02
1989	0.37	0.81	0.07	0.00	0.00	0.00	0.00	0.03	0.21	0.11	0.08	0.07
1990	0.17	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1991	0.00	0.00	0.00	0.00	0.19	0.02	0.00	0.01	0.02	0.07	0.44	0.20
1992	0.48	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.43	0.21	0.13	2.21
1993	0.74	0.04	0.03	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.23	0.14
1994	0.09	0.00	0.03	0.04	0.05	0.07	0.07	0.09	0.03	0.04	0.05	0.03
1995	0.04	0.02	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03
1996	0.37	2.23	0.60	0.00	0.00	0.00	0.14	0.20	0.17	0.14	0.14	0.05
1997	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.05	0.02
1998	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.02	0.00
1999	0.00	0.00	0.00	0.00	0.00	0.06	0.03	0.00	0.00	0.00	0.00	0.00
1	<0.08			2			3			>1.0		

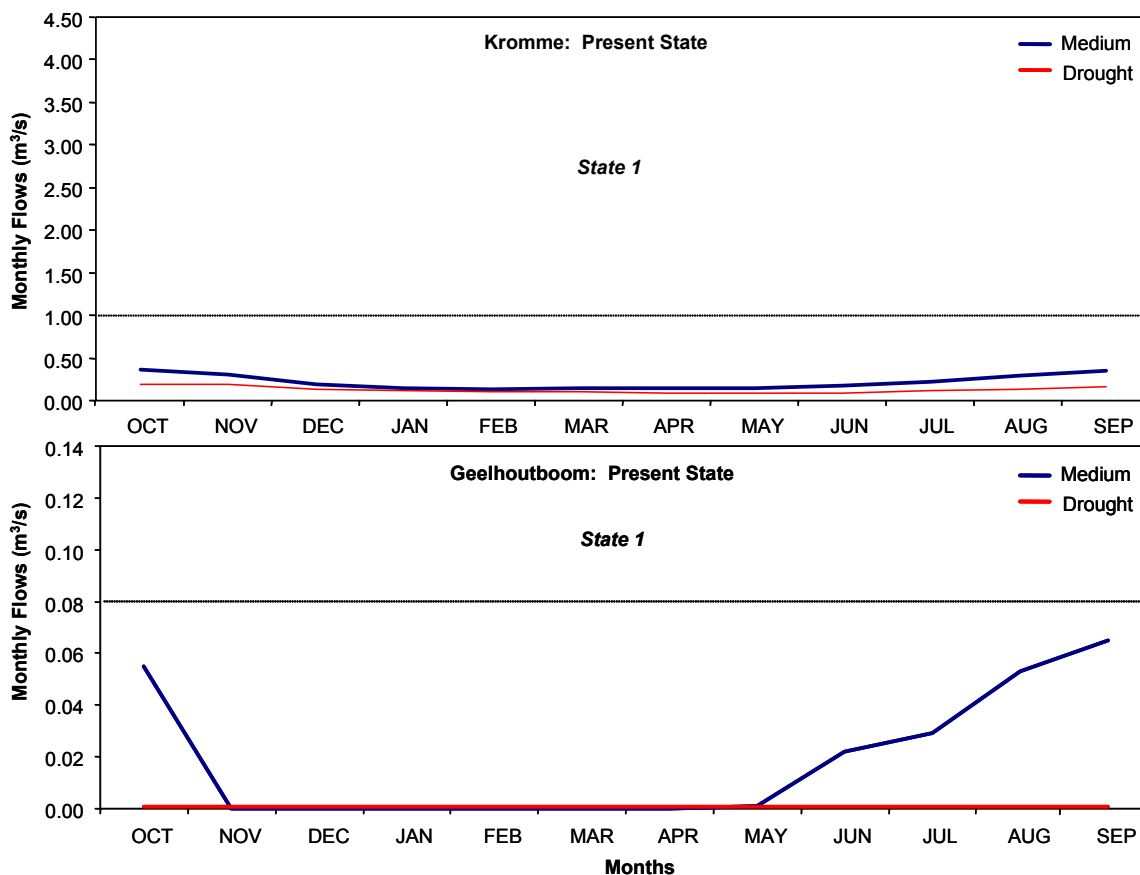
Geelhoutboom: Summary of flow distributions for Present State

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	1.05	1.21	0.34	0.43	0.29	0.32	0.28	1.17	0.90	1.18	1.72	2.09
90%ile	0.37	0.36	0.05	0.00	0.05	0.07	0.08	0.18	0.21	0.18	0.41	0.57
80%ile	0.24	0.11	0.01	0.00	0.00	0.01	0.04	0.07	0.10	0.11	0.17	0.22
70%ile	0.13	0.06	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.07	0.13	0.16
60%ile	0.08	0.03	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.04	0.08	0.09
50%ile	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.05	0.06
40%ile	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.03
30%ile	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02
20%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

ii. Occurrence and duration of different abiotic states under Present State

Estimated occurrence and duration of the different Abiotic States in the Kromme Estuary and Geelhoutboom tributary under the Present State, based on simulated monthly river inflow from the Kromme and Geelhoutboom rivers are indicated in Tables C-10 and C-11, respectively.

To provide a conceptual overview of the annual distribution of Abiotic States under the Present State for the Kromme Estuary and Geelhoutboom tributary, median monthly flows (representative of seasonal conditions) and 10%ile flows (representative of drought conditions) were used to depict the situation for normal and drought periods:



8.3 Reference Condition

i. Seasonal variability in river inflow

Monthly simulated runoff data (73-year period) for the Reference Condition of the Kromme Estuary and Geelhoutboom tributary are provided in Tables C-12 and C-13, respectively. A summary of the flow distributions (mean monthly flows in m³/s), derived from the simulated data set, is provided below (hatched months represent flows less than 0.2 m³/s hypersaline conditions can potentially develop):

Kromme: Summary of flow distributions for Reference Condition

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	20.03	28.03	7.48	10.43	10.87	13.31	16.52	37.33	21.62	27.62	35.63	36.27
90%ile	10.74	8.51	3.58	2.01	3.58	3.66	2.75	9.62	5.59	5.21	12.81	10.21
80%ile	7.19	3.87	2.40	1.19	1.58	2.08	2.04	3.48	4.01	3.61	5.35	5.76
70%ile	4.23	2.89	1.89	1.04	1.04	1.20	1.68	1.78	2.59	3.22	4.33	4.57
60%ile	3.62	2.44	1.37	0.73	0.68	0.93	1.21	1.37	1.88	2.56	3.05	3.39
50%ile	2.83	1.98	1.11	0.59	0.59	0.78	0.95	1.06	1.53	2.11	2.58	2.73
40%ile	2.48	1.79	0.93	0.49	0.43	0.61	0.78	0.81	1.25	1.74	2.00	2.25
30%ile	2.24	1.50	0.84	0.42	0.33	0.48	0.59	0.69	0.86	1.49	1.66	1.87
20%ile	1.59	1.27	0.71	0.38	0.28	0.38	0.44	0.54	0.70	0.98	1.44	1.56
10%ile	1.35	0.95	0.53	0.32	0.25	0.28	0.34	0.39	0.52	0.74	1.05	1.13
1%ile	0.46	0.29	0.31	0.13	0.15	0.16	0.17	0.17	0.24	0.27	0.42	0.61

Geelhoutboom: Summary of flow distributions for Reference Condition

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	1.10	1.20	0.40	0.44	0.53	0.54	0.34	1.36	0.96	1.25	1.71	2.07
90%ile	0.47	0.37	0.17	0.09	0.13	0.17	0.19	0.27	0.26	0.19	0.44	0.58
80%ile	0.28	0.19	0.12	0.07	0.07	0.10	0.08	0.14	0.16	0.14	0.18	0.26
70%ile	0.19	0.14	0.09	0.05	0.05	0.07	0.07	0.07	0.10	0.10	0.15	0.20
60%ile	0.14	0.12	0.07	0.04	0.04	0.04	0.05	0.05	0.07	0.09	0.11	0.14
50%ile	0.12	0.09	0.05	0.03	0.02	0.03	0.04	0.04	0.06	0.08	0.10	0.11
40%ile	0.10	0.08	0.05	0.03	0.02	0.02	0.03	0.04	0.04	0.06	0.08	0.08
30%ile	0.08	0.07	0.04	0.02	0.02	0.02	0.02	0.03	0.04	0.05	0.06	0.07
20%ile	0.07	0.06	0.04	0.02	0.02	0.02	0.02	0.02	0.03	0.04	0.05	0.06
10%ile	0.06	0.05	0.03	0.02	0.01	0.01	0.02	0.01	0.02	0.03	0.04	0.05
1%ile	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.03

Table C-12 Monthly simulated runoff data in m³/s (73-year period) for the Reference Condition into the Kromme Estuary

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1927	1.07	0.93	0.52	0.25	0.67	7.95	2.81	1.07	0.87	0.81	1.16	2.07
1928	2.35	4.13	1.54	0.52	0.39	0.29	0.31	0.54	0.84	3.38	2.72	3.98
1929	3.03	1.52	0.67	0.32	3.84	1.09	1.18	1.06	1.70	1.70	3.26	3.54
1930	2.95	1.61	0.86	0.93	0.44	0.37	0.43	0.52	0.55	2.58	1.67	9.83
1931	14.03	3.79	5.68	7.28	4.00	1.48	0.90	0.71	1.53	1.46	1.14	33.84
1932	10.35	4.29	1.88	0.54	0.63	0.64	2.35	10.72	4.07	2.66	20.56	5.71
1933	2.67	3.88	1.46	1.57	1.80	1.54	0.93	0.67	0.71	3.39	2.14	1.50
1934	11.73	2.81	0.95	0.32	0.86	0.54	1.11	33.31	8.08	4.04	6.90	4.90
1935	3.66	3.86	1.87	0.74	0.36	0.89	0.99	3.22	1.79	1.91	1.57	1.68
1936	2.72	10.66	2.74	0.73	0.46	1.08	0.65	0.39	1.38	2.31	1.66	2.26
1937	1.85	1.64	1.27	0.72	0.39	0.28	0.45	1.10	1.03	0.89	0.97	1.67
1938	1.79	3.32	1.11	0.42	8.17	3.96	2.09	1.35	0.91	1.82	6.89	4.53
1939	3.04	2.79	4.52	2.07	7.29	3.68	2.05	1.46	3.39	3.30	2.38	2.93
1940	2.22	1.46	0.61	0.64	0.46	0.51	1.27	0.81	4.94	1.95	1.38	1.56
1941	2.56	1.98	3.30	2.18	0.80	0.46	0.52	1.67	1.88	1.71	1.48	1.23
1942	2.15	1.88	1.21	1.15	0.63	0.53	0.63	0.58	11.44	3.37	2.90	4.66
1943	2.77	8.92	3.60	0.99	0.64	1.16	1.15	47.66	9.05	4.70	3.48	5.40
1944	3.61	1.88	0.87	0.40	0.29	0.28	0.30	21.99	12.32	4.12	3.24	2.56
1945	4.45	2.18	0.80	0.38	0.33	2.68	1.24	0.61	0.59	3.83	4.39	3.35
1946	3.71	1.86	0.70	0.33	0.22	1.10	2.51	4.70	5.73	18.33	4.55	2.78
1947	2.31	1.60	0.84	0.40	0.30	0.63	4.71	1.79	1.44	1.43	1.54	2.33
1948	10.33	3.30	1.25	0.83	0.64	0.38	0.37	0.43	0.36	0.31	0.45	0.55
1949	0.40	14.06	3.13	0.46	0.25	0.18	0.31	0.46	0.40	7.33	5.42	3.66
1950	3.87	18.65	3.19	9.11	2.54	0.83	0.44	1.39	2.20	15.17	5.16	7.94
1951	3.69	1.65	0.74	0.56	7.79	1.57	0.68	0.77	1.00	1.00	6.06	21.73
1952	6.24	2.98	1.35	0.52	0.47	0.38	0.35	0.27	1.17	3.13	4.29	6.07
1953	35.12	9.92	2.08	0.73	0.27	2.78	1.68	10.46	4.39	7.61	24.77	7.13
1954	2.60	1.97	0.89	0.46	16.33	3.60	1.21	0.90	0.88	0.95	4.19	2.73
1955	2.29	15.74	2.45	0.61	0.61	0.90	0.66	12.21	3.21	1.71	2.13	10.67
1956	12.53	6.28	4.23	1.43	1.50	1.27	1.38	1.95	2.29	2.11	2.63	5.92
1957	3.72	1.82	0.66	0.25	0.11	0.82	0.54	6.28	2.70	1.72	4.61	2.69
1958	2.38	1.28	0.82	3.05	1.11	0.89	2.02	1.72	1.40	2.14	5.24	3.34
1959	3.25	1.83	1.49	5.67	1.14	0.49	0.86	1.34	1.63	3.70	2.79	4.33
1960	2.34	1.40	0.76	0.44	0.59	7.69	2.33	3.65	2.46	1.96	2.00	1.69
1961	1.50	1.02	0.45	0.28	0.30	1.40	1.51	1.00	0.69	0.80	17.03	3.92
1962	5.03	2.60	1.00	1.26	0.69	10.62	6.99	4.34	2.74	2.38	2.40	1.89
1963	1.35	1.26	2.01	1.46	0.69	0.84	0.74	0.57	8.03	2.63	6.74	30.86
1964	9.12	2.82	1.27	0.50	0.25	2.44	1.75	2.71	2.51	2.12	1.57	1.20
1965	10.84	5.57	2.32	1.19	1.64	0.61	0.46	0.59	0.55	0.70	1.78	2.07
1966	1.64	1.48	0.86	0.34	0.27	0.83	15.38	5.26	3.33	3.27	2.94	4.18
1967	2.83	1.67	0.96	0.42	0.28	0.40	2.04	1.73	42.06	8.49	4.55	24.98
1968	6.19	2.65	1.08	0.48	0.32	0.34	0.34	0.34	1.27	1.10	1.09	2.28
1969	2.93	1.46	0.50	0.32	0.34	0.23	0.18	0.14	0.11	0.16	0.90	1.11
1970	1.77	1.11	6.32	1.14	2.40	1.10	9.54	5.66	4.35	19.40	52.76	12.54
1971	2.68	2.62	1.11	0.39	4.01	1.06	2.28	1.77	1.71	2.24	2.58	1.84
1972	0.87	0.50	0.23	0.12	0.20	0.78	0.89	0.79	0.60	0.41	0.48	0.63
1973	0.68	0.74	0.41	0.96	1.05	6.33	2.38	1.72	1.59	1.14	19.71	10.30
1974	3.90	1.33	0.48	0.34	1.04	2.08	0.97	0.43	0.74	0.97	1.48	2.08
1975	1.38	0.74	0.69	0.38	0.36	1.74	1.68	1.36	1.35	3.34	3.22	2.53
1976	7.44	3.86	2.16	0.71	1.80	1.10	0.83	21.80	5.01	2.44	2.15	3.02
1977	2.29	1.99	1.26	0.59	0.30	0.42	0.95	0.89	1.90	1.82	1.78	1.56
1978	7.64	2.67	2.22	1.19	0.83	0.45	0.39	0.74	1.40	5.34	28.97	9.40
1979	4.22	2.24	0.92	0.50	0.31	0.18	0.40	0.38	0.77	0.73	0.66	1.33
1980	1.36	1.45	1.57	3.02	1.16	20.24	4.25	13.82	3.93	2.56	20.43	5.79
1981	7.52	3.94	1.65	0.70	0.34	0.57	10.75	2.36	1.14	1.70	1.73	1.56
1982	1.23	0.74	0.35	0.13	0.16	0.13	0.23	0.53	0.84	48.77	9.25	3.06
1983	2.50	1.89	0.82	0.33	0.20	0.68	0.40	0.25	0.42	0.79	0.82	0.72
1984	0.48	0.32	0.93	1.03	1.03	0.58	1.80	0.90	1.26	1.51	1.22	0.80
1985	4.24	1.98	1.91	1.19	0.58	0.32	0.23	0.18	0.44	0.53	2.69	1.90
1986	6.82	3.03	1.13	0.46	0.27	0.23	1.44	0.78	2.70	1.74	1.42	4.95
1987	2.26	0.96	0.59	0.28	0.28	0.29	0.79	0.91	2.31	1.76	1.64	1.53
1988	1.58	0.95	0.76	0.38	0.25	0.17	0.91	0.72	0.60	1.32	1.08	1.69
1989	11.01	16.19	3.51	0.95	1.28	0.78	1.22	1.23	5.04	2.68	1.98	1.88
1990	3.57	2.18	0.85	0.32	0.22	0.18	0.14	0.18	0.33	0.34	1.05	0.91
1991	1.58	1.04	0.83	0.47	8.74	2.09	0.62	0.64	0.84	3.19	13.70	4.63
1992	14.16	6.90	2.01	1.04	1.09	0.51	0.74	0.78	13.68	3.87	3.52	42.52
1993	9.74	2.07	2.95	1.04	0.58	0.45	0.52	1.83	1.79	3.95	7.03	4.62
1994	6.45	2.40	6.96	13.81	2.50	2.08	1.78	2.64	1.96	1.54	1.67	1.71
1995	1.45	1.55	3.79	1.24	0.62	0.66	0.51	0.40	0.29	1.20	2.40	2.85
1996	11.44	52.15	8.82	1.07	0.57	0.70	19.45	5.43	4.18	3.48	3.01	2.22
1997	1.61	1.25	0.57	0.38	0.23	6.85	1.11	0.98	0.85	0.86	4.90	2.33
1998	1.44	1.13	0.94	0.57	0.31	0.46	0.44	0.55	0.52	2.88	1.77	1.08
1999	0.51	0.19	0.35	1.77	1.87	3.10	1.79	1.06	0.67	0.46	0.36	0.64
	1	<0.2		1	0.2-1.0		2	1.0-8.0		3	>8.0	

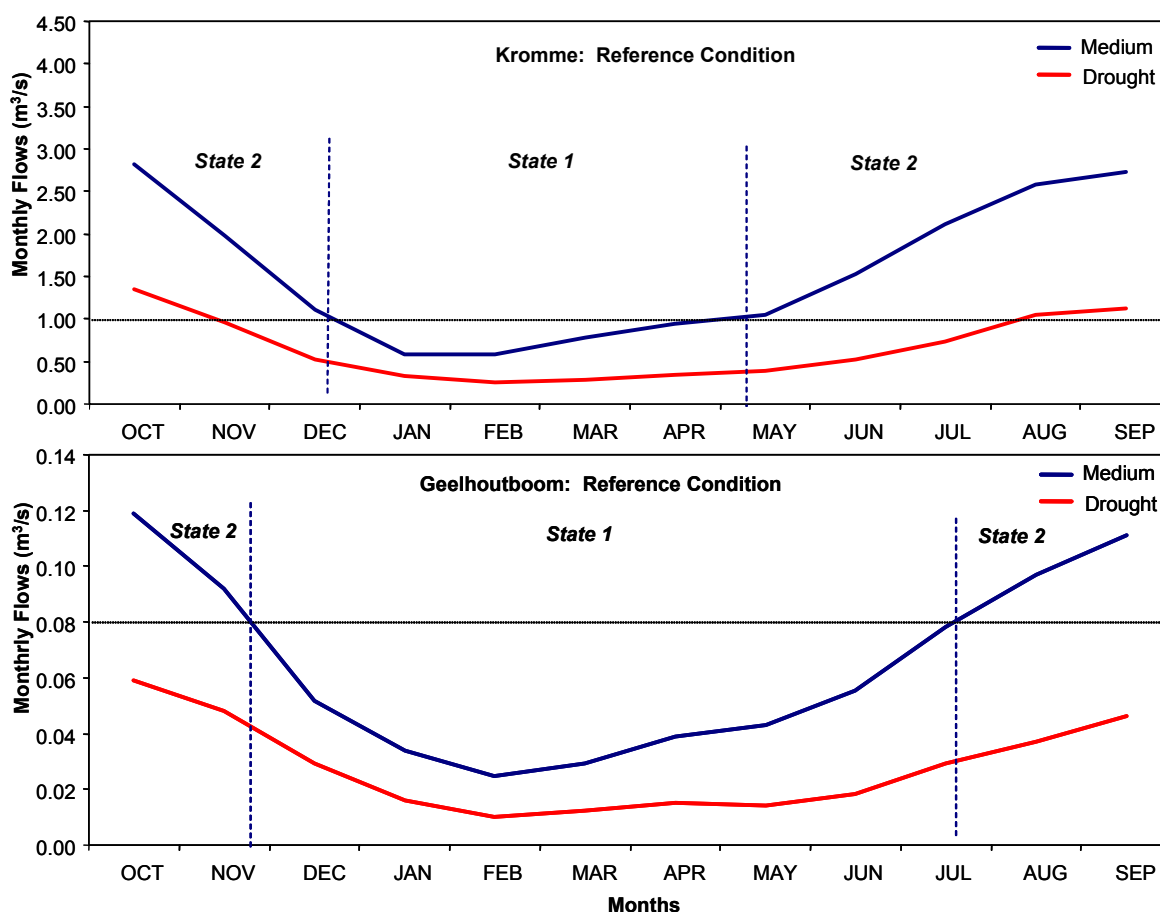
Table C-13 Monthly simulated runoff data in m³/s (73-year period) for the Reference Condition into the Geelhoutboom tributary

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1927	0.04	0.04	0.02	0.01	0.01	0.44	0.20	0.05	0.04	0.03	0.04	0.07
1928	0.09	0.14	0.07	0.03	0.02	0.01	0.01	0.02	0.03	0.09	0.09	0.18
1929	0.13	0.07	0.04	0.02	0.08	0.06	0.05	0.04	0.06	0.06	0.10	0.11
1930	0.12	0.08	0.03	0.04	0.02	0.02	0.02	0.02	0.02	0.05	0.05	0.20
1931	0.46	0.22	0.25	0.67	0.29	0.07	0.05	0.03	0.04	0.05	0.05	1.93
1932	0.78	0.26	0.12	0.04	0.02	0.02	0.04	0.20	0.15	0.09	0.56	0.32
1933	0.12	0.15	0.07	0.04	0.04	0.05	0.04	0.03	0.03	0.10	0.09	0.07
1934	0.30	0.17	0.05	0.02	0.02	0.01	0.04	1.23	0.55	0.17	0.20	0.20
1935	0.17	0.16	0.10	0.04	0.02	0.02	0.02	0.08	0.06	0.06	0.06	0.05
1936	0.12	0.39	0.18	0.04	0.02	0.03	0.02	0.01	0.04	0.05	0.05	0.08
1937	0.07	0.07	0.05	0.03	0.02	0.01	0.02	0.04	0.04	0.04	0.04	0.05
1938	0.07	0.09	0.05	0.02	0.17	0.15	0.08	0.05	0.04	0.05	0.33	0.21
1939	0.13	0.11	0.11	0.09	0.13	0.13	0.08	0.05	0.08	0.09	0.08	0.11
1940	0.09	0.07	0.03	0.02	0.02	0.02	0.03	0.02	0.12	0.08	0.05	0.05
1941	0.08	0.07	0.16	0.11	0.04	0.02	0.02	0.07	0.07	0.07	0.06	0.05
1942	0.10	0.07	0.05	0.05	0.03	0.02	0.02	0.02	0.33	0.19	0.13	0.19
1943	0.14	0.26	0.17	0.06	0.03	0.07	0.07	1.68	0.71	0.18	0.15	0.23
1944	0.18	0.10	0.04	0.02	0.02	0.01	0.01	0.44	0.39	0.18	0.15	0.14
1945	0.25	0.14	0.05	0.02	0.01	0.14	0.08	0.03	0.02	0.09	0.11	0.10
1946	0.11	0.07	0.03	0.02	0.01	0.06	0.06	0.12	0.17	0.44	0.25	0.13
1947	0.10	0.08	0.04	0.02	0.02	0.03	0.19	0.10	0.06	0.05	0.05	0.07
1948	0.28	0.16	0.05	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02
1949	0.01	0.71	0.26	0.02	0.01	0.01	0.02	0.02	0.02	0.08	0.16	0.14
1950	0.15	0.41	0.20	0.34	0.17	0.04	0.02	0.04	0.05	0.24	0.18	0.27
1951	0.19	0.09	0.04	0.03	0.27	0.11	0.03	0.04	0.05	0.04	0.12	0.88
1952	0.40	0.13	0.07	0.03	0.02	0.02	0.02	0.01	0.03	0.08	0.14	0.27
1953	1.81	0.75	0.11	0.04	0.02	0.18	0.11	0.45	0.27	0.23	1.18	0.52
1954	0.13	0.08	0.05	0.03	0.70	0.28	0.06	0.04	0.04	0.05	0.17	0.14
1955	0.09	0.36	0.16	0.04	0.04	0.06	0.04	0.41	0.21	0.09	0.09	0.37
1956	0.72	0.39	0.22	0.09	0.09	0.07	0.06	0.07	0.10	0.09	0.11	0.25
1957	0.20	0.11	0.04	0.01	0.01	0.04	0.03	0.21	0.14	0.07	0.14	0.12
1958	0.09	0.06	0.04	0.12	0.07	0.03	0.07	0.06	0.05	0.06	0.11	0.11
1959	0.11	0.08	0.05	0.10	0.06	0.02	0.02	0.05	0.06	0.10	0.10	0.10
1960	0.07	0.05	0.03	0.02	0.03	0.26	0.15	0.16	0.13	0.10	0.10	0.08
1961	0.07	0.05	0.02	0.02	0.01	0.08	0.08	0.05	0.04	0.04	0.45	0.24
1962	0.19	0.13	0.05	0.09	0.05	0.36	0.27	0.14	0.10	0.09	0.08	0.07
1963	0.06	0.06	0.09	0.08	0.04	0.04	0.03	0.02	0.23	0.13	0.16	2.02
1964	0.75	0.15	0.07	0.03	0.01	0.03	0.04	0.06	0.07	0.06	0.05	0.05
1965	0.23	0.22	0.09	0.05	0.05	0.02	0.02	0.02	0.02	0.02	0.05	0.06
1966	0.06	0.07	0.04	0.02	0.01	0.01	0.35	0.27	0.15	0.12	0.12	0.17
1967	0.13	0.08	0.04	0.02	0.01	0.02	0.08	0.07	1.59	0.65	0.19	0.99
1968	0.43	0.12	0.06	0.03	0.02	0.02	0.02	0.02	0.03	0.04	0.04	0.05
1969	0.08	0.06	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.03	0.04
1970	0.06	0.05	0.17	0.07	0.06	0.05	0.33	0.27	0.18	1.04	2.91	1.01
1971	0.12	0.11	0.06	0.02	0.10	0.05	0.07	0.06	0.06	0.07	0.08	0.07
1972	0.04	0.03	0.01	0.01	0.01	0.04	0.05	0.04	0.04	0.02	0.02	0.03
1973	0.03	0.05	0.03	0.08	0.08	0.33	0.17	0.10	0.10	0.07	0.45	0.59
1974	0.25	0.08	0.04	0.03	0.05	0.09	0.05	0.02	0.03	0.04	0.08	0.14
1975	0.09	0.05	0.04	0.02	0.02	0.11	0.13	0.09	0.07	0.16	0.15	0.12
1976	0.28	0.20	0.08	0.04	0.15	0.08	0.05	0.67	0.34	0.12	0.10	0.20
1977	0.15	0.14	0.09	0.04	0.02	0.03	0.06	0.05	0.08	0.08	0.08	0.08
1978	0.14	0.15	0.09	0.07	0.05	0.03	0.02	0.03	0.05	0.14	1.25	0.61
1979	0.19	0.11	0.05	0.04	0.02	0.01	0.02	0.02	0.04	0.03	0.03	0.05
1980	0.07	0.08	0.06	0.16	0.08	0.80	0.34	0.28	0.20	0.13	0.87	0.42
1981	0.32	0.20	0.08	0.04	0.02	0.02	0.31	0.15	0.05	0.06	0.08	0.08
1982	0.07	0.05	0.02	0.01	0.01	0.01	0.01	0.02	0.03	1.78	0.72	0.14
1983	0.12	0.09	0.05	0.02	0.01	0.03	0.02	0.01	0.02	0.04	0.04	0.04
1984	0.03	0.02	0.03	0.06	0.05	0.02	0.03	0.03	0.06	0.06	0.06	0.04
1985	0.08	0.08	0.06	0.05	0.03	0.01	0.01	0.01	0.02	0.02	0.09	0.08
1986	0.30	0.19	0.07	0.03	0.02	0.01	0.05	0.04	0.15	0.09	0.07	0.19
1987	0.12	0.05	0.03	0.01	0.02	0.02	0.03	0.04	0.08	0.07	0.06	0.06
1988	0.06	0.05	0.04	0.02	0.02	0.01	0.05	0.04	0.02	0.04	0.04	0.07
1989	0.59	0.81	0.27	0.05	0.07	0.05	0.07	0.07	0.21	0.15	0.10	0.10
1990	0.18	0.12	0.05	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.04	0.04
1991	0.07	0.05	0.05	0.03	0.47	0.17	0.04	0.04	0.05	0.09	0.43	0.27
1992	0.48	0.38	0.13	0.07	0.04	0.02	0.05	0.04	0.55	0.26	0.13	2.20
1993	0.82	0.12	0.11	0.07	0.04	0.04	0.03	0.04	0.05	0.09	0.23	0.18
1994	0.14	0.08	0.14	0.13	0.11	0.10	0.08	0.09	0.07	0.06	0.06	0.07
1995	0.08	0.08	0.12	0.07	0.03	0.03	0.02	0.01	0.01	0.03	0.07	0.08
1996	0.48	2.21	0.75	0.06	0.03	0.02	0.32	0.20	0.17	0.15	0.15	0.12
1997	0.08	0.06	0.03	0.03	0.02	0.10	0.06	0.03	0.03	0.03	0.10	0.09
1998	0.06	0.06	0.05	0.03	0.02	0.02	0.02	0.02	0.02	0.11	0.08	0.05
1999	0.03	0.01	0.03	0.05	0.09	0.16	0.10	0.05	0.04	0.02	0.02	0.03
	1	<0.08			2	0.08-		3		>1.0		

ii. Occurrence and duration of different abiotic states under Reference Condition

Estimated occurrence and duration of the different Abiotic States in the Kromme Estuary and Geelhoutboom tributary under the Reference Condition, based on simulated monthly river inflow from the Kromme and Geelhoutboom Rivers are indicated in Tables C-12 and C-13, respectively.

To provide a conceptual overview of the annual distribution of Abiotic States under the Reference Condition for the Kromme Estuary and Geelhoutboom tributary, median monthly flows (representative of seasonal conditions) and 10%ile flows (representative of drought conditions) were used to depict the situation for normal and drought periods:



8.4 Scenario 1

i. Seasonal variability in river inflow

Monthly simulated runoff data (73-year period) for Scenario 1 into the Kromme Estuary and Geelhoutboom tributary are provided in Tables C-14 and C-11, respectively. A summary of the flow distributions (mean monthly flows in m³/s), derived from the simulated data set, is provided below (hatched months represent flows less than 0.2 m³/s when hypersaline conditions could potentially develop):

Kromme: Summary of flow distributions for Scenario 1 (5 x 10⁶ m³ release in Nov)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	13.66	25.96	5.02	4.68	2.32	3.63	4.55	26.02	14.72	16.25	22.94	26.05
90%ile	4.62	3.02	0.48	0.20	0.34	0.40	0.48	2.04	2.74	2.05	2.71	10.36
80%ile	1.95	2.41	0.27	0.15	0.16	0.23	0.22	0.38	0.52	0.38	1.10	3.17
70%ile	0.77	2.31	0.21	0.11	0.10	0.14	0.15	0.17	0.28	0.31	0.39	0.56
60%ile	0.41	2.22	0.16	0.08	0.09	0.10	0.12	0.14	0.18	0.23	0.31	0.40
50%ile	0.30	2.14	0.11	0.08	0.06	0.06	0.09	0.09	0.14	0.18	0.25	0.30
40%ile	0.24	2.11	0.11	0.06	0.04	0.05	0.07	0.08	0.11	0.15	0.20	0.22
30%ile	0.19	2.09	0.10	0.05	0.04	0.05	0.05	0.06	0.08	0.12	0.15	0.18
20%ile	0.16	2.06	0.08	0.05	0.04	0.03	0.05	0.05	0.06	0.09	0.11	0.13
10%ile	0.13	2.03	0.06	0.03	0.02	0.03	0.03	0.03	0.04	0.06	0.08	0.10
1%ile	0.05	0.52	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.04	0.06

Geelhoutboom: Summary of flow distributions for Scenario 1 (Present State)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	1.05	1.21	0.34	0.43	0.29	0.32	0.28	1.17	0.90	1.18	1.72	2.09
90%ile	0.37	0.36	0.05	0.00	0.05	0.07	0.08	0.18	0.21	0.18	0.41	0.57
80%ile	0.24	0.11	0.01	0.00	0.00	0.01	0.04	0.07	0.10	0.11	0.17	0.22
70%ile	0.13	0.06	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.07	0.13	0.16
60%ile	0.08	0.03	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.04	0.08	0.09
50%ile	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.05	0.06
40%ile	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.03
30%ile	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02
20%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

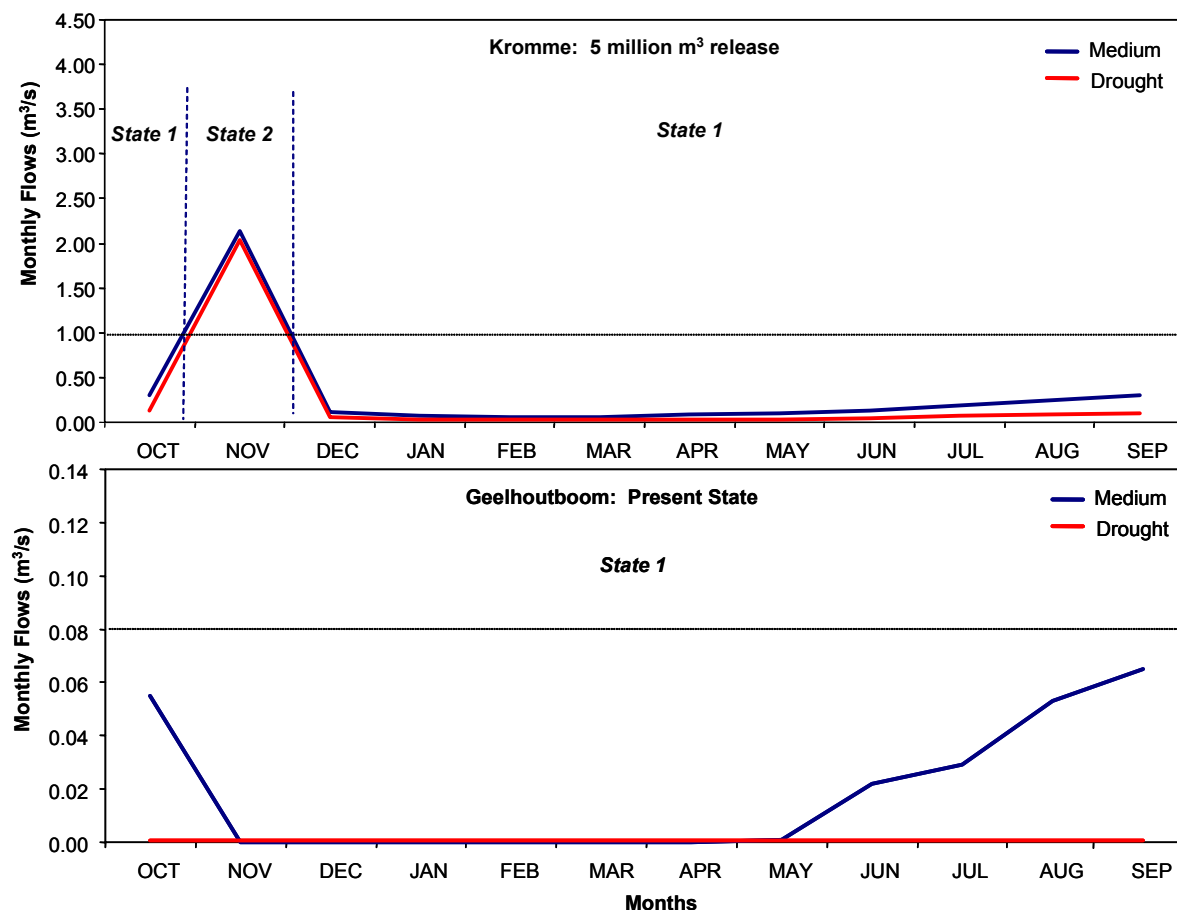
Table C-14 Monthly simulated runoff data in m³/s (73-year period) for Scenario 1 (5 x 10⁶ m³ release in Nov) into the Kromme Estuary

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1927	0.09	2.02	0.05	0.03	0.03	1.00	0.49	0.10	0.09	0.07	0.09	0.21
1928	0.25	2.30	0.16	0.06	0.04	0.03	0.02	0.05	0.06	0.20	0.20	0.47
1929	0.31	2.09	0.08	0.03	0.17	0.14	0.10	0.08	0.14	0.13	0.26	0.29
1930	0.27	2.09	0.07	0.08	0.05	0.04	0.05	0.04	0.04	0.12	0.11	0.53
1931	1.09	2.46	0.69	1.90	0.74	0.15	0.10	0.06	0.09	0.13	0.11	27.16
1932	9.84	2.65	0.27	0.08	0.05	0.05	0.08	2.69	2.53	0.75	19.52	3.72
1933	0.27	2.34	0.16	0.08	0.09	0.11	0.08	0.06	0.06	0.23	0.21	0.16
1934	4.17	2.35	0.11	0.04	0.04	0.03	0.08	23.68	7.73	2.00	4.75	2.31
1935	0.77	2.35	0.23	0.09	0.04	0.05	0.05	0.18	0.15	0.15	0.13	0.12
1936	0.27	2.98	0.42	0.09	0.05	0.06	0.05	0.03	0.09	0.12	0.11	0.19
1937	0.16	2.08	0.11	0.08	0.04	0.02	0.05	0.08	0.09	0.08	0.08	0.12
1938	0.15	2.14	0.11	0.04	0.37	0.34	0.19	0.12	0.10	0.12	0.86	0.57
1939	0.33	2.22	0.27	0.19	0.33	0.37	0.21	0.14	0.23	0.27	0.20	0.30
1940	0.20	2.08	0.07	0.05	0.04	0.04	0.06	0.05	0.27	0.18	0.11	0.12
1941	0.19	2.08	0.37	0.24	0.09	0.05	0.05	0.15	0.18	0.15	0.15	0.12
1942	0.23	2.09	0.11	0.12	0.07	0.05	0.05	0.05	0.76	0.47	0.37	0.55
1943	0.33	2.67	0.42	0.13	0.08	0.16	0.15	32.06	8.85	2.67	1.10	3.21
1944	0.88	2.15	0.10	0.05	0.04	0.02	0.02	9.08	11.52	2.07	1.22	0.37
1945	1.82	2.25	0.10	0.05	0.03	0.31	0.17	0.06	0.05	0.21	0.28	0.26
1946	0.25	2.09	0.07	0.03	0.02	0.13	0.12	0.27	0.39	10.37	1.80	0.43
1947	0.23	2.11	0.10	0.05	0.04	0.06	0.43	0.23	0.14	0.12	0.11	0.18
1948	0.76	2.32	0.11	0.05	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.04
1949	0.03	3.60	0.64	0.05	0.03	0.02	0.04	0.04	0.04	0.18	0.37	0.38
1950	0.36	3.03	0.50	0.96	0.41	0.09	0.05	0.08	0.13	0.66	0.51	5.94
1951	2.62	2.13	0.09	0.07	0.62	0.24	0.07	0.08	0.11	0.10	0.35	13.39
1952	3.51	2.25	0.16	0.07	0.05	0.03	0.03	0.03	0.07	0.18	0.34	0.69
1953	23.49	8.88	0.24	0.09	0.04	0.40	0.24	1.25	2.14	6.15	18.28	6.47
1954	0.30	2.12	0.10	0.06	5.61	7.66	0.32	0.16	0.11	0.12	0.48	0.38
1955	0.21	6.53	4.50	0.08	0.09	0.13	0.09	2.16	2.79	0.38	0.24	11.08
1956	9.24	16.09	3.47	0.21	0.19	0.16	0.14	0.20	0.28	0.26	0.31	5.84
1957	5.21	2.17	0.09	0.03	0.02	0.08	0.06	0.47	0.31	0.17	0.36	0.31
1958	0.20	2.06	0.08	0.26	0.16	0.08	0.16	0.15	0.13	0.14	0.28	0.28
1959	0.29	2.09	0.11	0.23	0.12	0.05	0.05	0.10	0.14	0.25	0.25	0.26
1960	0.16	2.04	0.07	0.05	0.08	0.57	0.35	0.42	0.34	0.29	0.27	0.22
1961	0.16	2.04	0.05	0.03	0.03	0.18	0.18	0.11	0.08	0.08	1.10	0.63
1962	0.54	2.23	0.11	0.19	0.10	0.89	0.77	0.41	0.27	0.24	0.21	0.19
1963	0.13	2.06	0.21	0.18	0.09	0.08	0.07	0.05	0.52	0.35	0.46	10.79
1964	6.93	2.31	0.16	0.06	0.02	0.06	0.08	0.14	0.16	0.14	0.12	0.10
1965	0.52	3.09	0.21	0.11	0.10	0.05	0.04	0.05	0.05	0.04	0.12	0.14
1966	0.13	2.08	0.10	0.05	0.02	0.03	0.77	0.65	0.40	0.35	0.34	0.49
1967	0.33	2.11	0.09	0.04	0.02	0.03	0.18	0.16	22.95	7.51	2.68	25.62
1968	4.10	2.22	0.13	0.06	0.04	0.04	0.04	0.03	0.07	0.08	0.08	0.12
1969	0.18	2.06	0.05	0.03	0.04	0.03	0.02	0.01	0.02	0.02	0.06	0.08
1970	0.14	2.03	0.37	0.16	0.13	0.10	0.76	0.67	0.51	2.96	31.73	11.66
1971	2.04	2.21	0.13	0.05	0.22	0.11	0.15	0.14	0.15	0.17	0.20	0.17
1972	0.09	1.99	0.03	0.01	0.02	0.08	0.10	0.09	0.08	0.05	0.05	0.07
1973	0.07	2.03	0.06	0.18	0.17	0.75	0.40	0.25	0.26	0.17	1.29	6.69
1974	0.63	2.11	0.08	0.06	0.10	0.19	0.12	0.05	0.06	0.09	0.20	0.38
1975	0.21	2.04	0.08	0.05	0.06	0.24	0.29	0.19	0.18	0.37	0.41	0.32
1976	0.80	2.46	0.18	0.08	0.34	0.18	0.11	5.51	4.04	0.32	0.29	0.56
1977	0.39	2.29	0.21	0.09	0.04	0.07	0.14	0.11	0.19	0.19	0.19	0.19
1978	0.34	2.33	0.21	0.16	0.11	0.06	0.05	0.07	0.11	0.34	15.61	14.28
1979	0.50	2.18	0.11	0.08	0.04	0.02	0.05	0.05	0.08	0.08	0.07	0.12
1980	0.16	2.10	0.13	0.37	0.17	2.07	0.93	9.56	9.70	0.52	14.43	8.66
1981	5.45	2.44	0.18	0.08	0.04	0.05	0.70	0.34	0.13	0.19	0.22	0.21
1982	0.15	2.03	0.05	0.02	0.02	0.01	0.02	0.03	0.07	31.38	12.91	0.40
1983	3.76	2.14	0.10	0.04	0.02	0.06	0.05	0.03	0.04	0.09	0.09	0.09
1984	0.07	1.98	0.07	0.13	0.10	0.05	0.07	0.06	0.14	0.14	0.13	0.09
1985	0.17	2.12	0.13	0.10	0.06	0.03	0.03	0.02	0.04	0.04	0.20	0.19
1986	0.69	2.36	0.16	0.07	0.04	0.03	0.12	0.08	0.33	0.23	0.16	0.50
1987	0.27	2.05	0.06	0.03	0.04	0.03	0.07	0.08	0.19	0.16	0.15	0.15
1988	0.14	0.40	0.08	0.05	0.04	0.02	0.10	0.08	0.05	0.08	0.08	0.16
1989	1.43	4.22	0.65	0.11	0.15	0.10	0.16	0.16	0.59	0.39	0.28	0.26
1990	0.49	2.21	0.11	0.05	0.02	0.02	0.02	0.02	0.03	0.03	0.08	0.08
1991	0.16	0.57	0.11	0.06	1.05	0.38	0.08	0.09	0.13	0.22	1.23	0.71
1992	1.36	2.98	0.29	0.16	0.09	0.05	0.10	0.08	1.43	0.71	0.37	24.78
1993	7.63	2.23	0.26	0.15	0.09	0.08	0.07	0.09	0.11	0.23	2.71	3.12
1994	4.74	2.12	3.07	11.84	0.48	0.45	0.54	1.57	0.64	0.32	0.51	0.17
1995	0.20	2.13	0.30	0.15	0.08	0.06	0.05	0.03	0.02	0.06	0.15	0.19
1996	3.44	51.36	6.36	0.13	0.06	0.05	13.84	4.43	3.23	2.32	1.86	0.46
1997	0.18	2.06	0.06	0.06	0.04	0.22	0.13	0.07	0.07	0.07	0.24	0.24
1998	0.13	2.06	0.11	0.06	0.04	0.03	0.05	0.05	0.04	0.26	0.19	0.10
1999	0.06	1.96	0.07	0.10	0.20	0.36	0.23	0.11	0.08	0.05	0.05	0.07
	1	<0.2		1	0.2-1.0	2	1.0-8.0		3	>8.0		

ii. Occurrence and duration of different abiotic states under Scenario 1

Estimated occurrence and duration of the different Abiotic States in the Kromme Estuary and Geelhoutboom tributary under Scenario 1, based on simulated monthly river inflow into the Kromme Estuary and Geelhoutboom tributary are indicated in Tables C-14 and C-11, respectively.

To provide a conceptual overview of the annual distribution of Abiotic States under Scenario 1 for



the Kromme Estuary and Geelhoutboom tributary, median monthly flows (representative of seasonal conditions) and 10%ile flows (representative of drought conditions) were used to depict the situation for normal and drought periods:

8.5 Scenario 2

i. Seasonal variability in river inflow

Monthly simulated runoff data (73-year period) for Scenario 2 into the Kromme Estuary and Geelhoutboom tributary are provided in Tables C-15 and C-11, respectively. A summary of the flow distributions (mean monthly flows in m³/s), derived from the simulated data set, is provided below (hatched months represent flows less than 0.2 m³/s when hypersaline conditions could potentially develop):

Kromme: Summary of flow distributions for Scenario 2 (10 x 10⁶ m³ released in Oct and Jan)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	14.33	26.15	5.61	6.08	2.03	3.68	4.20	26.53	14.61	17.05	23.44	26.19
90%ile	4.82	1.64	0.61	2.07	0.34	0.40	0.48	1.62	2.87	2.19	3.50	10.87
80%ile	3.16	0.61	0.28	2.02	0.16	0.23	0.22	0.43	0.52	0.48	1.19	3.33
70%ile	2.44	0.38	0.21	1.98	0.10	0.14	0.15	0.18	0.28	0.32	0.40	0.59
60%ile	2.26	0.30	0.16	1.95	0.09	0.10	0.12	0.14	0.17	0.23	0.31	0.42
50%ile	2.17	0.22	0.11	1.94	0.06	0.06	0.09	0.09	0.13	0.18	0.24	0.31
40%ile	2.11	0.18	0.11	1.93	0.04	0.05	0.07	0.08	0.10	0.15	0.19	0.21
30%ile	2.06	0.16	0.10	1.92	0.04	0.05	0.05	0.06	0.08	0.12	0.15	0.17
20%ile	2.03	0.13	0.08	1.91	0.04	0.03	0.05	0.05	0.06	0.09	0.11	0.13
10%ile	1.97	0.11	0.06	1.90	0.02	0.03	0.03	0.03	0.04	0.06	0.08	0.10
1%ile	0.57	0.04	0.04	0.11	0.02	0.02	0.02	0.02	0.02	0.02	0.04	0.06

Geelhoutboom: Summary of flow distributions for Scenario 2 (Present State)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	1.05	1.21	0.34	0.43	0.29	0.32	0.28	1.17	0.90	1.18	1.72	2.09
90%ile	0.37	0.36	0.05	0.00	0.05	0.07	0.08	0.18	0.21	0.18	0.41	0.57
80%ile	0.24	0.11	0.01	0.00	0.00	0.01	0.04	0.07	0.10	0.11	0.17	0.22
70%ile	0.13	0.06	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.07	0.13	0.16
60%ile	0.08	0.03	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.04	0.08	0.09
50%ile	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.05	0.06
40%ile	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.03
30%ile	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02
20%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

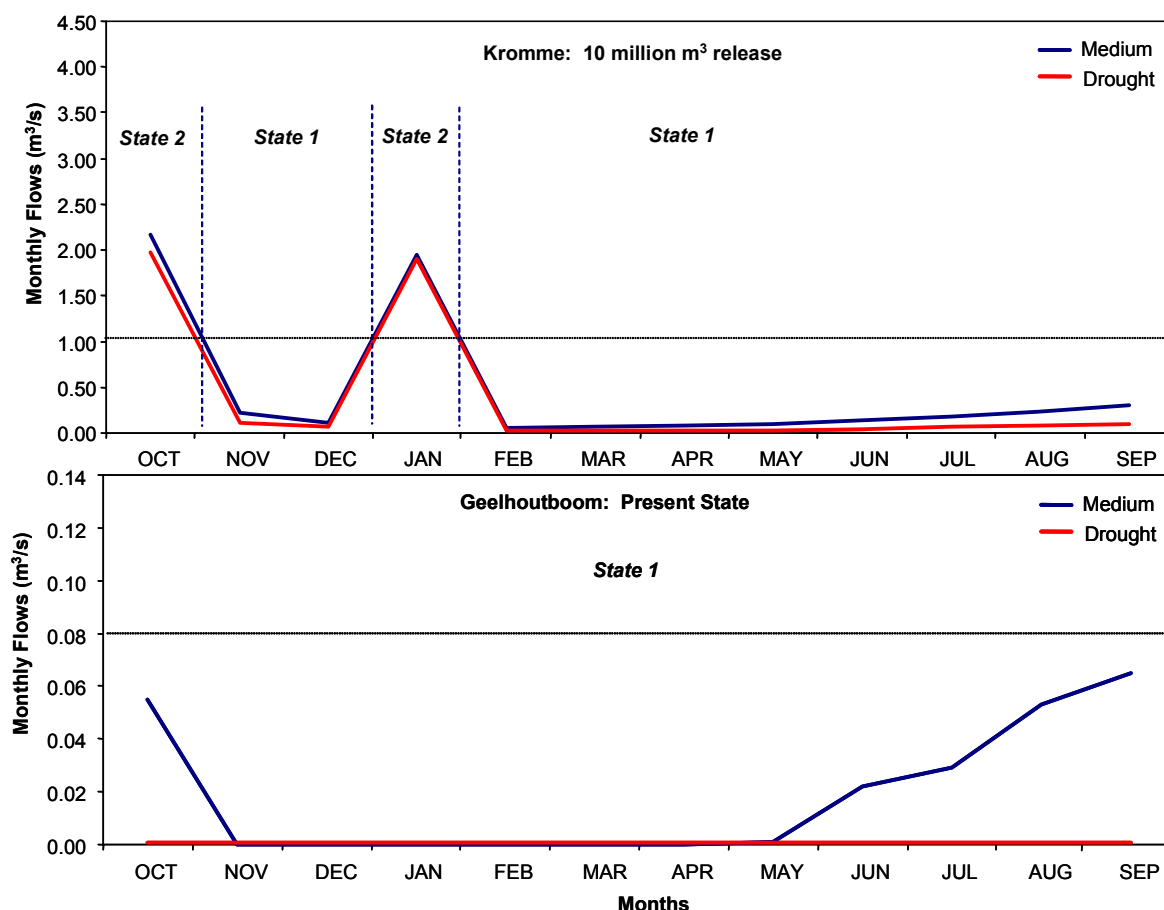
Table C-15 Monthly simulated runoff data in m³/s (73-year period) for Scenario 2 (10 x 10⁶ m³ released in Oct and Jan) into the Kromme Estuary

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1927	1.96	0.09	0.05	1.90	0.03	1.00	0.49	0.10	0.09	0.07	0.09	0.21
1928	2.12	0.37	0.16	1.93	0.04	0.03	0.02	0.05	0.06	0.19	0.19	0.41
1929	2.17	0.16	0.08	1.90	0.17	0.14	0.10	0.08	0.13	0.13	0.24	0.25
1930	2.16	0.17	0.07	1.95	0.05	0.04	0.05	0.04	0.04	0.12	0.11	0.46
1931	3.05	0.53	0.69	3.76	0.74	0.15	0.10	0.06	0.08	0.14	0.11	27.26
1932	10.02	1.89	0.27	1.94	0.05	0.05	0.08	2.69	2.67	0.89	19.66	3.88
1933	2.14	0.41	0.16	1.95	0.09	0.11	0.08	0.06	0.06	0.22	0.20	0.15
1934	4.40	0.65	0.11	1.90	0.04	0.03	0.08	24.57	7.87	2.14	4.88	2.47
1935	2.31	0.42	0.23	1.96	0.04	0.05	0.05	0.18	0.14	0.15	0.13	0.12
1936	2.13	1.47	0.42	1.96	0.05	0.06	0.05	0.03	0.08	0.12	0.11	0.17
1937	2.03	0.15	0.11	1.94	0.04	0.02	0.05	0.08	0.09	0.08	0.08	0.12
1938	2.01	0.21	0.11	1.91	0.37	0.34	0.19	0.12	0.09	0.12	0.86	0.57
1939	2.19	0.29	0.27	2.05	0.33	0.37	0.21	0.14	0.23	0.27	0.19	0.30
1940	2.07	0.15	0.07	1.91	0.04	0.04	0.06	0.05	0.26	0.18	0.11	0.11
1941	2.05	0.15	0.37	2.11	0.09	0.05	0.05	0.15	0.17	0.15	0.15	0.12
1942	2.09	0.17	0.11	1.99	0.07	0.05	0.05	0.05	0.76	0.49	0.37	0.55
1943	2.19	0.74	0.42	1.99	0.08	0.16	0.15	31.58	8.98	2.81	1.23	3.36
1944	2.35	0.22	0.10	1.91	0.04	0.02	0.02	8.94	11.65	2.20	1.35	0.35
1945	2.57	0.32	0.10	1.91	0.03	0.31	0.17	0.06	0.05	0.20	0.25	0.23
1946	2.15	0.16	0.07	1.90	0.02	0.13	0.12	0.27	0.39	11.37	1.93	0.58
1947	2.10	0.18	0.10	1.92	0.04	0.06	0.43	0.23	0.13	0.12	0.11	0.16
1948	2.65	0.39	0.11	1.92	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.04
1949	1.90	1.67	0.64	1.92	0.03	0.02	0.04	0.04	0.04	0.17	0.35	0.31
1950	2.24	1.17	0.50	2.83	0.41	0.09	0.05	0.08	0.12	0.66	0.51	6.01
1951	2.81	0.20	0.09	1.93	0.62	0.24	0.07	0.08	0.10	0.10	0.35	15.11
1952	3.69	0.32	0.16	1.93	0.05	0.03	0.03	0.03	0.06	0.18	0.31	0.66
1953	25.40	9.07	0.24	1.96	0.04	0.40	0.24	1.25	1.34	6.28	18.41	6.63
1954	2.17	0.19	0.10	1.93	4.55	7.82	0.45	0.29	0.11	0.12	0.53	0.36
1955	2.09	5.50	4.69	1.95	0.09	0.13	0.09	1.07	2.92	0.51	0.24	11.38
1956	9.42	16.27	3.65	2.07	0.19	0.16	0.14	0.20	0.28	0.26	0.31	5.29
1957	5.39	0.24	0.09	1.90	0.02	0.08	0.06	0.47	0.31	0.16	0.34	0.30
1958	2.08	0.13	0.08	2.13	0.16	0.08	0.16	0.15	0.12	0.14	0.30	0.28
1959	2.16	0.17	0.11	2.10	0.12	0.05	0.05	0.10	0.13	0.24	0.23	0.37
1960	2.03	0.11	0.07	1.92	0.08	0.57	0.36	0.44	0.34	0.29	0.27	0.20
1961	2.03	0.11	0.05	1.90	0.03	0.18	0.18	0.11	0.08	0.08	1.12	0.63
1962	2.40	0.30	0.11	2.06	0.10	0.89	0.77	0.41	0.27	0.24	0.21	0.17
1963	1.99	0.13	0.21	2.04	0.09	0.08	0.07	0.05	0.52	0.36	0.46	12.23
1964	7.11	0.38	0.16	1.93	0.02	0.06	0.08	0.14	0.15	0.13	0.12	0.10
1965	2.39	3.25	0.21	1.98	0.10	0.05	0.04	0.05	0.05	0.04	0.11	0.14
1966	2.00	0.15	0.10	1.91	0.02	0.03	0.77	0.65	0.40	0.35	0.34	0.49
1967	2.20	0.18	0.09	1.91	0.02	0.03	0.18	0.16	22.20	7.64	2.81	25.78
1968	4.29	0.30	0.13	1.93	0.04	0.04	0.04	0.03	0.07	0.08	0.08	0.12
1969	2.05	0.13	0.05	1.90	0.04	0.03	0.02	0.01	0.02	0.01	0.06	0.08
1970	2.01	0.10	0.37	2.03	0.13	0.10	0.76	0.67	0.51	2.96	33.18	11.82
1971	2.22	1.52	0.13	1.92	0.22	0.11	0.15	0.14	0.14	0.17	0.21	0.15
1972	1.96	0.06	0.03	1.88	0.02	0.08	0.10	0.09	0.08	0.05	0.05	0.06
1973	1.94	0.10	0.06	2.04	0.17	0.75	0.40	0.25	0.26	0.17	1.29	7.19
1974	2.50	0.19	0.08	1.93	0.10	0.19	0.12	0.05	0.06	0.09	0.19	0.31
1975	2.08	0.11	0.08	1.91	0.06	0.24	0.29	0.19	0.17	0.42	0.43	0.31
1976	2.67	0.54	0.18	1.94	0.34	0.18	0.11	5.01	4.17	0.46	0.29	0.67
1977	2.26	0.36	0.21	1.96	0.04	0.07	0.14	0.11	0.18	0.18	0.18	0.17
1978	2.26	0.41	0.21	2.03	0.11	0.06	0.05	0.07	0.10	0.34	15.67	14.44
1979	2.36	0.25	0.11	1.94	0.04	0.02	0.05	0.05	0.08	0.08	0.07	0.12
1980	2.03	0.17	0.13	2.23	0.17	2.08	0.93	9.05	9.83	0.65	14.56	8.81
1981	5.64	1.09	0.18	1.95	0.04	0.05	0.70	0.78	0.13	0.31	0.22	0.20
1982	2.02	0.10	0.05	1.89	0.02	0.01	0.02	0.03	0.06	31.65	13.04	0.50
1983	4.00	0.25	0.10	1.91	0.02	0.06	0.05	0.03	0.04	0.09	0.09	0.09
1984	1.93	0.05	0.07	1.99	0.10	0.05	0.07	0.06	0.13	0.14	0.12	0.09
1985	2.04	0.19	0.13	1.97	0.06	0.03	0.03	0.02	0.04	0.04	0.19	0.17
1986	2.56	0.43	0.16	1.93	0.04	0.03	0.12	0.08	0.33	0.22	0.15	0.46
1987	2.14	0.12	0.06	1.03	0.04	0.03	0.07	0.08	0.18	0.16	0.14	0.14
1988	0.61	0.10	0.08	0.08	0.04	0.02	0.10	0.08	0.05	0.08	0.08	0.15
1989	3.31	2.29	0.65	1.98	0.15	0.10	0.16	0.16	0.59	0.39	0.28	0.26
1990	2.36	0.28	0.11	1.91	0.02	0.02	0.02	0.02	0.03	0.03	0.08	0.08
1991	0.45	0.12	0.11	0.13	1.05	0.38	0.08	0.09	0.12	0.23	1.23	0.71
1992	3.23	1.06	0.29	2.03	0.09	0.05	0.10	0.08	1.43	0.71	0.37	25.22
1993	7.82	0.30	0.84	2.01	0.09	0.08	0.07	0.09	0.11	0.22	3.67	3.28
1994	4.92	0.24	5.25	12.02	0.67	0.61	0.67	1.71	0.77	0.46	0.65	0.33
1995	2.07	0.20	0.30	2.01	0.08	0.06	0.05	0.03	0.02	0.06	0.15	0.17
1996	3.67	51.55	6.54	2.00	0.06	0.05	12.58	4.57	3.36	2.45	1.99	0.61
1997	2.05	0.13	0.06	1.93	0.04	0.22	0.13	0.07	0.07	0.07	0.22	0.20
1998	2.00	0.13	0.11	1.93	0.04	0.03	0.05	0.05	0.04	0.25	0.18	0.10
1999	1.93	0.03	0.07	1.97	0.20	0.36	0.23	0.11	0.08	0.05	0.05	0.06
	1	<0.2		1	0.2-1.0		2	1.0-8.0		3	>8.0	

ii. Occurrence and duration of different abiotic states under Scenario 2

Estimated occurrence and duration of the different Abiotic States in the Kromme Estuary and Geelhoutboom tributary under Scenario 2, based on simulated monthly river inflow into the Kromme Estuary and Geelhoutboom tributary are indicated in Tables C-15 and C-11, respectively.

To provide a conceptual overview of the annual distribution of Abiotic States under Scenario 2 for the Kromme Estuary and Geelhoutboom tributary, median monthly flows (representative of seasonal conditions) and 10%ile flows (representative of drought conditions) were used to depict the situation for normal and drought periods:



8.6 Scenario 3

i. Seasonal variability in river inflow

Monthly simulated runoff data (73-year period) for Scenario 3 into the Kromme Estuary and Geelhoutboom tributary are provided in Tables C-16 and C-10, respectively. A summary of the flow distributions (mean monthly flows in m³/s), derived from the simulated data set, is provided below (hatched months represent flows less than 0.2 m³/s when hypersaline conditions can potentially develop):

Kromme: Summary of flow distributions for Scenario 3 (Present State)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	13.60	25.85	5.08	4.70	2.48	3.67	4.41	26.39	14.37	16.56	22.96	25.98
90%ile	4.50	1.72	0.56	0.28	0.40	0.45	0.48	1.48	2.66	1.97	2.98	10.39
80%ile	1.79	0.82	0.35	0.23	0.24	0.31	0.25	0.49	0.56	0.44	1.09	3.08
70%ile	0.76	0.48	0.28	0.19	0.18	0.22	0.21	0.22	0.32	0.31	0.43	0.61
60%ile	0.47	0.39	0.23	0.16	0.16	0.17	0.17	0.18	0.21	0.26	0.36	0.41
50%ile	0.36	0.30	0.19	0.15	0.13	0.14	0.14	0.15	0.18	0.22	0.29	0.35
40%ile	0.31	0.27	0.18	0.14	0.11	0.13	0.13	0.14	0.15	0.20	0.25	0.26
30%ile	0.25	0.24	0.17	0.13	0.11	0.12	0.11	0.11	0.13	0.17	0.20	0.22
20%ile	0.22	0.22	0.15	0.12	0.11	0.11	0.10	0.10	0.11	0.13	0.17	0.17
10%ile	0.19	0.19	0.14	0.11	0.10	0.10	0.09	0.09	0.08	0.11	0.14	0.16
1%ile	0.11	0.13	0.11	0.09	0.07	0.03	0.07	0.06	0.06	0.05	0.09	0.10

Geelhoutboom: Summary of flow distributions for Scenario 3 (as per River Class C/D)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	1.07	1.21	0.36	0.43	0.32	0.35	0.28	1.18	0.90	1.18	1.72	2.08
90%ile	0.37	0.36	0.10	0.05	0.08	0.09	0.09	0.20	0.21	0.18	0.41	0.58
80%ile	0.24	0.14	0.07	0.03	0.04	0.05	0.04	0.08	0.11	0.12	0.17	0.23
70%ile	0.15	0.11	0.05	0.03	0.02	0.03	0.03	0.04	0.07	0.08	0.13	0.17
60%ile	0.10	0.08	0.04	0.02	0.02	0.02	0.03	0.03	0.04	0.05	0.09	0.11
50%ile	0.08	0.05	0.03	0.02	0.01	0.01	0.02	0.02	0.03	0.04	0.06	0.08
40%ile	0.06	0.04	0.02	0.01	0.01	0.01	0.02	0.02	0.02	0.04	0.04	0.05
30%ile	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.03	0.04
20%ile	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.03
10%ile	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02
1%ile	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01

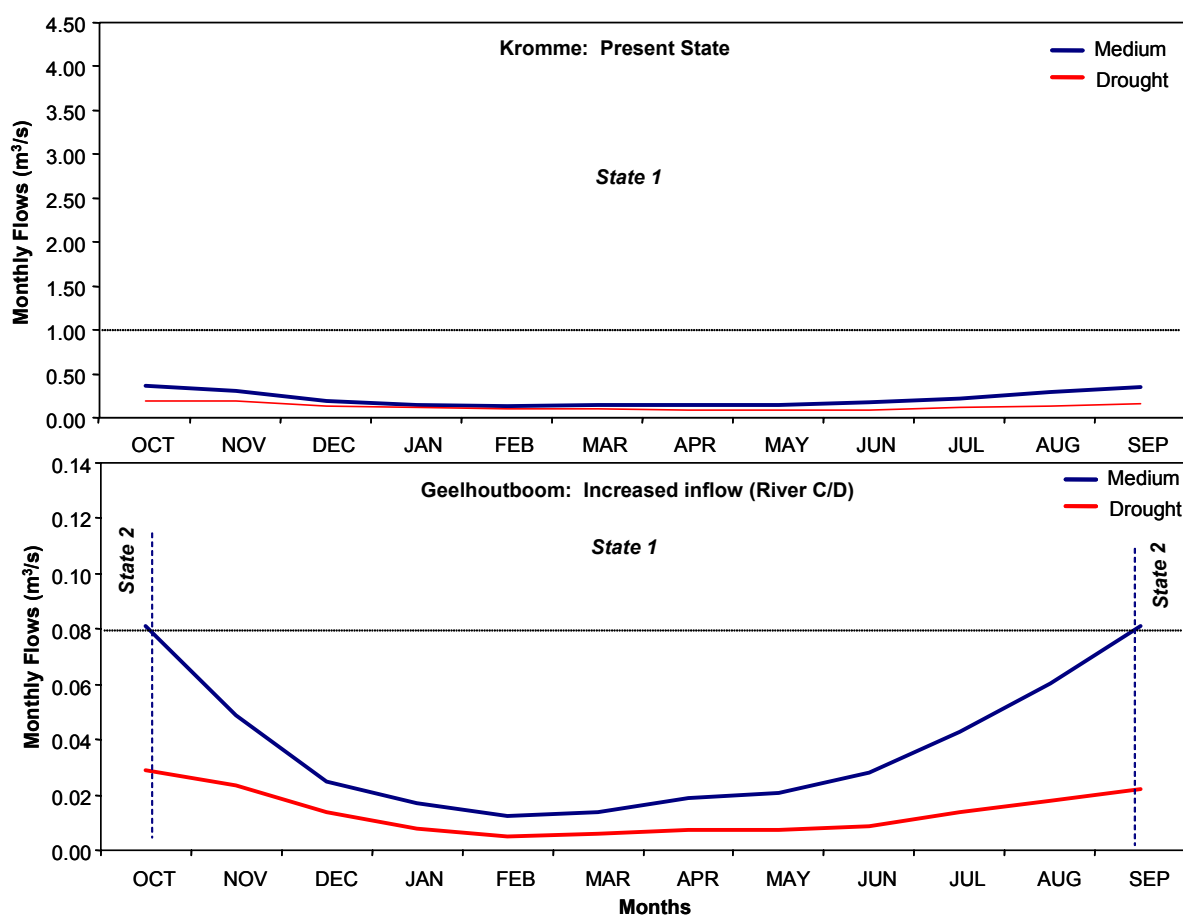
Table C-16 Monthly simulated runoff data in m³/s (73-year period) for Scenario 3 (as per River Class C/D) into the Geelhoutboom Tributary

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1927	0.02	0.02	0.01	0.01	0.01	0.22	0.13	0.02	0.02	0.01	0.03	0.07
1928	0.08	0.12	0.04	0.01	0.01	0.01	0.01	0.01	0.01	0.04	0.04	0.08
1929	0.06	0.04	0.02	0.01	0.04	0.03	0.02	0.02	0.03	0.03	0.05	0.05
1930	0.08	0.04	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.03	0.03	0.10
1931	0.34	0.14	0.24	0.67	0.22	0.03	0.02	0.01	0.02	0.04	0.03	1.95
1932	0.77	0.25	0.06	0.02	0.01	0.01	0.02	0.10	0.07	0.06	0.57	0.29
1933	0.06	0.14	0.04	0.02	0.02	0.03	0.02	0.01	0.01	0.05	0.04	0.03
1934	0.24	0.12	0.02	0.01	0.01	0.01	0.02	1.01	0.55	0.17	0.20	0.19
1935	0.14	0.13	0.05	0.02	0.01	0.01	0.01	0.04	0.03	0.03	0.03	0.03
1936	0.06	0.35	0.11	0.02	0.01	0.01	0.01	0.01	0.02	0.03	0.02	0.04
1937	0.04	0.03	0.03	0.02	0.01	0.00	0.01	0.02	0.02	0.02	0.02	0.03
1938	0.03	0.05	0.02	0.01	0.08	0.07	0.04	0.03	0.02	0.03	0.26	0.19
1939	0.10	0.08	0.07	0.04	0.09	0.13	0.06	0.04	0.08	0.09	0.05	0.11
1940	0.05	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.06	0.04	0.03	0.03
1941	0.04	0.03	0.08	0.05	0.02	0.01	0.01	0.03	0.04	0.03	0.03	0.03
1942	0.05	0.04	0.02	0.03	0.02	0.01	0.01	0.01	0.16	0.15	0.13	0.19
1943	0.08	0.26	0.12	0.03	0.02	0.04	0.03	1.64	0.70	0.18	0.12	0.23
1944	0.16	0.05	0.02	0.01	0.01	0.00	0.01	0.22	0.34	0.17	0.15	0.11
1945	0.25	0.07	0.02	0.01	0.01	0.07	0.04	0.01	0.01	0.04	0.05	0.05
1946	0.09	0.04	0.01	0.01	0.00	0.03	0.03	0.06	0.08	0.39	0.21	0.11
1947	0.06	0.04	0.02	0.01	0.01	0.01	0.09	0.05	0.03	0.03	0.02	0.03
1948	0.27	0.10	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.01
1949	0.01	0.41	0.18	0.01	0.01	0.00	0.01	0.01	0.01	0.04	0.08	0.07
1950	0.10	0.41	0.14	0.34	0.11	0.02	0.01	0.02	0.03	0.22	0.18	0.28
1951	0.14	0.05	0.02	0.01	0.13	0.05	0.02	0.02	0.02	0.03	0.13	0.89
1952	0.36	0.09	0.04	0.01	0.01	0.01	0.01	0.01	0.01	0.04	0.07	0.16
1953	1.82	0.72	0.05	0.02	0.01	0.09	0.05	0.42	0.26	0.23	1.19	0.49
1954	0.08	0.04	0.02	0.01	0.57	0.24	0.03	0.03	0.03	0.04	0.17	0.12
1955	0.06	0.36	0.09	0.02	0.02	0.03	0.02	0.31	0.19	0.08	0.08	0.38
1956	0.72	0.37	0.19	0.05	0.04	0.04	0.03	0.06	0.10	0.09	0.11	0.25
1957	0.18	0.05	0.02	0.01	0.00	0.02	0.01	0.10	0.07	0.04	0.07	0.09
1958	0.06	0.03	0.02	0.06	0.03	0.02	0.03	0.03	0.03	0.03	0.10	0.08
1959	0.09	0.04	0.03	0.05	0.03	0.01	0.01	0.02	0.03	0.05	0.05	0.08
1960	0.04	0.03	0.01	0.01	0.02	0.12	0.08	0.16	0.11	0.10	0.09	0.05
1961	0.04	0.03	0.01	0.01	0.01	0.04	0.04	0.03	0.02	0.02	0.31	0.20
1962	0.19	0.08	0.03	0.04	0.02	0.24	0.27	0.14	0.08	0.08	0.07	0.04
1963	0.03	0.03	0.05	0.04	0.02	0.02	0.02	0.01	0.11	0.12	0.17	2.04
1964	0.71	0.12	0.04	0.01	0.00	0.01	0.02	0.03	0.03	0.03	0.03	0.02
1965	0.11	0.21	0.05	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.03	0.03
1966	0.03	0.03	0.02	0.01	0.00	0.01	0.17	0.15	0.14	0.12	0.11	0.17
1967	0.09	0.04	0.02	0.01	0.01	0.01	0.04	0.04	1.43	0.63	0.19	1.00
1968	0.39	0.08	0.03	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.03
1969	0.04	0.03	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.02
1970	0.03	0.02	0.08	0.04	0.03	0.02	0.16	0.17	0.18	1.05	2.92	0.97
1971	0.08	0.08	0.03	0.01	0.05	0.03	0.03	0.03	0.03	0.04	0.06	0.03
1972	0.02	0.01	0.01	0.00	0.00	0.02	0.02	0.02	0.02	0.01	0.01	0.01
1973	0.01	0.02	0.01	0.04	0.04	0.16	0.08	0.06	0.08	0.05	0.46	0.60
1974	0.19	0.04	0.02	0.01	0.02	0.04	0.03	0.01	0.01	0.02	0.04	0.07
1975	0.05	0.03	0.02	0.01	0.01	0.05	0.06	0.04	0.04	0.12	0.15	0.09
1976	0.29	0.17	0.04	0.02	0.07	0.04	0.02	0.64	0.34	0.10	0.10	0.20
1977	0.12	0.11	0.05	0.02	0.01	0.01	0.03	0.03	0.04	0.04	0.04	0.04
1978	0.13	0.13	0.05	0.04	0.02	0.01	0.01	0.01	0.02	0.07	1.25	0.61
1979	0.16	0.05	0.03	0.02	0.01	0.00	0.01	0.01	0.02	0.02	0.01	0.03
1980	0.04	0.04	0.03	0.08	0.04	0.62	0.32	0.28	0.20	0.12	0.88	0.38
1981	0.32	0.15	0.04	0.02	0.01	0.01	0.15	0.08	0.04	0.07	0.07	0.06
1982	0.03	0.02	0.01	0.00	0.00	0.00	0.00	0.01	0.01	1.52	0.69	0.12
1983	0.09	0.05	0.02	0.01	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.02
1984	0.01	0.01	0.01	0.03	0.02	0.01	0.02	0.01	0.03	0.03	0.03	0.02
1985	0.04	0.04	0.03	0.02	0.01	0.01	0.01	0.00	0.01	0.01	0.04	0.04
1986	0.15	0.09	0.04	0.01	0.01	0.01	0.03	0.02	0.07	0.05	0.03	0.12
1987	0.06	0.03	0.01	0.01	0.01	0.01	0.02	0.02	0.04	0.04	0.03	0.03
1988	0.03	0.02	0.02	0.01	0.01	0.00	0.02	0.02	0.01	0.02	0.02	0.03
1989	0.37	0.81	0.17	0.03	0.03	0.02	0.03	0.03	0.21	0.13	0.09	0.08
1990	0.17	0.07	0.02	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.02
1991	0.04	0.03	0.02	0.01	0.23	0.08	0.02	0.02	0.03	0.07	0.44	0.23
1992	0.48	0.37	0.06	0.04	0.02	0.01	0.02	0.02	0.43	0.24	0.13	2.21
1993	0.78	0.08	0.07	0.03	0.02	0.02	0.02	0.02	0.02	0.05	0.22	0.16
1994	0.11	0.04	0.08	0.09	0.08	0.08	0.08	0.09	0.05	0.05	0.06	0.05
1995	0.06	0.05	0.09	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.03	0.04
1996	0.37	2.22	0.67	0.03	0.01	0.01	0.17	0.20	0.17	0.14	0.14	0.08
1997	0.04	0.03	0.01	0.01	0.01	0.05	0.03	0.01	0.02	0.01	0.05	0.04
1998	0.03	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.06	0.04	0.02
1999	0.01	0.01	0.01	0.02	0.04	0.08	0.05	0.03	0.02	0.01	0.01	0.01
1	<0.08				2		0.08-1.0		3		>1.0	

ii. Occurrence and duration of different abiotic states under Scenario 3

Estimated occurrence and duration of the different Abiotic States in the Kromme Estuary and Geelhoutboom tributary under Scenario 3, based on simulated monthly river inflow into the Kromme Estuary and Geelhoutboom tributary are indicated in Tables C-16 and C-10, respectively.

To provide a conceptual overview of the annual distribution of Abiotic States under the Reference Condition for the Kromme Estuary and Geelhoutboom tributary, median monthly flows (representative of seasonal conditions) and 10%ile flows (representative of drought conditions) were used to depict the situation for normal and drought periods:



8.7 Scenario 4

i. Seasonal variability in river inflow

Monthly simulated runoff data (73-year period) for Scenario 4 into the Kromme Estuary and Geelhoutboom tributary are provided in Tables C-14 and C-16, respectively. A summary of the flow distributions (mean monthly flows in m³/s), derived from the simulated data set, is provided below (hatched months represent flows less than 0.2 m³/s when hypersaline conditions can potentially develop):

Kromme: Summary of flow distributions for Scenario 4 (5 x 10⁶ m³ release in Nov)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	13.66	25.96	5.02	4.68	2.32	3.63	4.55	26.02	14.72	16.25	22.94	26.05
90%ile	4.62	3.02	0.48	0.20	0.34	0.40	0.48	2.04	2.74	2.05	2.71	10.36
80%ile	1.95	2.41	0.27	0.15	0.16	0.23	0.22	0.38	0.52	0.38	1.10	3.17
70%ile	0.77	2.31	0.21	0.11	0.10	0.14	0.15	0.17	0.28	0.31	0.39	0.56
60%ile	0.41	2.22	0.16	0.08	0.09	0.10	0.12	0.14	0.18	0.23	0.31	0.40
50%ile	0.30	2.14	0.11	0.08	0.06	0.06	0.09	0.09	0.14	0.18	0.25	0.30
40%ile	0.24	2.11	0.11	0.06	0.04	0.05	0.07	0.08	0.11	0.15	0.20	0.22
30%ile	0.19	2.09	0.10	0.05	0.04	0.05	0.05	0.06	0.08	0.12	0.15	0.18
20%ile	0.16	2.06	0.08	0.05	0.04	0.03	0.05	0.05	0.06	0.09	0.11	0.13
10%ile	0.13	2.03	0.06	0.03	0.02	0.03	0.03	0.03	0.04	0.06	0.08	0.10
1%ile	0.05	0.52	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.04	0.06

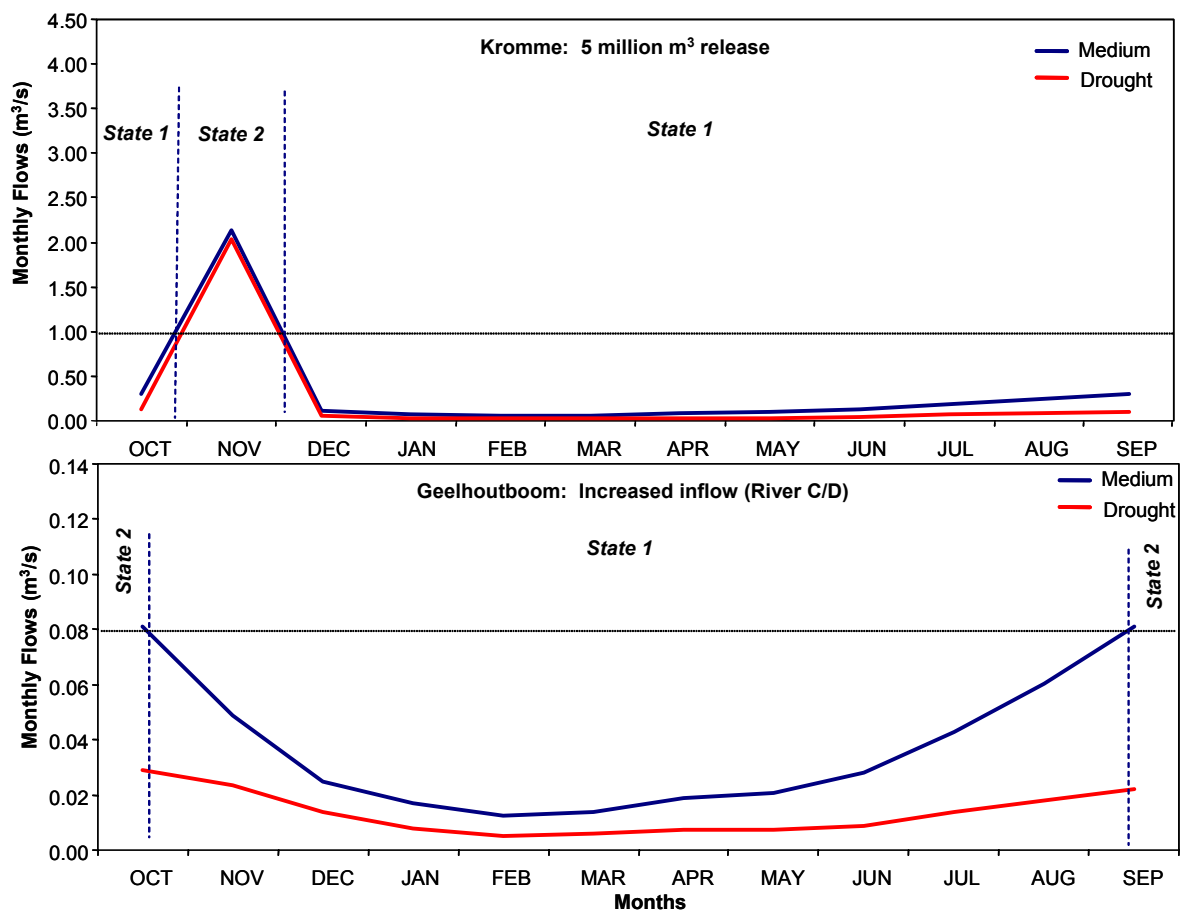
Geelhoutboom: Summary of flow distributions for Scenario 4 (as per River Class C/D)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	1.07	1.21	0.36	0.43	0.32	0.35	0.28	1.18	0.90	1.18	1.72	2.08
90%ile	0.37	0.36	0.10	0.05	0.08	0.09	0.09	0.20	0.21	0.18	0.41	0.58
80%ile	0.24	0.14	0.07	0.03	0.04	0.05	0.04	0.08	0.11	0.12	0.17	0.23
70%ile	0.15	0.11	0.05	0.03	0.02	0.03	0.03	0.04	0.07	0.08	0.13	0.17
60%ile	0.10	0.08	0.04	0.02	0.02	0.02	0.03	0.03	0.04	0.05	0.09	0.11
50%ile	0.08	0.05	0.03	0.02	0.01	0.01	0.02	0.02	0.03	0.04	0.06	0.08
40%ile	0.06	0.04	0.02	0.01	0.01	0.01	0.02	0.02	0.02	0.04	0.04	0.05
30%ile	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.03	0.04
20%ile	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.03
10%ile	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02
1%ile	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01

ii. Occurrence and duration of different abiotic states for Scenario 4

Estimated occurrence and duration of the different Abiotic States in the Kromme Estuary and Geelhoutboom tributary under Scenario 4, based on simulated monthly river inflow into the Kromme Estuary and Geelhoutboom tributary are indicated in Tables C-14 and C-16, respectively.

To provide a conceptual overview of the annual distribution of Abiotic States under the Reference Condition for the Kromme Estuary and Geelhoutboom tributary, median monthly flows (representative of seasonal conditions) and 10%ile flows (representative of drought conditions) were used to depict the situation for normal and drought periods:



8.8 Scenario 5

i. Seasonal variability in river inflow

Monthly simulated runoff data (73-year period) for Scenario 5 into the Kromme Estuary and Geelhoutboom tributary are provided in Tables C-17 and C-11, respectively. A summary of the flow distributions (mean monthly flows in m³/s), derived from the simulated data set, is provided below (hatched months represent flows less than 0.2 m³/s when hypersaline conditions can potentially develop):

Kromme: Summary of flow distributions for Scenario 5 (7.5 x 10⁶ m³ release in Oct and Nov)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	14.29	26.06	5.12	4.71	2.24	3.66	4.64	27.62	15.03	17.43	23.57	26.39
90%ile	4.76	2.02	0.48	0.20	0.34	0.40	0.48	2.39	2.83	2.12	4.15	10.73
80%ile	3.07	1.39	0.27	0.15	0.16	0.23	0.22	0.43	0.52	0.43	1.17	3.25
70%ile	2.35	1.25	0.21	0.11	0.10	0.14	0.15	0.18	0.28	0.31	0.40	0.57
60%ile	2.16	1.16	0.16	0.08	0.09	0.10	0.12	0.14	0.17	0.22	0.32	0.43
50%ile	2.07	1.08	0.11	0.08	0.06	0.06	0.09	0.09	0.13	0.18	0.24	0.30
40%ile	2.02	1.05	0.11	0.06	0.04	0.05	0.07	0.08	0.10	0.15	0.19	0.21
30%ile	1.97	1.02	0.10	0.05	0.04	0.05	0.05	0.06	0.08	0.12	0.15	0.17
20%ile	1.93	1.00	0.08	0.05	0.04	0.03	0.05	0.05	0.06	0.09	0.11	0.13
10%ile	1.87	0.97	0.06	0.03	0.02	0.03	0.03	0.03	0.04	0.06	0.08	0.10
1%ile	0.57	0.52	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.04	0.06

Geelhoutboom: Summary of flow distributions for Scenario 5 (Present State)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	1.05	1.21	0.34	0.43	0.29	0.32	0.28	1.17	0.90	1.18	1.72	2.09
90%ile	0.37	0.36	0.05	0.00	0.05	0.07	0.08	0.18	0.21	0.18	0.41	0.57
80%ile	0.24	0.11	0.01	0.00	0.00	0.01	0.04	0.07	0.10	0.11	0.17	0.22
70%ile	0.13	0.06	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.07	0.13	0.16
60%ile	0.08	0.03	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.04	0.08	0.09
50%ile	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.05	0.06
40%ile	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.03
30%ile	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02
20%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

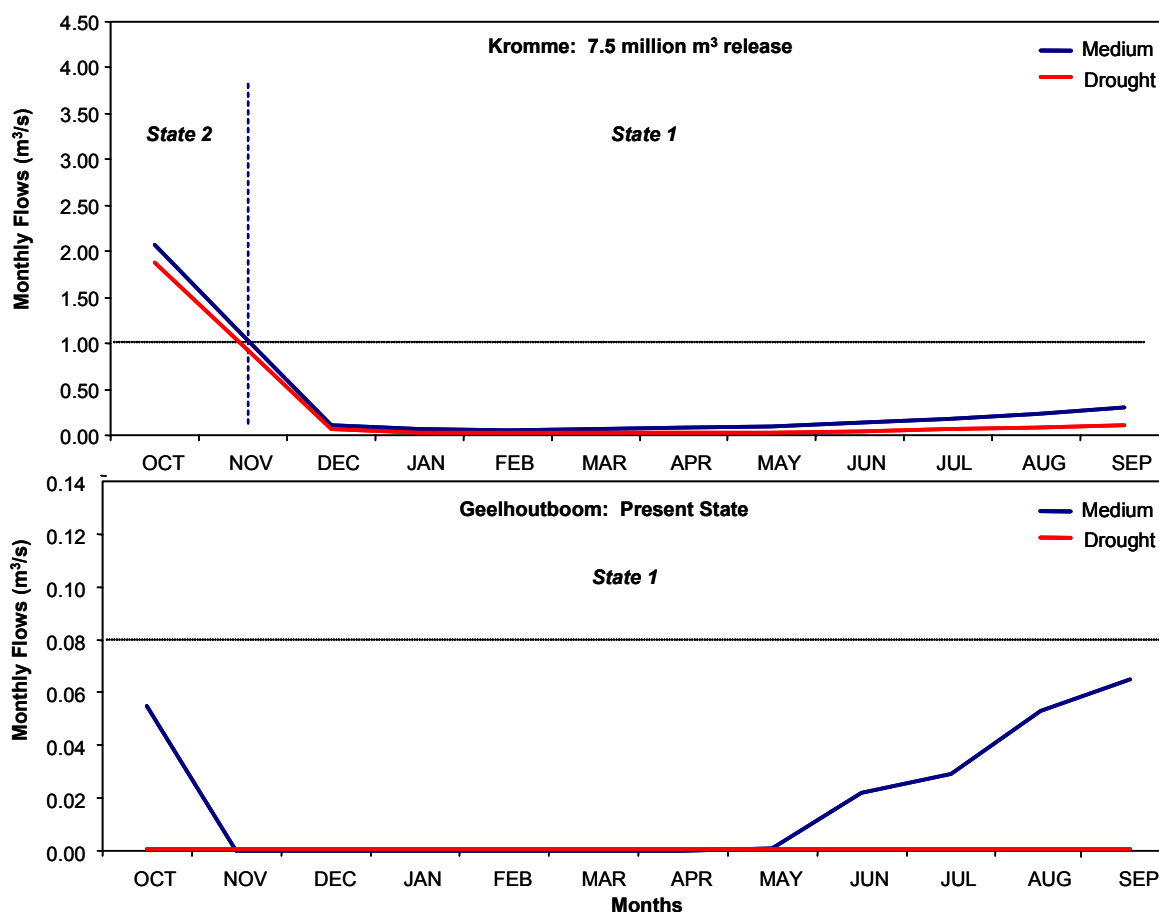
Table C-17 Monthly simulated runoff data in m³/s (73-year period) for Scenario 5 (7.5 x 10⁶ m³ release in Oct and Nov) into the Kromme Estuary

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1927	1.87	0.95	0.05	0.03	0.03	1.00	0.49	0.10	0.09	0.07	0.09	0.21
1928	2.02	1.24	0.16	0.06	0.04	0.03	0.02	0.05	0.06	0.19	0.19	0.41
1929	2.07	1.03	0.08	0.03	0.17	0.14	0.10	0.08	0.13	0.13	0.24	0.25
1930	2.06	1.03	0.07	0.08	0.05	0.04	0.05	0.04	0.04	0.12	0.11	0.46
1931	2.96	1.40	0.69	1.90	0.74	0.15	0.10	0.06	0.08	0.14	0.11	28.18
1932	9.93	1.80	0.27	0.08	0.05	0.05	0.08	4.06	2.60	0.82	19.59	3.80
1933	2.04	1.28	0.16	0.08	0.09	0.11	0.08	0.06	0.06	0.22	0.20	0.15
1934	4.50	1.29	0.11	0.04	0.04	0.03	0.08	25.26	7.80	2.07	4.81	2.39
1935	2.22	1.29	0.23	0.09	0.04	0.05	0.05	0.18	0.14	0.15	0.13	0.12
1936	2.04	1.94	0.42	0.09	0.05	0.06	0.05	0.03	0.08	0.12	0.11	0.17
1937	1.94	1.02	0.11	0.08	0.04	0.02	0.05	0.08	0.09	0.08	0.08	0.12
1938	1.92	1.08	0.11	0.04	0.37	0.34	0.19	0.12	0.09	0.12	0.86	0.57
1939	2.10	1.16	0.27	0.19	0.33	0.37	0.21	0.14	0.23	0.27	0.19	0.30
1940	1.97	1.02	0.07	0.05	0.04	0.04	0.06	0.05	0.26	0.18	0.11	0.11
1941	1.96	1.02	0.37	0.24	0.09	0.05	0.05	0.15	0.17	0.15	0.15	0.12
1942	1.99	1.03	0.11	0.12	0.07	0.05	0.05	0.05	0.76	0.49	0.37	0.55
1943	2.10	1.61	0.42	0.13	0.08	0.16	0.15	33.69	8.92	2.74	1.17	3.29
1944	2.26	1.09	0.10	0.05	0.04	0.02	0.02	9.40	11.58	2.13	1.29	0.35
1945	2.47	1.19	0.10	0.05	0.03	0.31	0.17	0.06	0.05	0.20	0.25	0.23
1946	2.05	1.03	0.07	0.03	0.02	0.13	0.12	0.27	0.39	11.82	1.86	0.50
1947	2.01	1.05	0.10	0.05	0.04	0.06	0.43	0.23	0.13	0.12	0.11	0.16
1948	2.56	1.26	0.11	0.05	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.04
1949	1.81	2.54	0.64	0.05	0.03	0.02	0.04	0.04	0.04	0.17	0.35	0.31
1950	2.15	2.04	0.50	0.96	0.41	0.09	0.05	0.08	0.12	0.66	1.18	6.05
1951	2.71	1.07	0.09	0.07	0.62	0.24	0.07	0.08	0.10	0.10	0.35	15.31
1952	3.60	1.19	0.16	0.07	0.05	0.03	0.03	0.03	0.06	0.18	0.31	0.66
1953	25.50	8.97	0.24	0.09	0.04	0.40	0.24	1.25	2.70	6.22	18.35	6.55
1954	2.07	1.06	0.10	0.06	5.30	7.74	0.39	0.23	0.11	0.12	0.48	0.36
1955	1.99	5.18	4.60	0.08	0.09	0.13	0.09	2.54	2.86	0.44	0.24	11.23
1956	9.33	16.18	3.56	0.21	0.19	0.16	0.14	0.20	0.28	0.26	0.38	6.45
1957	5.30	1.10	0.09	0.03	0.02	0.08	0.06	0.47	0.31	0.16	0.34	0.30
1958	1.99	1.00	0.08	0.26	0.16	0.08	0.16	0.15	0.12	0.14	0.30	0.28
1959	2.07	1.03	0.11	0.23	0.12	0.05	0.05	0.10	0.13	0.24	0.23	0.93
1960	1.93	0.98	0.07	0.05	0.08	0.57	0.36	0.44	0.34	0.29	0.27	0.20
1961	1.94	0.98	0.05	0.03	0.03	0.18	0.18	0.11	0.08	0.08	1.12	0.63
1962	2.31	1.17	0.11	0.19	0.10	0.89	0.77	0.41	0.27	0.24	0.21	0.17
1963	1.90	1.00	0.21	0.18	0.09	0.08	0.07	0.05	0.52	0.36	0.46	12.99
1964	7.02	1.25	0.16	0.06	0.02	0.06	0.08	0.14	0.15	0.13	0.12	0.10
1965	2.30	3.35	0.21	0.11	0.10	0.05	0.04	0.05	0.05	0.04	0.11	0.14
1966	1.90	1.02	0.10	0.05	0.02	0.03	0.77	0.65	0.40	0.35	0.34	0.49
1967	2.10	1.05	0.09	0.04	0.02	0.03	0.18	0.16	23.89	7.58	2.74	25.70
1968	4.20	1.16	0.13	0.06	0.04	0.04	0.04	0.03	0.07	0.08	0.08	0.12
1969	1.95	1.00	0.05	0.03	0.04	0.03	0.02	0.01	0.02	0.01	0.06	0.08
1970	1.91	0.97	0.37	0.16	0.13	0.10	0.76	0.67	0.51	2.96	33.81	11.74
1971	2.13	1.43	0.13	0.05	0.22	0.11	0.15	0.14	0.14	0.17	0.21	0.15
1972	1.86	0.93	0.03	0.01	0.02	0.08	0.10	0.09	0.08	0.05	0.05	0.06
1973	1.84	0.97	0.06	0.18	0.17	0.75	0.40	0.25	0.26	0.17	1.29	8.64
1974	2.41	1.05	0.08	0.06	0.10	0.19	0.12	0.05	0.06	0.09	0.19	0.31
1975	1.98	0.98	0.08	0.05	0.06	0.24	0.29	0.19	0.17	0.42	0.43	0.31
1976	2.58	1.40	0.18	0.08	0.34	0.18	0.11	5.84	4.11	0.39	0.29	0.56
1977	2.16	1.23	0.21	0.09	0.04	0.07	0.14	0.11	0.18	0.18	0.18	0.17
1978	2.16	1.27	0.21	0.16	0.11	0.06	0.05	0.07	0.10	0.34	16.08	14.36
1979	2.27	1.12	0.11	0.08	0.04	0.02	0.05	0.05	0.08	0.08	0.07	0.12
1980	1.94	1.04	0.13	0.37	0.17	2.08	0.93	9.70	9.77	0.59	14.49	8.73
1981	5.54	1.38	0.18	0.08	0.04	0.05	0.70	1.79	0.13	0.19	0.22	0.20
1982	1.92	0.97	0.05	0.02	0.02	0.01	0.02	0.03	0.06	31.84	12.97	0.42
1983	3.90	1.08	0.10	0.04	0.02	0.06	0.05	0.03	0.04	0.09	0.09	0.09
1984	1.84	0.92	0.07	0.13	0.10	0.05	0.07	0.06	0.13	0.14	0.12	0.09
1985	1.94	1.06	0.13	0.10	0.06	0.03	0.03	0.02	0.04	0.04	0.19	0.17
1986	2.46	1.30	0.16	0.07	0.04	0.03	0.12	0.08	0.33	0.22	0.15	0.46
1987	2.04	0.99	0.06	0.03	0.04	0.03	0.07	0.08	0.18	0.16	0.14	0.14
1988	0.61	0.40	0.08	0.05	0.04	0.02	0.10	0.08	0.05	0.08	0.08	0.15
1989	3.22	3.16	0.65	0.11	0.15	0.10	0.16	0.16	0.59	0.39	0.28	0.26
1990	2.27	1.15	0.11	0.05	0.02	0.02	0.02	0.02	0.03	0.03	0.08	0.08
1991	0.45	0.57	0.11	0.06	1.05	0.38	0.08	0.09	0.12	0.23	1.23	0.71
1992	3.14	1.92	0.29	0.16	0.09	0.05	0.10	0.08	1.43	0.71	0.37	25.20
1993	7.73	1.17	0.26	0.15	0.09	0.08	0.07	0.09	0.11	0.22	4.50	3.20
1994	4.83	1.06	4.28	11.93	0.58	0.53	0.60	1.64	0.70	0.39	0.58	0.25
1995	1.98	1.07	0.30	0.15	0.08	0.06	0.05	0.03	0.02	0.06	0.15	0.17
1996	3.76	51.45	6.45	0.13	0.06	0.05	14.17	4.50	3.29	2.39	1.93	0.53
1997	1.95	1.00	0.06	0.06	0.04	0.22	0.13	0.07	0.07	0.07	0.22	0.20
1998	1.91	1.00	0.11	0.06	0.04	0.03	0.05	0.05	0.04	0.25	0.18	0.10
1999	1.83	0.90	0.07	0.10	0.20	0.36	0.23	0.11	0.08	0.05	0.05	0.06
	1	<0.2		1	0.2-1.0		2	1.0-8.0		3	>8.0	

ii. Occurrence and duration of different abiotic states under Scenario 5

Estimated occurrence and duration of the different Abiotic States in the Kromme Estuary and Geelhoutboom tributary under Scenario 5, based on simulated monthly river inflow into the Kromme Estuary and Geelhoutboom tributary are indicated in Tables C-17 and C-11, respectively.

To provide a conceptual overview of the annual distribution of Abiotic States under the Reference Condition for the Kromme Estuary and Geelhoutboom tributary, median monthly flows (representative of seasonal conditions) and 10%ile flows (representative of drought conditions) were used to depict the situation for normal and drought periods:



9. CONCLUDING REMARKS

9.1 Kromme Estuary – marine dominated system

The major conclusions of the hydrodynamic and water quality study is that the Kromme Estuary was a marine dominated system under its Reference Condition, i.e. under the Reference Condition the estuary often functioned as an “arm of the sea”. The results indicate that a classical “full salinity gradient” was often not present during the low flow periods under the Reference Condition. By the classical “full salinity gradient” the authors refer to estuaries such as the Breede Estuary, in which freshwater is mixed throughout the water column in the upper reaches to form a freshwater zone.

This conclusion is based on the results from the 3-dimensional model simulations and is also concluded from the templates for the Reference Condition and Present State Scenarios.

The hydrodynamics of the Kromme Estuary are largely determined by its bathymetry. The lower 5 km of the estuary is relatively shallow with depths of about 2 metres, a meandering channel and sandbanks. Further upstream, the estuary deepens to depths of 3 to 5 metres to the limit of tidal influence approximately 14 km from the mouth, where the river flow is spilled over a rocky sill onto the surface water of the estuary. The Kromme Estuary's bathymetry prevents efficient mixing under low flow conditions in the upper and middle reaches of the estuary, resulting in strong stratification with limited flushing of the more saline bottom waters (between 10 and 35 ppt).

The analysis of the simulated runoff data show that the river inflow ($>8 \text{ m}^3/\text{s}$) under which this strong stratification would disintegrate, a “full salinity gradient” could develop but this very rarely occurred under the Reference Condition and almost never at Present State.

The perception that a “full salinity gradient” existed under the Natural Condition was enhanced by the way in which measured salinity concentrations were presented in the literature, referring especially to the measurements undertaken in 1972 and 1973 (CSIR, 1988, based on Hecht, 1973). Maximum, average and minimum salinities measured during this period are plotted in a figure, but the graph for the minimum concentrations was based on the surface salinity measurements. Note that these values are only valid for the relatively small surface layer and not for the entire water column and are misleading because they create the impression that a full salinity gradient was present.

This perception also developed because very little reliable pre-dam(s) development information is available on the ecology. Many specialists therefore undertook comparisons between the Kromme and adjacent estuarine systems, such as the Gamtoos Estuary. Unfortunately, the relationship between flow and bathymetry differs significantly for the neighbouring estuaries as they are shallower and narrower in their upper reaches than the Kromme Estuary. For such estuaries even a relatively little river inflow will then be enough for the development of a freshwater mixing zone. The majority of the estuaries in the region therefore always develop “full salinity gradients” caused by their bathymetry. The existence of a rocky sill and depths of 3 to 5 m at the upstream end of the Kromme Estuary is very rare and is indirectly the most important reason why “a full salinity gradient” does not develop at low and medium river flows.

9.2 Salinity gradient in the Geelhoutboom River

The Geelhoutboom River is the main tributary of the Kromme Estuary. It becomes shallower and narrower with distance upstream and while it is small, it normally has a “full salinity gradient” even when the river flow is low. For the purpose of the assessment conducted in this study, it was assumed that the salinity gradient is only of significance if it can be detected between 1 and 2 km from the confluence with the Kromme at values ranging between 20–25 ppt.

Until about 15 years ago, the catchment of the Geelhoutboom was apparently largely undeveloped and this small component was probably in a healthy state because of its river flow. It was also a remaining source of freshwater for the Kromme Estuary, after the large dams had been constructed. Unfortunately some relatively large farm dams have recently been constructed in the catchment of the Geelhoutboom River and VERY LITTLE to NO river flow is at present entering the estuary.

The “full salinity gradient” has now disappeared for most of the year in this tributary and salinity values are at present that of the Kromme Estuary (35 ppt).

9.3 Freshwater signal to the marine environment

In evaluating the various simulated monthly runoff Scenarios special significance needs to be given to the freshwater signal that it sends to the marine environment during average and high flow events.

Under the Present State, no signal is being propagated to the marine environment. It should also be noted that under Scenario 3 (only increase the flows to the Geelhoutboom tributary, without increasing the flows in the Kromme) the freshwater signal will only reach the main Kromme Estuary and very little of it would be detectable in the marine environment.

In comparison, sending the signal to the marine environment (Scenario 1, 2 and 5) without providing the required habitat in the Geelhoutboom tributary (Scenario 4) might also lead to unsuccessful recruitment as new recruits might not have the ideal habitat available for survival.

Therefore, the importance of the freshwater signal to the marine environment and its role in the recruitment of invertebrate and fish species needs to be evaluated in the workshop discussions.

9.4 Retention time versus phytoplankton production

The retention time of the Kromme Estuary is related to the hydrodynamics of the system, which in turn is determined by the bathymetry. For the most part the estuary displays strong stratification with the upper layers of the water column being replenished over very short periods, ranging between 1 day to 3.5 weeks, while the bottom layers of the water column can remain isolated for weeks to months at a time.

In discussions relating to phytoplankton production and retention time, the major focus was on the upper layers of the water column, as production peaks at about 0.5 m due to light availability.

During high flow events ($>8.0 \text{ m}^3/\text{s}$) the average retention time for freshwater entering the Kromme is between 1-6 days, which does not allow for successful utilisation of the increased nutrient load that is coming from the catchment. Most of this water would initially be in the upper layer, with some mixing of bottom layers depending on the size and duration of flows. Under these high flow conditions, water from the Kromme Estuary also flushes a significant part of the Geelhoutboom tributary within 1–3 weeks, thereby also reducing the retention time in the tributary.

Under low flow conditions ($<1.0 \text{ m}^3/\text{s}$) the retention time for freshwater entering the Kromme varies between 2–7 weeks in the upper layer of the water column. This increase in retention time is inversely related to a decrease in the nutrient load entering the system. Under low flow conditions the water flushed into the Geelhoutboom tributary from the Kromme remains 2–4 weeks. Bearing in mind that the Geelhoutboom tributary might in this case be the ideal habitat for phytoplankton production, it is only ~2.7 km in length and does not provide extensive water column habitat.

The Geelhoutboom tributary flushes within a day or two at flow of $> 1.0 \text{ m}^3/\text{s}$ coming from its catchment, while at flows less than $> 1.0 \text{ m}^3/\text{s}$ very little nutrients enter the system to allow for phytoplankton production.

In short, the Kromme Estuary has low phytoplankton production due to the low nutrient load entering it from the catchments under average and low flow conditions, but also because the residence time of the upper layers of the estuary is too short to utilise the nutrients entering the system effectively.

9.5 Shortcomings of 1-D modelling

A number of previous hydrodynamic studies of the Kromme Estuary have been undertaken using the one-dimensional MIKE11 model (Hecht, 1973). However, due to the nature of the hydrodynamic functioning of the Kromme Estuary under the present low freshwater inflow regime, a more sophisticated modelling software is required. Specifically, the one-dimensional modelling is unable to adequately account for the stratified flow regime that exists in the Kromme Estuary under most freshwater inflow Scenarios, particularly after periods of low freshwater inflow, which result in the estuary assuming predominantly marine characteristics. Freshwater inflows into the estuary under these conditions result in highly stratified conditions and residence times for freshwater in the estuary are typically much shorter than anticipated and than those indicated by a one-dimensional model (Van Ballegooyen *et al.*, 2004).

9.6 3-D modelling exaggerates mixing, needs field validation

To adequately simulate the hydrodynamic conditions in the Kromme, a full three-dimensional hydrodynamic simulation is required. However, even the fully three-dimensional hydrodynamic model has its limitation in simulating the highly stratified conditions that occur, particularly within the upper reaches of the Kromme Estuary. The use of a σ -coordinate system and limitations on the vertical resolution in the model (and associated requirement for a small time step), result in a degree of artificial vertical mixing that over time results in the artificial reduction of vertical stratification in the model. The consequences of this artificial mixing is that the model simulations will, to a degree, overestimate the residence time of freshwater in the system and may indicate a greater degree of flushing of the bottom waters by fresh surface waters than occurs in reality. These effects will be particularly apparent in the upper reaches where the freshwater enters the Kromme Estuary. However, an evaluation of more extreme inflows than generally simulated here (van Ballegooyen *et al.*, 2004) suggested that the model results would remain sufficiently accurate (in terms of vertical stratification of the water column) for a period of approximately one month or more provided that the vertical resolution in the model is adequate.

Given the uncertainties in the modelling results introduced by potential artificial vertical mixing, the Scenarios predicted and decided upon in this report should be investigated by test release(s) to provide the necessary field validation for the predicted hydrodynamic states of the estuary for any inflow Scenario that is to be considered as part of a management strategy.

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ATTACHMENT A^C

FIELD DATA COLLECTED DURING 2004/2005 AS PART OF THIS STUDY

Date	Stn No	Time	Distance mouth (km)	Long	Lat	Depth	Temp	Sal	pH	DO (mg/l)	Turbidity (NTU)	NO ₂ -N (µg/l)	NO ₃ -N (µg/l)	NH ₃ -N (µg/l)	PO ₄ -P (µg/l)	SiO ₄ -Si (µg/l)
18/02/2004	1	11:50:00	0.00	34 08.513	24 50.682	1.90	21.6	34.8								
						1.50	21.6	34.8								
						1.00	21.6	35.4								
						0.00	21.6	35.4	7.81	7.5	0.10	<10	<10	<10	<10	73
	2	12:04:00	2.50	34 08.533	24 49.253	2.35	23.7	35.8		6.4						
						2.00	23.7	36.5		6.3						
						1.50	23.7	36.4		6.4						
						1.00	23.6	36.4		6.5						
						0.50	23.7	36.4		6.4						
						0.00	23.6	36.3	7.76	6.5	0.17	<10	35	<10	15	305
						2.17	23.8	35.3		6.1						
	3	12:26:00	3.30	34 08.472	24 48.423	1.50	23.8	36.7		6.1						
						1.00	23.8	36.7		6.1						
						0.50	23.8	36.7		6.2						
						0.00	23.9	36.7	7.88	6.4	0.24	<10	40	<10	25	533
						2.23	24.2	36.9		5.7						
	4	12:45:00	5.40	34 07.495	24 47.845	1.50	24.3	37.4		6.1						
						1.00	24.3	37.3		6.2						
						0.50	24.3	37.2		6.2						
						0.00	24.3	37.2	7.91	6.4	0.22	10	17	<10	20	633
						2.32	24.5	38.2		6.2						
	5	12:58:00	7.70	34 06.640	24 46.991	1.50	24.6	38.3		6.3						
						1.00	24.7	38.3		6.5						
						0.50	24.7	38.2		6.6						
						0.00	24.6	38.2	7.84	6.8	0.44	<10	<10	<10	21	650
						1.00	25.1	38.9		6.3						
	6	13:12:00	9.50	34 06.330	24 46.334	0.50	25.2	38.9		6.3						
						0.00	25.5	38.8	7.89	6.8	0.17	<10	<10	<10	28	658
						0.60	25.3	39.0		5.7						
						0.00	25.3	39.0	7.91	5.8	0.24	<10	18	<10	40	830

Date	Stn No	Time	Distance mouth (km)	Long	Lat	Depth	Temp	Sal	pH	DO (mg/l)	Turbidity (NTU)	NO ₂ -N (µg/l)	NO ₃ -N (µg/l)	NH ₃ -N (µg/l)	PO ₄ -P (µg/l)	SiO ₄ -Si (µg/l)
18/02/2004	8	14:01:00	8.40	34 06.827	24 46.318	2.80	24.8	38.4	7.93	6.4	0.20	<10	<10	<10	22	550
						2.00	25.0	38.4		6.6						
						1.50	25.1	38.4		6.6						
						0.00	25.1	38.4		6.4						
						0.50	25.2	38.4		6.6						
						0.00	25.2	38.3	7.86	6.7	0.19	<10	<10	<10	18	641
	9	14:19:00	10.50	34 07.427	24 45.473	2.90	24.8	38.7	8.04	6.6	0.22	<10	<10	<10	17	716
						2.50	24.8	38.7		6.5						
						2.00	24.9	38.7		6.6						
						1.50	25.0	38.7		6.6						
						1.00	25.1	38.7		6.8						
						0.50	25.4	38.6		7.2						
	10	14:51:00	11.40	34 07.031	24 44.835	0.00	25.5	38.6	8.00	7.3	0.28	<10	<10	<10	18	708
						2.00	25.1	38.3		6.8						
						1.50	25.1	38.8		6.7						
						1.00	25.1	38.6		6.8						
						0.50	25.1	38.8		6.7						
						0.00	25.1	38.7	8.01	6.7	0.09	<10	<10	<10	17	608
	11	15:05:00	11.90	34 07.114	24 44.381	4.39	24.8	38.7	8.00	6.0	0.13	<10	<10	<10	19	516
						4.00	24.8	38.8		5.9						
						3.50	24.9	38.7		6.1						
						3.00	25.1	38.9		6.4						
						2.50	25.4	38.8		6.7						
						2.00	25.4	38.8		6.8						
						1.50	25.4	38.8		6.8						
						1.00	25.4	38.8		6.8						
						0.50	25.5	38.8		6.8						
						0.00	25.5	38.8	7.95	6.9	0.20	<10	<10	<10	11	633

Date	Stn No	Time	Distance mouth (km)	Long	Lat	Depth	Temp	Sal	pH	DO (mg/l)	Turbidity (NTU)	NO ₂ -N (µg/l)	NO ₃ -N (µg/l)	NH ₃ -N (µg/l)	PO ₄ -P (µg/l)	SiO ₄ -Si (µg/l)
	12	15:54:00	12.40	34 06.765	24 43.572	3.97	24.8	38.6	8.02	6.1	0.15	<10	<10	<10	19	698
						3.50	25.1	38.8		6.5						
						3.00	25.2	38.7		6.7						
						2.50	25.2	38.7		6.8						
						2.00	25.2	38.7		6.7						
						1.50	25.2	38.7		6.7						
						1.00	25.2	38.7		6.7						
						0.50	25.3	38.7		6.8						
						0.00	25.3	38.7	8.03	6.7	0.38	<10	14	<10	32	666
	13	15:38:00	13.40	34 06.695	24 43.546	2.07	25.5	38.8		7.0						
						1.50	25.3	38.7		6.9						
						1.00	25.7	38.8		7.3						
						0.50	25.7	38.8		7.4						
						0.00	25.8	38.7	8.02	7.4	0.17	<10	<10	<10	20	600

Date	Stn No	Time	Distance mouth (km)	Long	Lat	Depth	Temp	Sal
19/02/2004	1	10:41:00	0.00	34 08.513	24 50.682	1.30	22.8	35.7
	1	10:41:00				0.50	22.8	33.7
	1	10:41:00				0.00	22.8	35.6
	2	11:00:00	2.50	34 08.533	24 49.253	1.76	23.3	36.3
	2	11:00:00				1.50	23.3	36.3
	2	11:00:00				1.00	23.3	36.3
	2	11:00:00				0.50	23.3	36.3
	2	11:00:00				0.00	23.3	36.2
	3	11:20:00	3.30	34 08.472	24 48.423	1.90	23.6	36.5
	3	11:20:00				1.50	23.6	36.5
	3	11:20:00				1.00	23.6	36.5
	3	11:20:00				0.50	23.7	36.6
	3	11:20:00				0.00	23.7	36.4
	4	11:37:00	5.40	34 07.495	24 47.845	1.15	24.1	35.0
	4	11:37:00				0.50	24.0	36.9
	4	11:37:00				0.00	24.0	36.8
	5	11:45:00	7.70	34 06.640	24 46.6991	1.65	24.5	38.1
	5	11:45:00				1.00	24.6	38.1
	5	11:45:00				0.50	24.6	38.1
	6	11:50:00	9.50	34 06.330	24 46.334	0.00	24.7	38.1
	6	11:50:00				0.40	24.9	39.0
	6	11:50:00				0.00	25.1	38.8
	7	11:55:00	10.30			0.40	25.2	39.4
	7	11:55:00				0.00	25.4	38.9
	8	12:05:00	8.40	34 06.827	24 46.318	2.25	24.6	38.6
	8	12:05:00				1.50	24.6	38.6
	8	12:05:00				1.00	24.8	38.6
	8	12:05:00				0.50	24.8	38.5
	8	12:05:00				0.00	24.8	38.5

Date	Stn No	Time	Distance mouth (km)	Long	Lat	Depth	Temp	Sal	Stn No	Time	Distance mouth (km)	Long	Lat	Depth	Sal
19/02/2004	9	12:12:00	10.50	34 07.247	24 45.473	2.95	24.6	38.8	12	12:38:00	13.10	34 06.765	24 43.572	3.06	38.8
	9	12:12:00				2.50	24.7	38.8	12	12:38:00				2.50	38.8
	9	12:12:00				2.00	24.8	38.8	12	12:38:00				2.00	38.8
	9	12:12:00				1.50	24.8	38.8	12	12:38:00				1.50	38.8
	9	12:12:00				1.00	24.8	38.8	12	12:38:00				1.00	38.8
	9	12:12:00				0.50	24.8	38.8	12	12:38:00				0.50	38.8
	9	12:12:00				0.00	24.8	38.7	12	12:38:00				0.00	38.7
	10	12:51:00	11.40	34 07.031	24 44.835	1.30	24.9	38.9	13	12:42:00	13.40	34 06.695	24 43.546	0.80	38.8
	10	12:51:00				0.50	24.9	38.9	13	12:42:00				0.50	38.9
	10	12:51:00				0.00	24.9	35.9	13	12:42:00				0.00	38.8
	11	12:20:00	11.90	34 07.114	24 44.381	3.90	24.5	38.4							
	11	12:20:00				3.50	24.6	38.8							
	11	12:20:00				3.00	24.7	38.8							
	11	12:20:00				2.50	24.8	38.8							
	11	12:20:00				2.00	24.9	38.8							
	11	12:20:00				1.50	24.9	38.8							
	11	12:20:00				1.00	25.0	38.8							
	11	12:20:00				0.50	24.9	38.8							
	11	12:20:00				0.00	24.9	38.8							
	12A	12:28:00	12.50	34 06.994	24 44.077	4.88	24.7	38.7							
	12A	12:28:00				4.50	24.8	38.8							
	12A	12:28:00				4.00	24.8	38.8							
	12A	12:28:00				3.50	24.8	38.8							
	12A	12:28:00				3.00	24.8	38.8							
	12A	12:28:00				2.50	24.8	38.8							
	12A	12:28:00				2.00	24.8	38.8							
	12A	12:28:00				1.50	24.8	38.8							
	12A	12:28:00				1.00	24.8	38.8							
	12A	12:28:00				0.50	24.9	38.8							
	12A	12:28:00				0.00	24.8	38.5							

Date	Stn No	Time	Distance mouth (km)	Long (S)	Lat (E)	Depth	Temp	Sal	pH	DO	Turbidity	Secchi Depth (m)	NO ₂ -N (µg/l)	NO ₃ -N (µg/l)	NH ₃ -N (µg/l)	PO ₄ -P (µg/l)	SiO ₄ -Si (µg/l)
30/07/2004	Sea					0.00		35.00	8.07				<10	26	18	13	189
						0.10											
						0.00	14.47	36.40	7.92	8.5	0.51	1.00	<10	20	<10	<10	129
						s: 34.13910	e: 24.83162	0.50	14.47								
						1.00	14.46	36.40									
						1.58	14.46	36.34									
						2.50											
						34 08.533	24 49.253	0.00	14.23		0.75	0.75	<10	11	<10	15	167
						s: 34.14066	e: 24.31237	0.50	14.24								
						1.00	14.24	36.44									
						1.44	14.24	36.41									
						3.30											
						34 08.472	24 48.423	0.00	14.10	8.5	0.62	0.65	<10	<10	<10	11	242
						s: 34.13850	e: 24.80574	0.50	14.10								
						1.00	14.11	36.47									
						1.50	14.12	36.47									
						1.89	14.12	36.47									
						5.40											
						34 07.495	24 47.845	0.00	13.44		0.81	0.50	<10	<10	<10	20	317
						s: 34.12241	e: 24.79276	0.50	13.44								
						1.00	13.43	36.54									
						1.50	13.43	36.53									
						2.00	13.43	36.54									
						2.50	13.43	36.54									
						3.00	13.43	36.54									
						3.70	13.44	36.05									
						7.70											
						34 06.640	24 46.991	0.00	13.38	8.05	3.1	1.80	<10	<10	<10	24	327
						s: 34.11114	e: 24.78234	0.50	13.39								
						1.00	13.32	36.55									
						1.50	13.38	36.55									
						2.00	13.37	36.54									

Date	Stn No	Time	Distance mouth (km)	Long (S)	Lat (E)	Depth	Temp	Sal	pH	DO	Turbidity	Secchi Depth (m)	NO ₂ -N (µg/l)	NO ₃ -N (µg/l)	NH ₃ -N (µg/l)	PO ₄ -P (µg/l)	SiO ₄ -Si (µg/l)
	6		9.50	34 06.330	24 46.334	0.00	13.38	35.89	7.92		0.55	0.33	<10	<10	43	74	527
				s: 34.10611	e: 24.75781	0.33	13.39	35.87									
	7		10.20	s: 34.10771	e: 24.75834	0.00	13.18	34.96	8.08	8.3	0.40	0.60	<10	<10	55	74	598
						0.64	13.15	35.02									
	8		8.40	34 06.827	24 46.318	0.00	13.34	36.58	8.07		0.7	1.50	<10	<10	<10	25	317
				s: 34.11319	e: 24.77359	0.50	13.34	36.58									
						1.00	13.34	36.58									
						1.40	13.34	36.58									
	9		10.50	34 07.427	24 45.473	0.00	13.43	36.59	7.99	6.7	0.9	1.25	<10	<10	<10	25	356
				s: 34.12000	e: 24.76092	0.50	13.43	36.59									
						1.00	13.43	36.59									
						1.50	13.42	36.59									
						2.00	13.43	36.59									
						2.50	13.42	36.59									
						3.00	13.42	36.59									
						3.51	13.43	36.59									
	13		13.40	34 06.695	24 43.546	0.00	13.42	36.46	7.88		0.63		<10	26	10	19	433
				s: 34.11274	e: 24.72567	0.50	13.44	36.44									
						1.00	13.45	36.45									
						1.50	13.46	36.44									
						2.00	13.46	36.45									
						2.62	14.45	36.45									
River						0.00			6.93				10	88	<10	10	2885

Data Collected From Impofu Dam

Date	Stn No	Depth	Temp	EC (mS/m)	Sal	pH	DO (mg/l)	Turbidity (NTU)	SS (mg/l)	NO ₂ -N (µg/l)	NO ₃ -N (µg/l)	NH ₃ -N (µg/l)	PO ₄ -P (µg/l)	SiO ₄ -Si (µg/l)
15/11/1998	ME	0	21.3		0.4									
		1	20.3		0.3									
		10	20.2		0.3									
		20	19.5		0.3									
		50	19.0		0.3									
	MF	0	20.8		0.3									
		10	19.7		0.3									
		40	18.5		0.3									
16/11/1998	D1	0.00								9	339	51	6	
	Scharler	1.00								9	348	47	5	
	D1	10.00								11	295	44	4	
	D1	20.00								9	326	39	5	
	D1	50.00								10	316	36	6	
	D2	0.00								10	363	76	5	
	D2	10.00								9	399	75	5	
	D2	40.00								8	378	72	5	
06/12/2004	ME	0	23.4		0.3	8.32	10.5	22.1	2.4	<10	144	19	<10	1927
		10	23.2		0.3	8.31	9.0	17.3	1.2	<10	143	<10	<10	1927
		20	22.4		0.0	8.28	5.9	43.9	0.8	<10	199	11	<10	1979
		30	18.0		0.3	8.15	6.2	9.6	4.8	<10	206	<10	<10	2031
		35	20.4		0.0	8.06	5.8	44.4	11.2	<10	250	15	<10	2292
	MF	0	20.7		0.0	7.74	9.4	41.2	2.4	<10	140	<10	<10	1875
		10	20.4		0.0	7.43	9.5	41.0	1.2	<10	142	12	<10	1849
		20	21.0		0.0	8.03	5.2	38.8	1.2	<10	206	13	<10	2057
		30	19.8		0.0	8.18	4.4	49.2	10.8	<10	243	21	<10	2266

Date	Stn No	Depth	Temp	EC (mS/m)	Sal	pH	DO (mg/l)	Turbidity (NTU)	SS (mg/l)	NO ₂ -N (µg/l)	NO ₃ -N (µg/l)	NH ₃ -N (µg/l)	PO ₄ -P (µg/l)	SiO ₄ -Si (µg/l)
18/01/2005	ME	35.98	14.68	0.614		6.64	4.44	44.60	11.6	<10	107	9	<10	1770
		36.74	14.63	0.614		6.62	4.22	44.40						
		34.51	14.61	0.614		6.56	3.61	56.80						
		32.72	14.71	0.614		6.55	3.49	51.80						
		30.90	14.87	0.614		6.53	3.43	46.10	0.2	<10	115	10	<10	1798
		29.24	15.03	0.613		6.53	3.49	39.20						
		27.56	15.18	0.613		6.52	3.62	36.10						
		25.93	15.38	0.614		6.51	3.75	33.50						
		24.13	15.64	0.614		6.50	3.96	29.10						
		22.44	16.08	0.626		6.49	4.04	25.20						
		20.59	16.76	0.622		6.48	4.17	22.00	0.4	<10	417	37	<10	2416
		18.60	18.09	0.624		6.47	4.08	18.30						
		16.75	19.83	0.637		6.46	3.94	15.20						
		14.78	22.17	0.641		6.46	3.74	13.00						
		12.86	23.15	0.636		6.47	3.86	11.10						
		10.94	23.29	0.637		6.51	4.39	9.20	1.6	<10	475	16	<10	1854
		9.08	23.41	0.637		6.55	5.36	7.90						
		7.37	23.48	0.637		6.59	6.08	7.00						
		5.83	23.53	0.637		6.63	6.91	6.30						
		4.08	23.55	0.637		6.67	7.38	5.60						
		2.04	23.57	0.637		6.70	7.75	5.30						
		0.36	23.64	0.637		6.73	8.01	5.00	1.6	<10	358	24	<10	2444
	MF	9.49	23.62	0.638		6.74	7.71	30.20	1.6	<10	112	16	<10	1980
		7.02	23.91	0.639		6.75	7.37	12.50						
		4.86	24.12	0.639		6.77	7.70	7.80						
		3.69	24.21	0.639		6.79	7.92	5.80						
		2.90	24.25	0.639		6.80	8.08	4.60						
		2.52	24.27	0.639		6.80	8.17	3.90						
		0.59	24.29	0.639		6.81	8.21	3.30	3.6	<10	112	12	<10	2022

ATTACHMENT B^C
NUMERICAL MODELLING ASSESSMENT

1. INTRODUCTION

1.1 Purpose of modelling study

The hydrodynamic modelling is intended to provide information for decisions on the quantity of freshwater to be released and the nature of the releases to meet certain desired ecological outcomes. Specifically the purpose of the hydrodynamic modelling study is to investigate the quantity and nature of the release of freshwater into the Kromme River required to raise the management “class” of the estuary by at least one class.

A number of previous hydrodynamic studies of the Kromme Estuary have been undertaken using the one-dimensional MIKE11 model (e.g. CSIR, 1994). However, due to the nature of the hydrodynamic functioning of the Kromme Estuary under the present low freshwater inflow regime, a more sophisticated modelling study is required. Specifically, the one-dimensional modelling is unable to adequately account for the stratified flow regime that exists in the Kromme Estuary, particularly after periods of low freshwater inflow, which results in the system assuming predominantly marine characteristics (i.e. the estuary becomes an “arm of the sea” with salinities typical of the offshore marine environment). Freshwater inflows into the estuary under these conditions result in highly stratified conditions and residence times for freshwater in the estuary are typically much shorter than anticipated and than those indicated by a one-dimensional model (Van Ballegooyen *et al.*, 2004).

To adequately simulate these hydrodynamic conditions required a full three-dimensional hydrodynamic simulation. For the purposes of this study we have elected to use the DELFT3D-FLOW three-dimensional hydrodynamic model (see Section 5.2).

1.2 Structure of the Hydrodynamic Modelling Report

This report describes the hydrodynamic modelling study undertaken in support of the assessment of freshwater for the Kromme Estuary. Section 2 provides a description of the environment to the extent that it is relevant to the modelling study. Section 3 describes the model set-up, calibration and verification, while Section 4 summarises the Scenarios modelled. The hydrodynamic functioning of the Kromme Estuary and model results are summarised in Section 5, but the major findings of these model simulations (in terms of defining hydrodynamic Scenarios of relevance) are reported in the main body of this report. Section 6 contains the conclusions and recommendations of the three-dimensional hydrodynamic modelling study.

2. DESCRIPTION OF THE ESTUARY AND SURROUNDS

The description of the estuary that follows is limited to those features that are of relevance to the hydrodynamic functioning of the estuary. A more complete description of the estuary and its surrounds is given in the main body of the report.

2.1 Physiography of estuary

The head of the estuary (i.e. the upstream limit to tidal influence) is located at a rocky sill some 14 km upstream of the river mouth that opens into St Francis Bay. A major tributary of the estuary is the Geelhoutboom, which enters the estuary some 7 km upstream of the mouth of the estuary. There are a number of smaller tributaries, the most significant of these being the Sand River, which drains part of a by-pass dunefield and joins the estuary approximately 1.3 km upstream of the estuary mouth (Bickerton and Pierce, 1988). Both of these tributaries contribute very little freshwater inflow into the Kromme Estuary.

The mouth of the estuary is permanently open and the bathymetry in the mouth region is highly variable with the water depths typically less than -2 m MSL. A longshore sediment transport has resulted in a massive sandspit of about half a kilometre long, which extends from the south bank of the estuary mouth and tends to push the mouth channel northwards. A marina has been developed on the western bank adjacent to the mouth. The narrow marina channels with depths ranging between -1 and -2 m MSL are connected to the estuary by two access channels (Smith *et al.*, 1991).

A moderate sedimentation of the lower reaches is taking place caused mainly by the influx of marine sediments through the constricted and permanently open mouth that is flood tide dominated (Reddering and Esterhuysen, 1983). The result is a net deposition of marine sand as far as 5 km upstream of the mouth. A number of significant sand-flat regions exist in the Kromme Estuary as well as fairly extensive sand/mud flats in the lower reaches of the estuary (Figure C-1 of the main report).

The bathymetry of the Kromme Estuary plays a large role in determining the unique hydrodynamic regime characterising this estuary. Approximately 5 km from the mouth, the estuary is characterised by relatively shallow channel depths of 1.5 m and a sandy bottom substrate (see Figure C-3 of the main report). Upstream of this, the estuary deepens to between 3 and 4 m until the region of confluence of the Geelhoutboom and the Kromme rivers where the water shallows to between -2 and -3 m MSL. The water depth in the Geelhoutboom is shallow and does not exceed a depth of -2 m MSL at its confluence with the Kromme River and shallows rapidly on moving upstream. Upstream of the confluence of the Geelhoutboom and the Kromme, the water depth in the Kromme increase to -4 to -5 m MSL in a reach of approximately 9 to 10.5 km from the mouth. There is a short stretch of shallower water (i.e. -3 m MSL) centred on a region approximately 11 km upstream of the river mouth. Upstream of this, the channel deepens, rapidly forming a deep basin that stretches from approximately 11.5 km upstream to the head of tidal influence where the depth exceeds 5 m MSL.

The sediment distribution in the estuary (Reddering and Esterhuysen, 1983) shows a gradation in substrate particle size from medium sand in the lowest 5 km to more angular fluvial sand particles with smaller grain sizes and higher organic content upstream 5 km from the mouth. The muds start to predominate at approximately 5 km upstream of the mouth where the water deepens and where, under average flow conditions, the tidal incursion of seawater occurs with each tidal cycle during spring tides. This sediment distribution is not unexpected as the conditions of mud flocculation governing the deposition behaviour of muds is a subtle function of both salinity and water column turbulence, both of which change substantially at a location approximately 5 km upstream of the mouth.

2.2 Hydrodynamic functioning

Water level variation is primarily determined by tides but significant changes will result with strong freshwater inflows. Also, there are large scale fluctuations in water levels in the ocean due to wind-driven set-up or set-down.

The tidal wave propagates upstream at an average speed of 5–7 m/s during both spring and neap tides. The shallowness of the lower estuary results in this low propagation speed in the lower reaches of the estuary and the deformation of the tidal wave form. There are significant lags between the lower three water level stations (WL1, WL2, and WL3). However, the lags in water level between Stations WL3 to WL5 are negligible.

The tidal range just inside the mouth of the estuary is 55% of that in the open ocean during spring tides. Further upstream the tidal range is approximately 45 to 50% of that measured in the ocean. During neap tides the tidal range just inside the mouth of the estuary is approximately 82% with the upstream end of the tidal range being approximately 78% of that in the open ocean. The greater reduction in tidal amplitudes during spring tides can largely be attributed to the shallow mouth conditions.

The tidal asymmetry is clearly evident in both the measured and simulated water level time series, resulting in flood flows of approximately 5 hours in duration and ebb flows of approximately 7.5 hours in the estuary.

Water column stratification in the estuary is generally limited due to the low freshwater inflows into the estuary and the shallow lower reaches where turbulence due to strong tidal flows mixes the water column. However, under moderate to high freshwater inflows the estuary becomes highly stratified upstream of the confluence of the Geelhoutboom and the Kromme, moderately stratified as far downstream as 5 km from the mouth where the water shallows and the high turbulence generated by tidal flows results in a well mixed water column all the way to the mouth of the estuary. Under sustained high flow conditions (Abiotic State 3), the bottom water will be slowly entrained into the fresher surface waters, ultimately resulting in a well-mixed freshwater column through most of the estuary, except for the very upper reaches where some higher salinity bottom waters may remain depending on the duration of the high freshwater inflows.

In terms of density stratification and modification of flow velocities with depth, these temperature variations are usually negligible compared to the influence of changes in salinity on density stratification of the water column.

A more complete description of the hydrodynamics of the system is given in the main report.

The maximum mid-channel current speeds are reported in the main document but are typically less than 0.3 m/s except for the mouth region where current speeds exceeding 1.0 m/s occur during spring tides and strong freshwater inflows to the estuary.

3. MODEL SET-UP, CALIBRATION AND VERIFICATION

3.1 Description of Hydrodynamic Model

The model used in this study is the DELFT3D-FLOW 3D hydrodynamic model. The DELFT3D-FLOW hydrodynamic model includes formulations and equations that take into account:

- Tidal forcing
- Wind shear stress on the water surface
- Wave-driven flows
- Bed shear stress at the seabed (including wave effects)
- Drying and flooding on tidal flats
- The effect of the earth's rotation (Coriolis force)
- Free surface gradients (barotropic effects)
- Horizontal gradients in pressure due to changes in water density (baroclinic effects)
- Water with variable density due to temperature or salinity differences (equation of state)
- Turbulence-induced mass and momentum fluxes (k-ε turbulence closure model)
- Insolation and air-sea interactions at the sea surface
- Transport of conservative constituents (advection-diffusion equation).

The system of equations in DELFT3D-FLOW comprise the horizontal momentum equations, the continuity equation, the equation of state, the advection-diffusion equation for heat, salt and other conservative tracers as well as formulations which take into account the role of insolation and air-sea heat fluxes in determining the stratification of the water column. The equations and their numerical implementation are described in detail in WL|Delft Hydraulics (1999). Simplified versions of these equations follow.

Conservation of momentum in x-direction:

$$\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + g \frac{\partial \eta}{\partial x} - f \cdot v + \frac{g \cdot u |U|}{C^2(d + \eta)} - \frac{F_x}{\rho(d + \eta)} - \nu \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) = 0$$

Conservation of momentum in y-direction:

$$\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + g \frac{\partial \eta}{\partial y} + f \cdot u + \frac{g \cdot v |U|}{C^2(d + \eta)} - \frac{F_y}{\rho(d + \eta)} - \nu \left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right) = 0$$

Conservation of mass, continuity equation:

$$\frac{\partial \eta}{\partial t} + \frac{\partial [(d + \eta)u]}{\partial x} + \frac{\partial [(d + \eta)v]}{\partial y} = 0$$

where:

η	=	water level elevation (m)
d	=	water depth (m)
u, v	=	velocity in the x-, y-directions, respectively (m/s)
U	=	magnitude of total current velocity (m/s)
$F_{x,y}$	=	x- and y- components of external forces (Pa)
f	=	Coriolis parameter $2\Omega \sin\theta$, where Ω is the earth's angular velocity and θ is the geographic latitude (rad/s)
g	=	acceleration due to gravity (m/s^2)
ρ	=	water density (kg/m^3)
ν	=	eddy viscosity (m^2/s)
C	=	Chézy coefficient ($\text{m}^{1/2}/\text{s}$)

The model incorporates a sophisticated k-ε turbulence closure scheme (WL|Delft Hydraulics, 1999).

The constituents of the water in the estuary are simulated using an advection-diffusion equation as indicated below.

Advection-diffusion equation:

$$\frac{\partial c}{\partial t} - \frac{\partial}{\partial x} \left(D_x \frac{\partial c}{\partial x} - u \cdot c \right) - \frac{\partial}{\partial y} \left(D_y \frac{\partial c}{\partial y} - v \cdot c \right) = Source - Sink$$

where:

c	=	constituent, e.g. salinity, temperature
u, v	=	current velocity in the x-, y-directions, respectively (m/s)
$D_{x,y}$	=	dispersion coefficients in the x-, y-directions (m ² /s)
$Source$	=	source term, e.g. heat influx when the constituent modeled is temperature
$Sink$	=	sink term, e.g. atmospheric heat loss when the constituent modeled is temperature

The horizontal turbulent dispersive transport of momentum and other constituents, such as temperature, are computed using prescribed eddy viscosity coefficients and eddy diffusivity coefficients, respectively. The vertical eddy viscosity and eddy diffusivity coefficients are computed by a k - ϵ turbulence closure model. The shear stress (τ_{seabed}) at the seabed induced by turbulent flow is assumed to be given by a quadratic friction law:

$$\tau_{seabed} = \rho \cdot \frac{g}{C_{3D}^2} |u_b|^2$$

where u_b is the near-bottom current speed and C_{3D} is a function of C_{2D} given by the White Colebrook formulation (WL|Delft Hydraulics, 1999):

$$C_{2D} = 18 \log_{10} \left(\frac{12H}{k_s} \right)$$

where H is the total water depth (m) and k_s is the Nikuradse roughness length (m).

Enhanced bed stresses due to wave effects are incorporated in the model using the friction formulation of Fredsøe (1984).

The magnitude of the wind shear stress on the water surface is modelled by the following quadratic expression

$$\tau_{wind} = \rho_a \cdot C_D (U_{10}) \cdot U_{10}^2$$

where:

ρ_a	=	density of air (kg/m ³)
C_D	=	wind drag coefficient which is typically a function of wind speed
U_{10}	=	wind speed 10 m above the water surface (m/s)

In the horizontal direction an irregularly-spaced, orthogonal, curvilinear grid is used. In the vertical direction use is made of a sigma-coordinate grid that results in a constant number of layers over the horizontal computational area. The thickness of the layer is thus proportional to the water depth at each horizontal position. An “anti-creep” procedure is used to limit numerical diffusion associated with the use of sigma-coordinates.

The time integration method used to solve the equations in DELFT3D-FLOW is the Alternating Direct Implicit type where the water levels and velocities are solved implicitly along grid lines. The accuracy of wave propagation in the grid is related to the Courant number. An appropriate time step is typically determined by comparison of the relevant model results for successively decreasing time steps (i.e. the time step is halved in successive simulations until further changes in the model outputs are negligible).

3.2 Available data for Kromme Implementation

Data available for the implementation and the calibration of the Delft 3D-FLOW hydrodynamic model in the Kromme Estuary are listed in Table 1.

Table 1 Available data for the implementation of the Delft 3D-FLOW in the Kromme Estuary

Data type	Comment
Model Set-up:	
Bathymetry	1988 cross-sections from Smith <i>et al.</i> (1991) and Reddering and Esterhuysen (1983)
State of the mouth	Initially based on above bathymetry data and orthographic maps/aerial photographs and optimized during modeling using water level data just upstream of the mouth
Water levels at mouth	Predicted tides based on tidal constituents representative of the region
River inflow	As specified in the various Scenarios and provided by Ninham Shand
Freshwater input from tributaries	As specified in the various Scenarios and provided by Ninham Shand
Temperature/salinity for the sea and river (at the head of the estuary)	Estimated from reported values in the literature. Only salinity needed to be specified. All runs were started assuming that the waters in the Kromme were marine, i.e. 35.25 ppt.
Longitudinal salinity profiles	Undertaken during the August 1998 survey (i.e. prior to the dam release)
Longitudinal temperature profiles	Undertaken during the August 1998 survey (i.e. prior to the dam release)
Model calibration and verification:	
Water levels	Water levels at 5 locations along the length of the Kromme Estuary (Smith <i>et al.</i> , 1991) were used to give the characteristics of water level variations in the estuary.
Longitudinal salinity profiles	Observation prior to the release and 1, 2, 4, 7, 18, and 28 days after the release
Longitudinal temperature profiles	Observation prior to the release and 1, 2, 4, 7, 18, and 28 days after the release

3.3 Model Set-up

The model set-up is described below.

3.3.1 Computational grid and bathymetry

Of greatest importance is the resolution of cross-shore bathymetry, an accurate portrayal of downstream extent of the estuary and an accurate resolution of the major bathymetric features of the estuary. In this study an important feature to resolve in the Kromme Estuary was the shallow water opposite the jetties approximately 5 km upstream of the mouth. The shallow waters in this section of the river result in increased tidal flows, which have a strong influence on the vertical structure of the water column. Upstream of this location in the deeper waters of the estuary the water column is strongly stratified with respect to salinity during moderate to high freshwater inflows while downstream of this location the water column is typically well-mixed (i.e. there is no appreciable change in salinity with depth) for all freshwater inflow Scenarios.

Furthermore there is a need to include a reasonable section of the marine environment offshore of the estuary mouth to reasonably deal with the fact that freshwater leaving the estuary is not

necessarily drawn back into the estuary mouth. Delft3D-FLOW has a technique for dealing with such a situation; however, it requires some *a priori* specification of time scales that are not necessarily well-known. Thus the choice to include a reasonable portion of the marine environment as indicated in Figure 1 to reduce the sensitivity of the model results to the time scales specified (See Section 3.2.2).

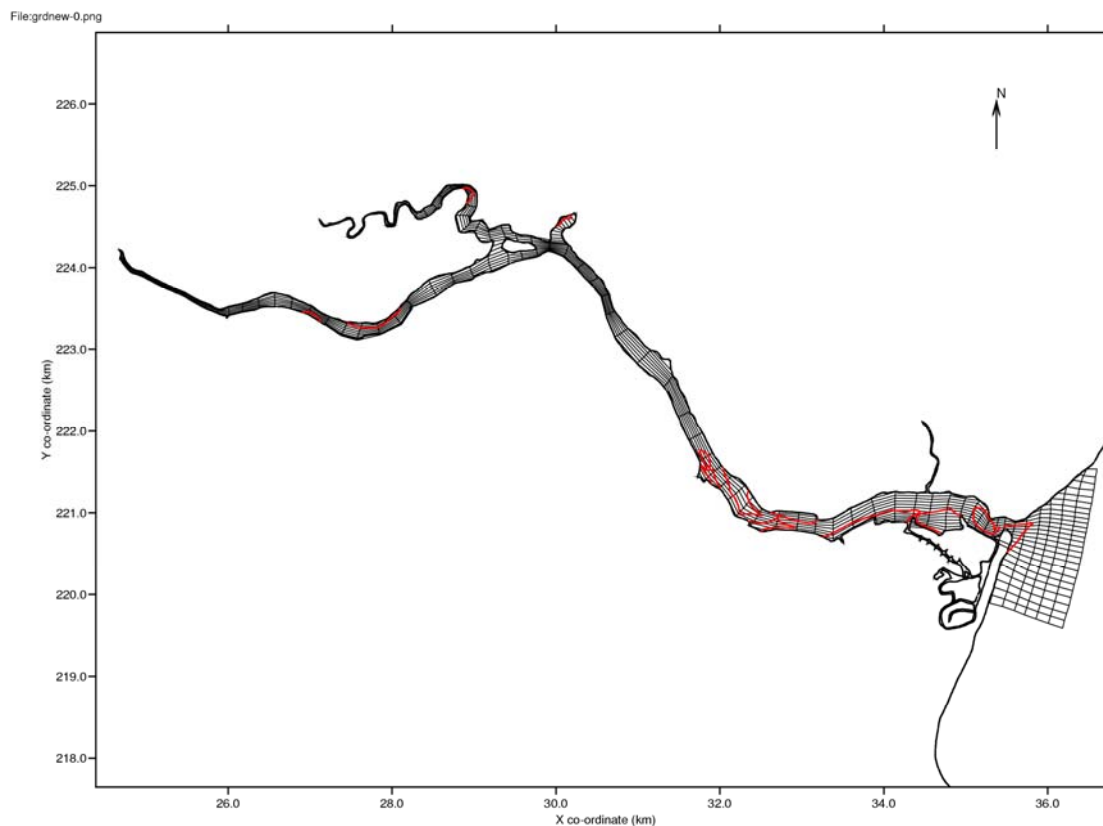


Figure 1 Computational Grid used in the modelling study

The bathymetry used in the model simulations was based on cross-sectional profiles of water depth reported by Smith *et al.* (1991) (Figure 2). The mouth configuration was initially based on the bathymetry data near the mouth and orthographic maps/aerial photographs and later optimised during modelling using water level data just upstream of the mouth.

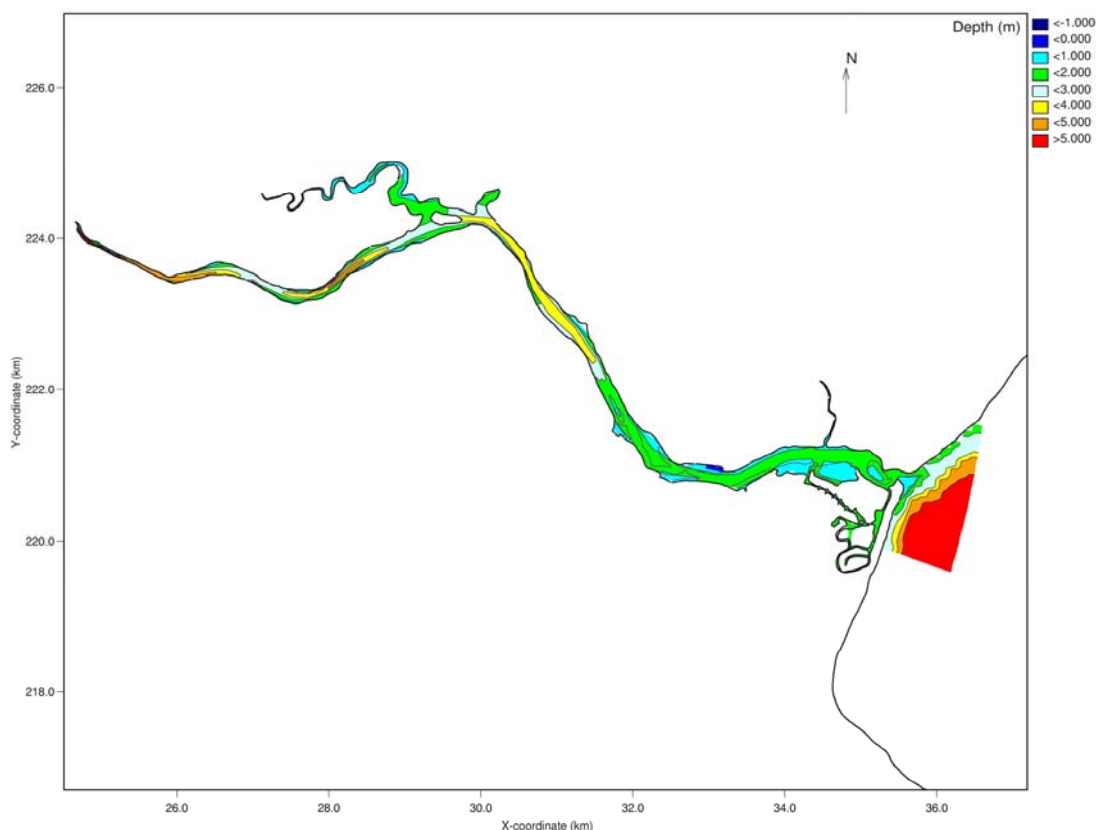


Figure 2 Model Bathymetry used for the Kromme Estuary

3.3.2 Open Boundary conditions

As no time series data were available for salinities at or near the mouth, a salinity of 35.25 ppt was assumed in the open ocean and a Thatcher-Harleman boundary condition was used with a “return period” or “time lag” of one hour. If the coastal ocean included in the model was large enough, such a Thatcher-Harlemann condition would not be required. However, the moment the ocean region included in the model is small enough for there to be a freshwater influence from the estuary at the open boundaries of the model, a Thatcher-Harlemann condition is required. A salinity of 0 ppt was assumed for the river inflow.

At the open ocean boundaries the sea level specified was the predicted tides. The tidal prediction was made using an appropriate linear combination of the tidal constituents for Port Elizabeth and Mossel Bay (Rosenthal and Grant, 1989) based on the distance of these two sites from the mouth of the Kromme Estuary (Table 2).

Table 2 Tidal constituents used to predict the tides in the open ocean

Tidal constituent	Amplitude (m)	Phase (degrees)
Z ₀	0.200	0.0
M ₂	0.530	101.6
S ₂	0.260	129.6
N ₂	0.110	94.5
K ₂	0.080	124.7
K ₁	0.060	169.3
μ ₂	0.020	85.6
O ₁	0.020	299.1
P ₁	0.020	165.1

3.3.3 Surface fluxes

The air-sea fluxes are not simulated here as they are considered to be a secondary effect on the time scales being modelled. Similarly wind-driven current and mixing are not included in the modelling study.

The evaporation data available for the region are those measured during 1993 and 1994 at the Impofu Dam by the department of Water Affairs and listed in Table 3 (CSIR 1994).

Table 3 Evaporation data for the Kromme region (CSIR 1994)

Month	Evaporation (mm)	Precipitation (mm)	Nett evaporation (mm)
October	131	95	36
November	169	94	75
December	194	46	148
January	198	45	153
February	176	18	158
March	175	3	172
April	112	112	0
May	75	51	24
June	75	197	-122
July	62	17	45
August	74	96	-22
September	86	266	-180

Based on these data an assumed water surface area of 3 km² (Bickerton and Pierce, 1988), the maximum rate for evaporative loss from the Kromme is approximately 500 000 m³ per month or 0.20 m³/s and from the Geelhoutboom approximately 45 000 m³ per month or < 0.02 m³/s. A similar calculation results in a total annual evaporative loss of approximately 1.5 million m³. For the freshwater flow under investigation it was not deemed necessary to include evaporative heat losses as the simulations were undertaken for the September to November period when evaporative losses are small. The modelling results, however, need to be re-interpreted if one is to extrapolate the results to the dry months when the evaporative losses are greater.

3.3.4 Initial conditions

As is typically the case, the model simulations were started at peak high tide. This is particularly recommended where there is wetting and drying of tidal flats in the model. The initial sea level in the model simulations was set equal to the water level imposed at the open boundary (i.e. predicted water level at high tide).

The initial salinity distribution in all cases was assumed to be a uniform 35.25 ppt at the initiation of the runs. It is appreciated that there may be a more complex distribution of salinity on occasion. However, given the low freshwater inflows to the Kromme and recent longitudinal salinity profile data, the assumption of uniform marine conditions in the estuary seems to be the most robust.

3.3.5 Model Parameters

The model parameters were optimised to ensure that the highly stratified conditions expected were simulated as accurately as possible. The model parameters used in the modelling study are as listed in Table 4. The optimal model parameters used in the model simulations for the Kromme Estuary is listed in Table 4.

Table 4 Numerical parameters used in DELFT3D-FLOW for the Kromme Estuary simulations

Parameter	Parameter value
Time step	15 seconds
No of vertical layers	32
Horizontal viscosity	1,0 m ² /s
Background vertical viscosity ⁽¹⁾	0,00005 m ² /s
Horizontal diffusivity	1,0 m ² /s
Background vertical diffusivity ⁽¹⁾	0,000001 m ² /s
Chézy coefficient	40 m/s
Wind stress coefficient ⁽²⁾	Not used
Turbulence closure model	<i>k-ε</i> turbulence closure
Advection scheme	Cyclic method
Sigma-coordinates correction	On
Forester filter vertical	On
Forester filter horizontal	Off
Atmospheric heat flux model	Not used

Notes: (1) These background values are added to the viscosity/diffusivity calculated by the *k-ε* turbulence closure scheme.

(2) Wind forcing was not used in the model simulations

3.4 Model calibration and verification

Model calibration and verification ideally requires two independent data sets, one to calibrate the model and the other to verify the model results. Two independent data sets (including flow data and all ancilliary measurements) were not available for this project therefore only a model calibration has been undertaken.

The major topographical features of the Kromme Estuary affecting the hydrodynamics and water levels in the estuary are:

- A permanently open mouth that restricts tidal flows.
- A shallow downstream stretch about 6 km long with a meandering sandy tidal channel within the main river bed.
- An upstream deeper basin where the channel occupies the whole width of the river bed.

The deeper basin upstream of WL3 results in the water level variations being similar at WL3 to WL5. This deeper basin, upstream of the restrictive channels and mouth of the Kromme Estuary, results in the amplitude of water level variations in the upstream section of the system being of similar magnitude and occurring simultaneously.

If wind forcing is important and wind-induced variations in sea level at the open-boundary are significant (Largier *et al.*, 1992; van Ballegooyen, 1996), these factors need to be taken into account in the model calibration. Similarly if upstream inflow conditions are significant they need to be taken into account in the model calibrations. During this calibration extra-tidal variations in water level were unknown and were not considered. Further, the upstream inflows and potential associated water level fluctuations were assumed to be negligible in the calibration simulations.

3.4.1 Water level calibration

Typically the first step in the calibration of the DELFT3D-FLOW model is undertaken using water level data at a number of sites along the length of the estuary. In the calibration procedure, discrepancies between the observed and modelled results typically were minimised by tuning model parameters such as boundary conditions, depths, storage volumes and bed roughness. The water level calibration here was undertaken by attempting first to reference the absolute water levels to MSL by choosing a mouth depth to match the lowest sea levels measured during neap tides with those in the model simulations, followed by bottom friction parameters and more

accurate resolution in the more restrictive lower reaches of the estuary to match the observed tidal delays and changes in tidal form observed in the estuary. The strong tidal asymmetry suggested a Chezy coefficient of 35 to 40 (i.e. strong bottom friction effects). Between tuning the mouth dimensions and bottom friction parameters in the mouth (i.e. the “effective” mouth dimensions), as well as the bathymetry and bottom friction parameters along the estuary, an adequate calibration with respect to water level was achieved. Largely, it is the bathymetric constrictions at the mouth and along the estuary that determine the amplitudes of variations in water level and the changes in bottom friction that determine the tidal delays at the mouth and along the estuary. The model was considered adequately calibrated once the characteristics of the simulated water levels matched those measured.

i. Measured water levels

The Kromme Estuary is sufficiently long that data from more than one location along the river is required to calibrate the hydrodynamic model. The mouth of the estuary is sufficiently restricted to limit tidal flows in the estuary and results in reduced tidal amplitudes throughout the estuary as well as tidal asymmetry (see Section 5.2 of the main report).

The only data available for such a calibration in the Kromme Estuary are those reported by Smith *et al.* (1991), comprising 5 water level measurement sites along the length of the estuary (as well as two in the marina). The location of the water level recorders in the river is given in Figure C-5 of the main report. The water levels were measured from 11 August 1988 to 14 August 1988, including the spring tide on 14 August and neap tide on 22 August 1988. The tidal asymmetry is clearly evident in these measured water level time series, resulting in flood flows of approximately 5 hours duration and ebb flows of approximately 7.5 hours in the estuary. The 1988 water level measurements indicate a tidal range at WL1 (located just inside the mouth of the estuary) of 55% of that in the open ocean during spring tides compared to those predicted for the open ocean. Further upstream (WL3 to WL5) there is an additional 5% (neap) to 10% (spring) reduction in tidal amplitudes, resulting in a tidal range upstream that is approximately 45 to 50% of that measured in the ocean. During neap tides the tidal range at WL1 being approximately 82% of that in the open ocean with that at the upstream end the tidal range being approximately 78% of that in the open ocean. The greater reduction in tidal amplitudes during spring tides can largely be attributed to the shallow mouth conditions. Further, during spring tides the tidal delays between the open ocean and WL1 (just upstream of the estuary mouth) were observed to be approximately 30 minutes at high water and approximately 2 hours and 10 minutes at low water. At the upstream end of the estuary high water occurs approximately 1.5 hours to 2 hours after predicted high water at sea and low water occurs approximately 3.5 to 4 hours after predicted low water at sea. During neap tides the tidal delays between the open ocean and WL1 (just upstream of the estuary mouth) were observed to be approximately 30 to 40 minutes at high water and approximately 1.5 to 2 hours at low water. At the upstream end of the estuary high water occurs approximately 0.5 to 1 hour after predicted high water at sea and low water occurs approximately 2.5 to 3 hours after predicted low water at sea.

ii. Simulated water levels

Unfortunately the digital data for these time series of water level have been lost so the calibration has been undertaken by comparing the main features of the tidal flows. The simulated water level data for the same period as the measured data indicates a clear tidal asymmetry with flood flows of approximately 4.25 to 4.5 hours duration and ebb flows of approximately 7.5 to 7.75 hours in the estuary.

The simulated water levels indicate a tidal range at WL1 (located just inside the mouth of the estuary) of 50 to 55%, 5% of that in the open ocean during spring tides compared to those predicted for the open ocean while during neap tides the tidal range further upstream is approximately 50% of that measured in the ocean. During neap tides the tidal range at WL1 is approximately 85% of that in the open ocean while that at the upstream end of the tidal range is approximately 75% of that in the open ocean (Figure 3).

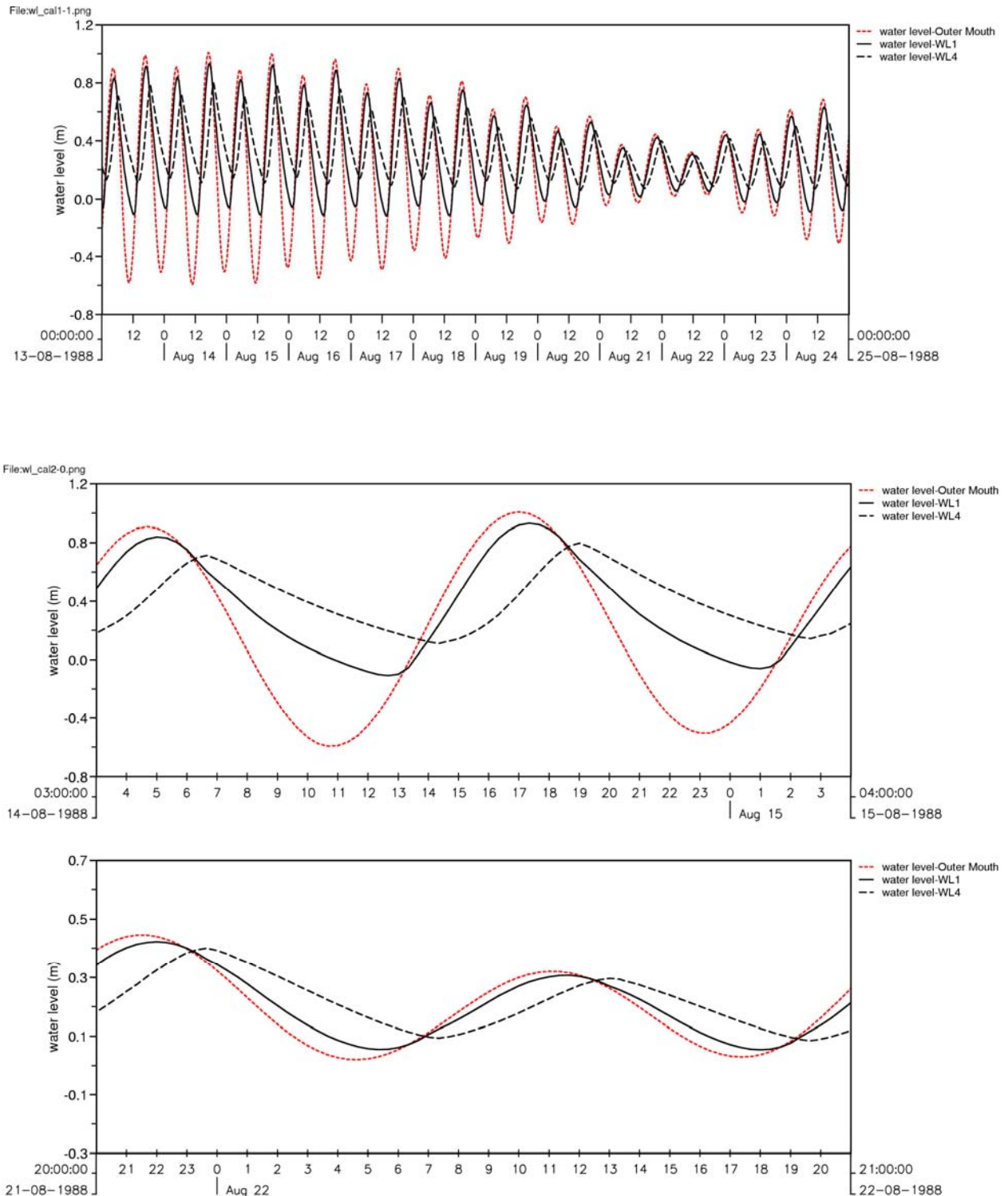


Figure 3 Simulated water levels for the period for which water level calibration data are available. The upper panel is the simulated water level time series for the full calibration period. The middle panel is a magnified view of the water levels at spring tide while the bottom panel is a magnified view of water levels during neap tides (Note the change in scale on the water level axis).

Further, during spring tides the tidal delays between the open ocean and WL1 (just upstream of the estuary mouth) were observed to be approximately 30 minutes at high water and approximately 2 hours at low water. At the upstream end of the estuary high water occurs approximately 1.75 hours to 2 hours after predicted high water at sea and low water occurs

approximately 3.5 to 4 hours after predicted low water at sea. During neap tides the tidal delays between the open ocean and WL1 (just upstream of the estuary mouth) were observed to be approximately 30 to 40 minutes at high water and approximately 1 to 1.5 hours at low water. At the upstream end of the estuary high water occurs approximately 1.5 to 2 hours after predicted high water at sea and low water occurs approximately 2.5 to 3 hours after predicted low water at sea.

The measured and simulated water level data are sufficiently similar to consider the water levels in the model to be adequately calibrated.

The calibration of the Kromme Estuary is not as highly sensitive to the mouth morphology but is sensitive to bathymetric constrictions further upstream and bottom friction parameters along the length of the estuary. In particular, in this study an important feature to resolve in the Kromme Estuary was the shallow water opposite the jetties approximately 5 km upstream of the mouth. The shallow waters in this section of the river and the resultant strong tidal flows had a strong influence on the vertical structure of the water column.

3.4.2 Salinity calibration

Further calibration of the DELFT3D-FLOW model was undertaken using the most conservative tracer, salinity, as on the time scales being simulated, it is a reflection of the model transport (advection and diffusion) only.

i. Impofu Dam Release

The salinity calibration was undertaken using the water quality surveys undertaken during a freshwater release from the Impofu Dam in 1998. The purpose of the release was to investigate the effect of a single freshwater release from the Impofu Dam on the salinity distribution pattern of the Kromme Estuary, amongst other aspects (CSIR, 1999; Scharler and Baird, 2000; Bate and Adams, 2000). Two million cubic metres of water was released from the Impofu Dam over a period of 3 days, at a flow rate of about 15 m³/s.

Prior to the release salinities in the estuary were high, around 34 ppt throughout the estuary (Figure 4). After the release, salinities in the estuary reached lowest levels on Day 3. Strong vertical stratification persisted in the upper and middle reaches of the estuary, where fresh conditions were limited to the surface waters. In the lower reaches vertical mixing and strong tidal influence resulted in the break-down of stratification, creating a well-mixed water body that was still largely marine dominated. Approximately 8 days after the release, salinities in the estuary were virtually the same as before (i.e. around 34 ppt throughout).

The release from the Impofu Dam started at 18:00 SAST on 16 November 1998 and stopped at 06:00 SAST 18 November 1998. There was some delay in the waters being released from the Impofu Dam reaching the rocky outcrop and entering the river. Further it is almost certain that not all of the water released from the dam (some 5 km) upstream of the rocky sill as an unknown volume filled the “hippo pools” between the dam and the estuary and/or may have been extracted by local farmers. We have assumed that this loss was minimal and that the full 2 million m³ entered the estuary, resulting in a 36 hour freshwater inflow at a rate of 15.34 m³/s. There was about a 6 hour delay before the first of the freshwater reached the head of the estuary. Taking into account the delays we assumed the following freshwater inflows at the rocky sill. Zero flow at 00:00 17 November, increasing linearly to 15.34 m³.s⁻¹ at 06:00 17 November. This flow rate was assumed to be maintained until 12:00 18 November. Thereafter the flow rate was assumed to linearly decrease to zero at 18:00 18 November. The discharge was assumed to occur into the upper 25% of the water column.

Prior to the release, salinities throughout the estuary were almost uniformly distributed, similar to seawater (i.e. ~35 ppt) (Figure 4a). Approximately 14 hours after the freshwater reached the head of the estuary (17 November at 12:00), the effect on salinity was noticeable up to about 8 km

downstream of the head of the estuary (Figure 4b). Strong stratification developed in the top 0.5 m to 1 m of the water column, with the freshwater flowing as a surface layer over the saline bottom layer. Salinities in the surface layer near the head of the estuary were less than 5 ppt increasing to about 30 ppt approximately 8 km further downstream, while salinities in the bottom layer remained around 35 ppt.

About 22 hours after the freshwater had reached the head of estuary, its influence was evident as far as the mouth (Figure 4c). Strong stratification still persisted in the upper 8-9 km of the estuary, where the surface layer deepened to approximately 1.5 m, with salinities of 0 ppt near the head of the estuary increasing to about 15 ppt approximately 8 km further downstream. Salinities in the bottom layer in the upstream section of the estuary remained high at around 34 ppt. Further downstream, about 5 km from the mouth, the water column, however, became vertically mixed with salinities of about 25 ppt. This was attributed to the influence of strong tidal currents in this shallow region which caused an increase in turbulence and therefore also in vertical mixing.

Approximately 3 days after the release, stratification showed a similar pattern as earlier (i.e. highly stratified upstream and well-mixed further downstream approximately 5 km from the mouth seawards), except that surface salinities near the head started to increase again to about 15 ppt as a result of no new freshwater entering the estuary (Figure 4d).

Within 8 days of the release, stratification was still evident in the upper 2 km of the estuary, but the rest of the water column was vertically mixed with salinities above 25 ppt, once again showing strong marine influence. Salinity measurements 18 days after the release indicated very little evidence of the freshwater release.

ii. Calibration using salinity data

The calibration of the model is reported in van Ballegooyen *et al.* (2004). However the, essence of the calibration is repeated here for the convenience of the reader.

It has been assumed that the pycnocline dynamics are dominated by changes in salinity thus the pycnocline dynamics are thus also calibrated when calibrating the model using the salinity field. For this reason (and to increase computational efficiency) we have not simulated the effects of temperature in the hydrodynamics of the Kromme Estuary as the effects of temperature variability on the density structure of the water column is negligible to those due to changes in salinity. Under low freshwater inflows, however, temperature effects may be significant, but these are generally not the conditions being simulated here.

Comparison of the measured salinity distributions (Figure 4) and the simulated salinity distributions (Figure 5) are in reasonable agreement and show that the major circulation and stratification features are reproduced for this rather extreme event. Van Ballegooyen *et al.* (2004) indicated that the model results remained reasonably accurate for up to a month; however, it should be noted that there is a tendency for artificial vertical mixing of the water column in the model due to a combination of factors including limited vertical resolution in the model, the solution algorithm and the use of a σ -coordinate system rather than a z-coordinate system in the DELFT3D-FLOW model (although the software has an algorithm to mitigate the artificial mixing associated with the use of a σ -coordinate system).

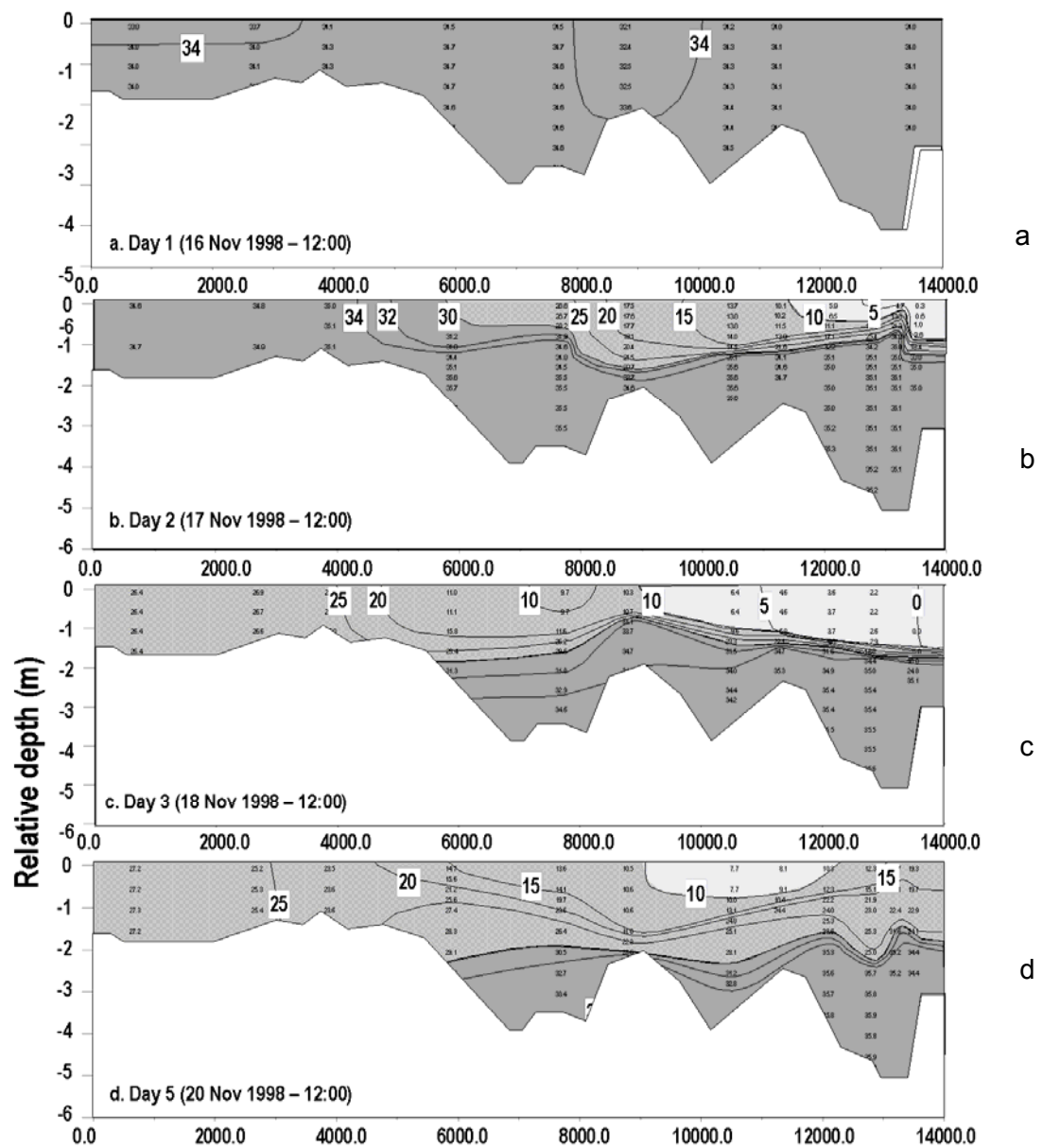


Figure 4 Measured salinity distributions in the Kromme Estuary during the Impofu Dam test release

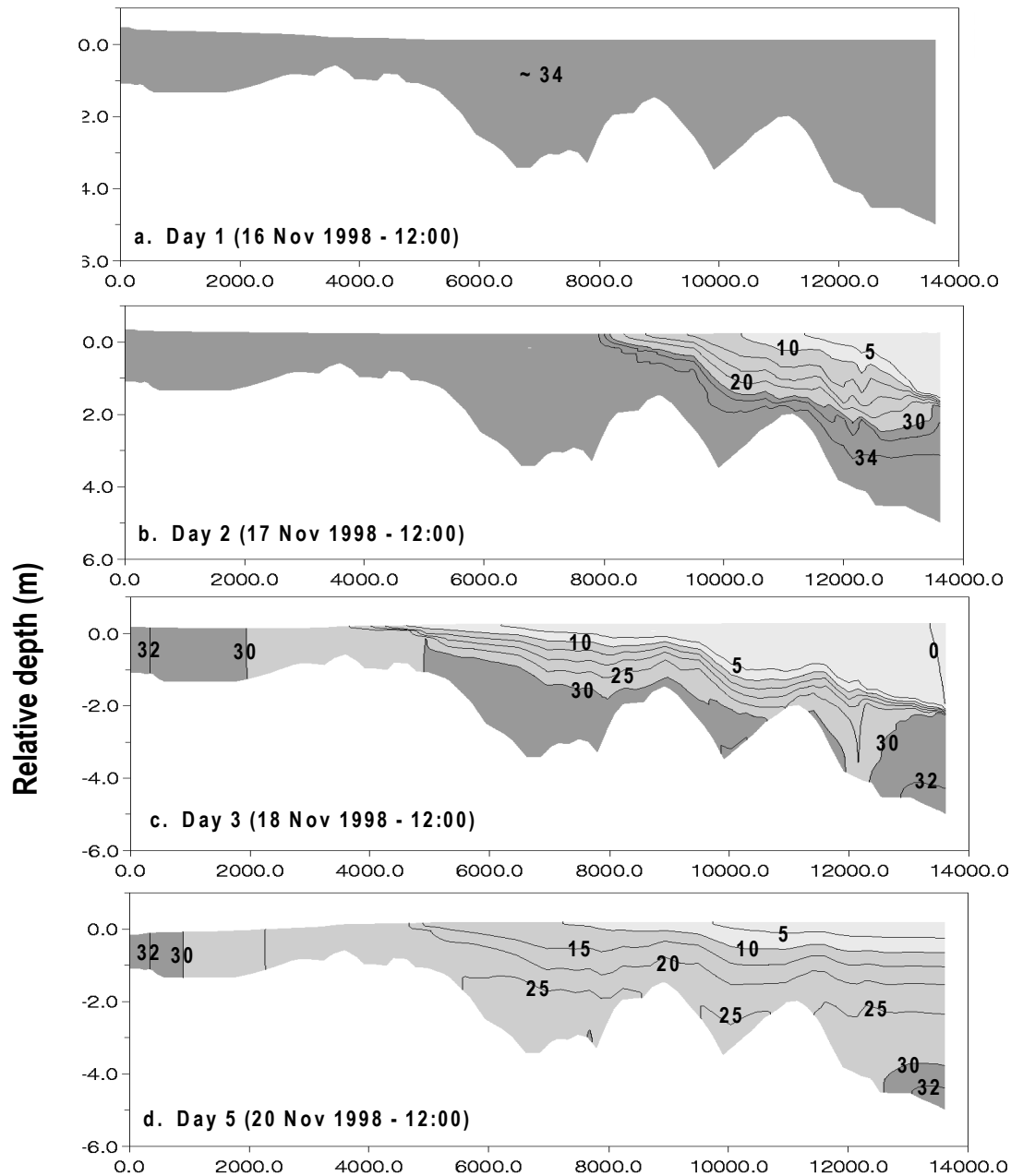


Figure 5 Simulated salinity distributions in the Kromme Estuary during the Impofu Dam test release

iii. Verification of the model

No suitable data are available to verify the model under similar stratified flow conditions.

4. SCENARIOS MODELLED

Two approaches were taken in developing the Scenarios that were modelled:

- A freshwater release of 2 million m³ was assumed and a number of model simulations were undertaken to determine the most effective freshwater release strategy to achieve the outcomes desired to make a significant change to the ecology of the system.
- A range of freshwater inflows (2, 5, 10 and 15 m³/s) were simulated for a 15-day period to determine how many days of a particular freshwater inflow that it would take to achieve the salinity distributions required by the ecological specialists. This was followed by “maintenance” freshwater releases (0.25, 0.5, 1 and 2 m³/s) to maintain the required salinity distributions.

In addition to the above, a number of simulations were undertaken to help estimate the Reference Conditions in both the Kromme and the Geelhoutboom. A number of runs were set up in both systems to determine the potential freshwater inflow volumes required for the various “states” defined using the prior model simulations as indicated in the two bullets above.

4.1 Ecological Requirements

Preliminary ecological requirements (i.e. salinity distributions defined both in terms of spatial extent and duration) were requested from the ecological specialists in an attempt to determine the freshwater inflow volumes that would result in a significant improvement in the water quality and ecological functioning of the system.

The ecological specialists were requested to provide suitable ecological requirements to raise the “class” of the estuary by one class. The feedback required was as follows:

- Vegetation – (Janine Adams): There is some salt accumulation on the supratidal regions of the salt marshes in the downstream region. There is indication of a need to flush these supratidal regions of the salt marshes. This would require that low salinity waters reach these marshes during Spring (preferably Equinox) tides. All that is required is flushing over a few tidal cycles. Piet Huizinga suggests that there is a possibility that rainfall during these periods may be sufficient to achieve the necessary flushing.
- Phytoplankton – (Gavin Snow): No feedback was received by the time that the model simulations were undertaken.
- Zooplankton/macroinvertebrates – (Tris Wooldridge): The suggestion is that, because we are talking about benthos and plankton mostly in this component, there are a few things to bear in mind, namely that:
 - the benthos will not respond to stratification in the deeper parts; however, if the water column is well mixed for the first 1.5 m (for example), then only the benthos in the shallower regions will benefit (<1.5 m depth).
 - most of this response will be in the middle and lower parts where sand becomes dominant rather than muds (although some muddy areas will benefit). The proportion of mud that will benefit can be modelled.
 - one of the dominant zooplankton species that is now mostly absent in the Kromme has resting (dormant) eggs that settle on the bottom in winter. They hatch in summer, but only if salinity is <20 ppt. So if we want to improve diversity and abundance, then the water column needs to be <20 ppt at the bottom.

The suggestion therefore is that (see Table 5) one chooses a scenario where, rather than mix the water column to the bottom in the upper reaches (where it is typically too deep and excessive freshwater may be required to mix the water column sufficiently for lower salinities to be observed at the bottom), one aims to mix the water column in the shallower middle (more muds) and lower reaches (more sand) and hopefully use less freshwater to

achieve the necessary ecological improvement. Under this scenario there will be a need for freshwater to reach the entrance to the Geelhoutboom so as to allow freshwater to be “pumped” into the lower reaches by the tides. The suggestion therefore is that it will be a better option not to change the salinity to three different values (in the table), but rather repeat the same scenario three times during summer (three releases that reduce salinity to <20 ppt in the middle and lower reaches three times). The requirement for the releases on all three occasions then can be argued later.

Table 5 Significant changes in the salinity regime of the Kromme Estuary in order to improve system’s health in terms of zooplankton and macrobenthos

	1st increase (“jump”)	2nd significant increase	3rd significant increase
What: Salinity ranges: <0, 10, 20, 30	<20 ppt	<15 ppt	<20 ppt
Where: Region: Mouth/middle/upper	Middle	Middle/upper	Middle
How long: Period (days):	20 days	20 days	20 days
Nature of change: Depth of stratification (m): 0.5/1.0/1.5/2.0/2.5/3.0/bottom	To the bottom	To the bottom	To the bottom
When: Month(s) that this needs to occur	Nov	Jan	Mar

- Fish - (Alan Whitfield): The response required is based on the specialists knowledge that juvenile marine fish recruitment into permanently open Eastern Cape estuaries increases dramatically when the salinity gradient (vertically integrated) between the head and mouth of the estuary equals or exceeds 19 ppt, e.g. 10 ppt at the head and 30 ppt at the mouth.

Further 'steps' in improving the 'health' of the Kromme Estuary would depend on increasing the duration of the above conditions during the spring and early summer (see Table 6).

- Birds – (Jane Turpie): The feedback was that one will only see a change as significant if there is a significant increase in abundance of food availability for the birds. They are not that sensitive to changes in salinity.

Table 6 Significant changes in the salinity regime of the Kromme Estuary in order to improve system’s health in terms of fish

	1st increase (“jump”)	2nd significant increase	3rd significant increase
What: Salinity ranges: <0, 10, 20, 30	10, 30, 30	10, 30, 30	10, 30, 30
Where: Region: Mouth/middle/upper	Head, Middle, Mouth	Head, Middle, Mouth	Head, Middle, Mouth
How long: Period (days):	30 days	60 days	90 days
Nature of change: Depth of stratification (m): 0.5/1.0/1.5/2.0/2.5/3.0/bottom	Above salinities are integrated water column values	Above salinities are integrated water column values	Above salinities are integrated water column values
When: Month(s) that this needs to occur	October	Oct-Nov	Oct- Dec

Based on the above feedback it was decided to aim at a minimum period of 30 days when the salinity at a mid-reach location downstream of the confluence with the Geelhoutboom is less than 20 ppt both at the surface and at depth (zooplankton and macrobenthos requirement). It was felt that there would be a significant salinity gradient between the head of the estuary and the mouth at all times if the above requirement of < 20 ppt at a mid-reach location downstream of the confluence with the Geelhoutboom was met. This was generally, but not always true to the extent indicated as a requirement, i.e. 10 ppt at the head, 30 ppt at the mid-reach and 30 ppt at the mouth.

4.2 Hydrodynamic Scenarios

From previous modelling studies (e.g. CSIR, 1999; van Ballegooyen *et al.*, 2004), we realised that not only the volume of freshwater introduced but also the rate of inflow would have a significant impact on the distribution of salinities achieved. For a given volume of freshwater inflow, potential Scenarios are:

- If the rate of freshwater inflows are too high and of too short a duration:
 - there will be little vertical mixing of the water column in the upstream reaches (i.e. salinities near the bottom will remain high and the bottom water unflushed).
 - The retention time of freshwater within the Kromme Estuary will be of limited duration.
 - However there will be a relatively strong low salinity signal that will reach the marine environment (i.e. the requisite cueing effect).
- For an intermediate flow rate and intermediate duration, it is expected that:
 - the turbulence generated upstream may be high enough to result in significant vertical mixing at upstream locations, resulting in the bottom water being flushed with lower salinity waters.
 - the retention time of freshwater in the Kromme would be significantly greater.
 - there is still a strong possibility that a low salinity signal will reach the mouth of the estuary at a sufficient magnitude to achieve an adequate cueing effect that by the very nature of the inflow will be of potentially longer duration.
- For a low flow rate of significant duration, it is expected that:
 - The flow rate will be far too low to create the turbulent mixing required in the upper reaches resulting in the bottom waters remaining unflushed and not exposed to freshwater conditions of any sort.
 - The retention time of water in the estuary will be greatest but the extent of the effects of freshwater will most probably be restricted to the surface water of the upper Kromme and perhaps the lower reaches of the Geelhoutboom.
 - It is unlikely that the freshwater will reach the mouth area in sufficient quantities to reduce the salinities to any great extent (i.e. limited or no cueing effect).

i. Scenario Set 1: Optimal use of existing freshwater allocation

Based on this knowledge the first part of the modelling study was to determine the optimal manner in which to utilise the existing 2 million m³ freshwater allocation. To do this, simulations were undertaken in which the total freshwater release was restricted to 2 million m³ of freshwater but released in a number of ways in terms of flow rates and flow durations. The simulations undertaken were:

- Scenario 2.0 (model Scenarios a20, b20, c20) – Release of 2 million m³ at the maximum release rate of 15 m³/s (i.e. a 37 hour release). This scenario was designed to investigate the consequences of a release at the maximum release rate.
- Scenario 2.1 (model Scenarios a21, b21, c21) - Release at 1.0725 m³/s for 14 days, followed by 0.545 m³/s for 15 days to maintain the desired salinity distributions. This scenario was designed to investigate if one was to "pre-freshen" the upper estuary in an attempt to use less

freshwater in the subsequent bigger flush in an attempt to mix low salinities to the bottom of the estuary.

- Scenario 2.2 (model Scenarios a22, b22, c22) - Release at $0.8 \text{ m}^3/\text{s}$ for 29 days. This Scenario was designed to investigate the efficacy of a long slow release.
- Scenario 2.3 (model Scenarios a23, b23, c23) - Release at $1.0725 \text{ m}^3/\text{s}$ for 14 days, followed by 8.175 for a day (24 hours). This scenario was designed to investigate if one was to "pre-freshen" the upper estuary in an attempt to use less freshwater in the subsequent more substantive flush than in Scenario 2.1 in an attempt to mix low salinities to the bottom of the estuary.
- Scenario 2.4 (model Scenarios a24, b24, c24) - Release at 8.175 for a day (24 hours), followed by $1.0725 \text{ m}^3/\text{s}$ for 14 days. The idea here was to "flush" the estuary to produce low salinity bottom waters and then follow this with a continual freshwater inflow in an attempt to maintain the low salinity, i.e. a freshwater flushing followed by a maintenance flow.

From these Scenarios it was realised that the volumes of water released are insufficient to achieve the requisite salinity distributions in the Kromme Estuary for a significant improvement in water quality and ecological functioning of the system.

ii. Scenario Set 2: Set-up and maintenance of desired salinity distributions

The second set of Scenarios comprised two sets of simulations. The initial simulations were designed to determine the quantity of freshwater and nature of freshwater release required to achieve the salinity distributions as specified by the ecological specialists. The second series of simulations were designed to determine the duration of "maintenance" freshwater releases required to maintain the required salinity distributions for the durations specified by the ecological specialists.

The following simulations were undertaken to determine the quantity of freshwater and nature of freshwater release required to achieve the salinity distributions as specified by the ecological specialists:

- Scenario S2 (i02) - comprises a release of $2 \text{ m}^3/\text{s}$ for a period of 14 days.
- Scenario S5 (i05) - comprises a release of $5 \text{ m}^3/\text{s}$ for a period of 14 days.
- Scenario S10 (i10) - comprises a release of $10 \text{ m}^3/\text{s}$ for a period of 14 days.
- Scenario S15 (i15) - comprises a release of $15 \text{ m}^3/\text{s}$ for a period of 14 days.

The approach was to allow a particular freshwater release to continue until the desired salinity distribution was achieved. This was then followed by simulation to determine the freshwater inflow rate required to maintain these desired conditions for a period of 30 days or more.

The results indicated that a discharge rate of between 5 and $10 \text{ m}^3/\text{s}$ was ideal to achieve the salinity distribution that could result in a first significant improvement in the ecological functioning of the system. For the "maintenance" runs that followed we therefore chose a $5 \text{ m}^3/\text{s}$ discharge rate as the starting point. The "maintenance" runs were started after 6 days of $5 \text{ m}^3/\text{s}$ discharge (i.e. on 20041022 000000). These "maintenance" freshwater inflow Scenarios were as follows:

- Scenario M1 - maintenance release of $0.25 \text{ m}^3/\text{s}$: (model scenario j05.mdf for the period 20040922 000000 to 20041007 000000 followed by model scenario n05 for the period 20041007 000000 to 20041022 000000o5)
- Scenario M2 - maintenance release of $0.5 \text{ m}^3/\text{s}$: (model scenario k05.mdf for the period 20040922 000000 to 20041007 000000 followed by model scenario o05 for the period 20041007 000000 to 20041022 000000o5)

- Scenario M3 - maintenance release of 0.25 m³/s: (model scenario l05.mdf for the period 20040922 000000 to 20041007 000000 followed by model scenario p05 for the period 20041007 000000 to 20041022 000000o5)
- Scenario M4 - maintenance release of 0.5 m³/s: (model scenario m05.mdf for the period 20040922 000000 to 20041007 000000 followed by model scenario q05 for the period 20041007 000000 to 20041022 000000o5)

The results of these simulations indicated that a 6-day 5m³/s freshwater release followed by a 1m³/s release would be adequate to meet the ecological requirements for a first significant jump or improvement in ecological functioning of the system.

iii. Scenario Set 3: Determination of Reference Conditions in Kromme Estuary

Based on the previous model results and simulated run-off data, it was decided to simulate steady flows of 0.3, 0.5, 1.0, 2.0, 3.0 m³/s to see if an equilibrium is reached within 30 days. If so, a Reference Condition (i.e. the potential frequency of occurrence of the states of the Kromme Estuary under Reference flow conditions) could be roughly defined using the results from the following model Scenarios:

- KR1 (model scenario r01.mdf) - one month run of 0.3 m³/s
(20040915000000 to 20041015 000000)
- KR2 (model scenario s01.mdf) - one month run of 0.5 m³/s
(20040915000000 to 20041015 000000)
- KR3 (model scenario t01.mdf) - one month run of 1.0 m³/s
(20040915000000 to 20041015 000000)
- KR4 (model scenario u01.mdf) - one month run of 2.0 m³/s
(20040915000000 to 20041015 000000)
- KR5 (model scenario v01.mdf) - one month run of 3.0 m³/s
(20040915000000 to 20041015 000000)

iv. Scenario Set 4: Determination of Reference Condition in Geelhoutboom

Based on the previous model results and simulated run-off data, it was decided to simulate steady flows of 0.02, 0.04, 0.08 and 0.12 m³/s to see if equilibrium is reached within 30 days. If so, a Reference Condition could be roughly defined using the following model results:

- GR1 (model scenario ga1) - one month run of 0.02 m³/s
(20040915000000 to 20041015 000000)
- GR1 (model scenario ga2) - one month run of 0.04 m³/s
(20040915000000 to 20041015 000000)
- GR1 (model scenario ga3) - one month run of 0.08 m³/s
(20040915000000 to 20041015 000000)
- GR1 (model scenario ga4) - one month run of 0.12 m³/s
(20040915000000 to 20041015 000000)

To check out flushing of Geelhoutboom (and effects on Kromme) under moderate to high flows we simulated two Scenarios

- GR1 (model scenario gf1) - one month run of 0.5 m³/s
(20040915000000 to 20041015 000000)
- GR1 (model scenario gf2) - one month run of 1.0 m³/s
(20040915000000 to 20041015 000000)

All of the above runs were computationally intensive in that they required approximately 35 hours of processor time on a 2 GHz Xeon processor and approximately 1 Gb of data storage to complete each 30-day simulation.

5. HYDRODYNAMIC FUNCTIONING OF KROMME ESTUARY

i. Scenario Set 1: Optimal use of existing freshwater allocation

The results of the modelling were as follows:

- Scenario 2.0 (model Scenarios a20, b20, c20) – The release of 2 million m³ at the maximum release rate of 15 m³/s (i.e. a 37 hour release) resulted in a fairly rapid mixing of low salinity waters into the deeper water in the vicinity of the Geelhoutboom and Kromme confluence and a reasonable low salinity signal exiting the mouth of the estuary. However, the retention of freshwater in the system was fairly short, i.e. the salinities rise above 20 ppt throughout the estuary in less than a month.
- Scenario 2.1 (model Scenarios a21, b21, c21) – A release at 1.0725 m³/s for 14 days, followed by 0.545 m³/s for 15 days to maintain the desired salinity distributions, resulted in the fresher water reaching greater depths in the upper and middle reaches after an approximate one-month period; however, there remained a significant presence of lower salinity water in the upper reaches after one month. The release resulted in little or no low salinity signal at the mouth of the estuary.
- Scenario 2.2 (model Scenarios a22, b22, c22) – A release at 0.8 m³/s for 29 days resulted in salinity distributions that are similar to those for Scenario 2.1, the only significant difference being that the lower salinity water initially took somewhat longer to be distributed throughout the estuary.

After running Scenarios 2.0 to 2.2 above it was realised that the flow rates and volumes were insufficient to provide the salinity distributions as specified by the various specialists. Analysis of Scenario 2.4 together with the previous results, suggested that flow rates > 1 m³/s were required to create an initial flushing of the system by freshwater so as to ensure lower salinity bottom waters in the vicinity of the Geelhoutboom and Kromme confluence as well as the deeper region slightly downstream of this location.

ii. Scenario Set 2: Set-up and maintenance of desired salinity distributions

At this point Scenario Set 2 was run in an attempt to determine what freshwater inflow rates are required to flush some of the deeper waters in the vicinity of the Geelhoutboom and Kromme confluence as well as the deeper region slightly downstream of this location with lower salinity waters. There was a realisation that high freshwater inflow rates would result in the freshwater flowing across the surface of the upper reaches and only being mixed into the bottom waters further downstream (i.e. approximately 5 to 6 km upstream of the estuary mouth). Conversely low freshwater inflow rates were expected to be too weak to generate the turbulence required to mix the surface and deeper waters in the upper reaches of the estuary. In a similar manner the freshwater entering the system would flow across the surface in these upper reaches and has a much reduced residence time in the mid and upper reaches of the Kromme.

The hypothesis was that some intermediate rate of freshwater inflow would be optimal in mixing the low salinity surface water into the bottom waters in the mid to upper reaches of the Kromme. This proved to be correct, in that a freshwater inflow of approximately 5m³/s for a period of 6 days (approximately 2.5 million m³ of freshwater) proved to be the most efficient (i.e. resulted in the least water usage) in generating 20 ppt bottom water at location S4 in the estuary (see Figure C-5 of the main report).

Further simulation indicated that this desired salinity distribution could be maintained at a maintenance flow of approximately 1 m³/s. To achieve the required salinity distributions for a duration of one month (as required by the ecological specialists) requires the release of a further 2.5 million m³. This implies that a total of approximately 5 million m³ of freshwater would need to be released over an approximate one month period to achieve the first significant improvement in

ecological functioning of the system. To maintain the desired salinity distribution for a further one month period would require a further approximate 2.5 million m³.

There are, however, limitations in the model simulations that would result in a degree of artificial mixing of the water column (See Section 3.4.2) that would not only overestimate the decrease in salinity of the deeper waters but would also indicate a greater retention time for freshwater in the system. For this reason these model predictions need to be validated with an experimental release and subsequent measurements before they are adopted into a management system for the estuary.

iii. Scenario Set 3: Determination of Reference Conditions in Kromme Estuary

These freshwater inflow Scenarios were simulated to help determine the frequency of occurrence of the various defined "States" of the Kromme Estuary as defined in the main report.

iv. Scenario Set 4: Determination of Reference Conditions in Geelhoutboom

These freshwater inflow Scenarios were simulated to help determine the frequency of occurrence of the various defined "States" of the Geelhoutboom tributary as defined in the main report.

An important observation made during the modelling study is that, for all but very large freshwater inflows (e.g. > 10 m³/s) the excursion of seawater into the system is large enough to result in the intrusion of high salinity waters into the deeper basins located approximately 5 km upstream of the estuary mouth.

Figures 6 and 7 comprise a time sequence of the salinity distribution along the axis of the estuary during spring tide. The sequence of images indicate the intrusion of high salinity seawater into the estuary and the subsequent sinking of this high salinity water into the deeper basins.

The significance of this behaviour is that the salinity observed in the vicinity of location S4 during spring tide is relatively insensitive to the strength of the freshwater inflows to the estuary. In Figure 8, the maximum salinity observed at location S4 is similar for both a 1 m³/s and a 2 m³/s freshwater inflow to the estuary. However, the salinity observed at depth is less for the greater freshwater inflow during neap tides.

A CD-ROM containing animations of salinity distributions for the various model Scenarios is supplied together with this written report so that the reader can view the simulation themselves, and in so doing, gain a better understanding of the unique dynamics of the Kromme Estuary.

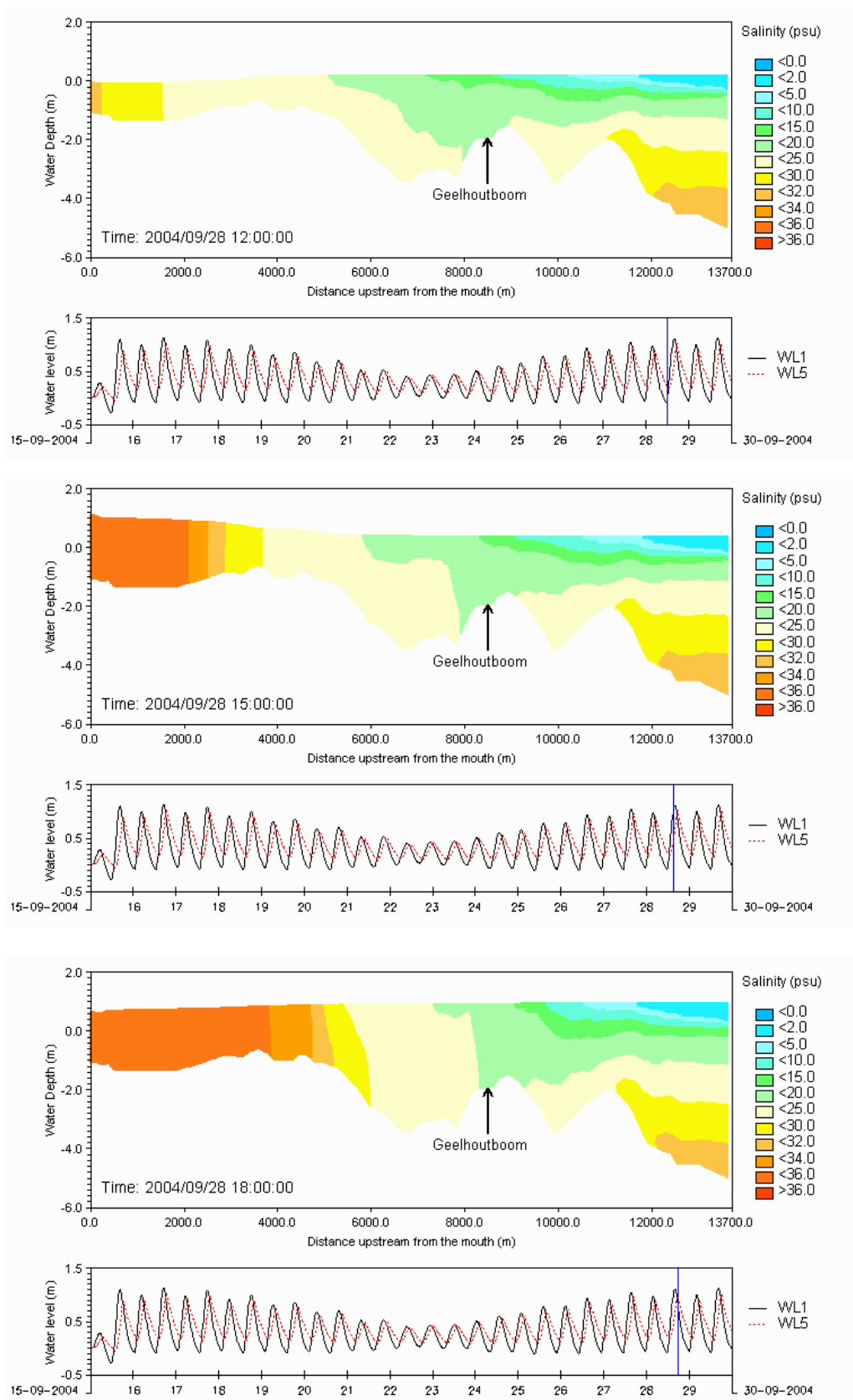


Figure 6 Sequence of simulated salinity distributions along the axis of the Kromme Estuary showing the salinity intrusions into the deeper basins (located approximately 5 km upstream of the mouth of the estuary) during spring tides

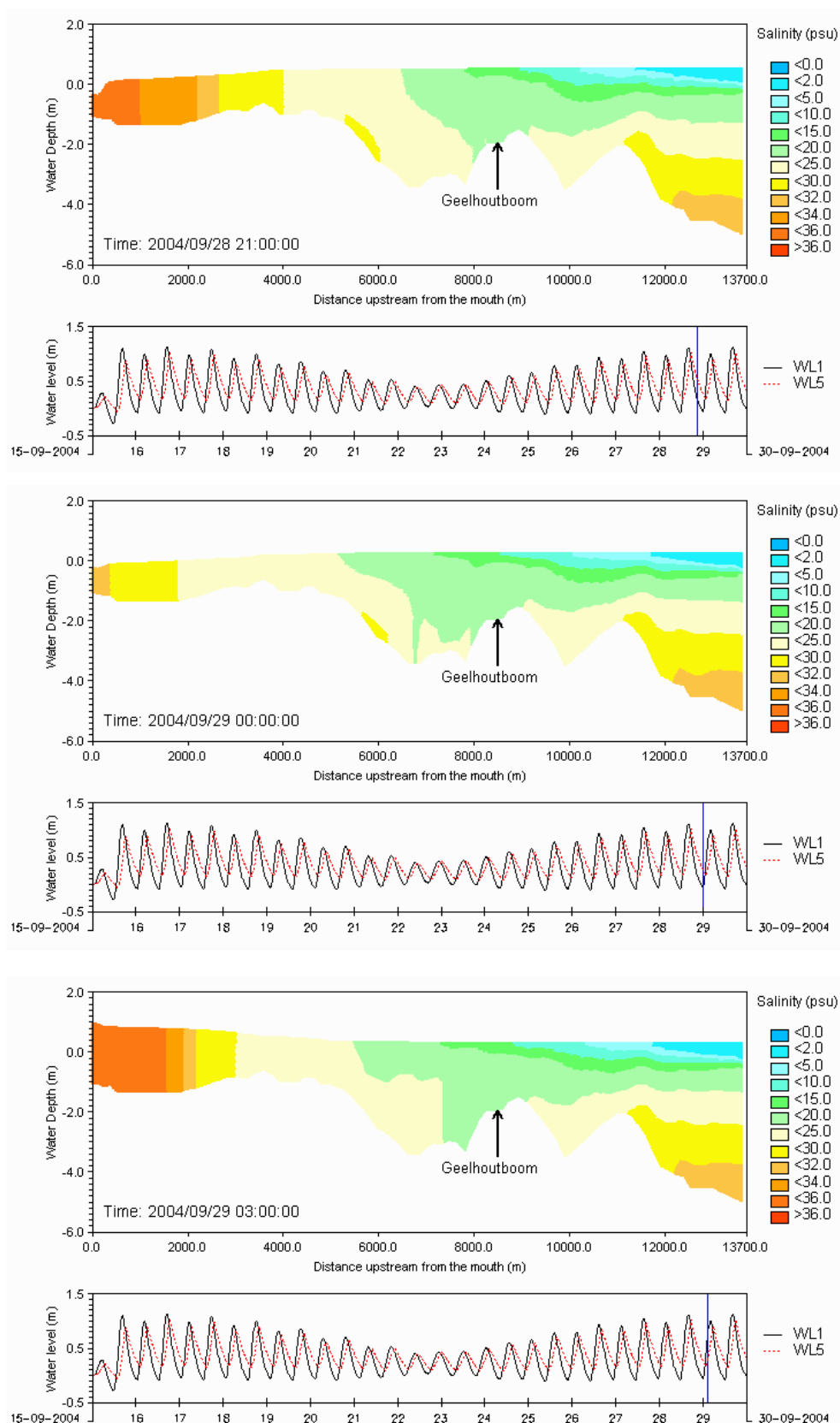
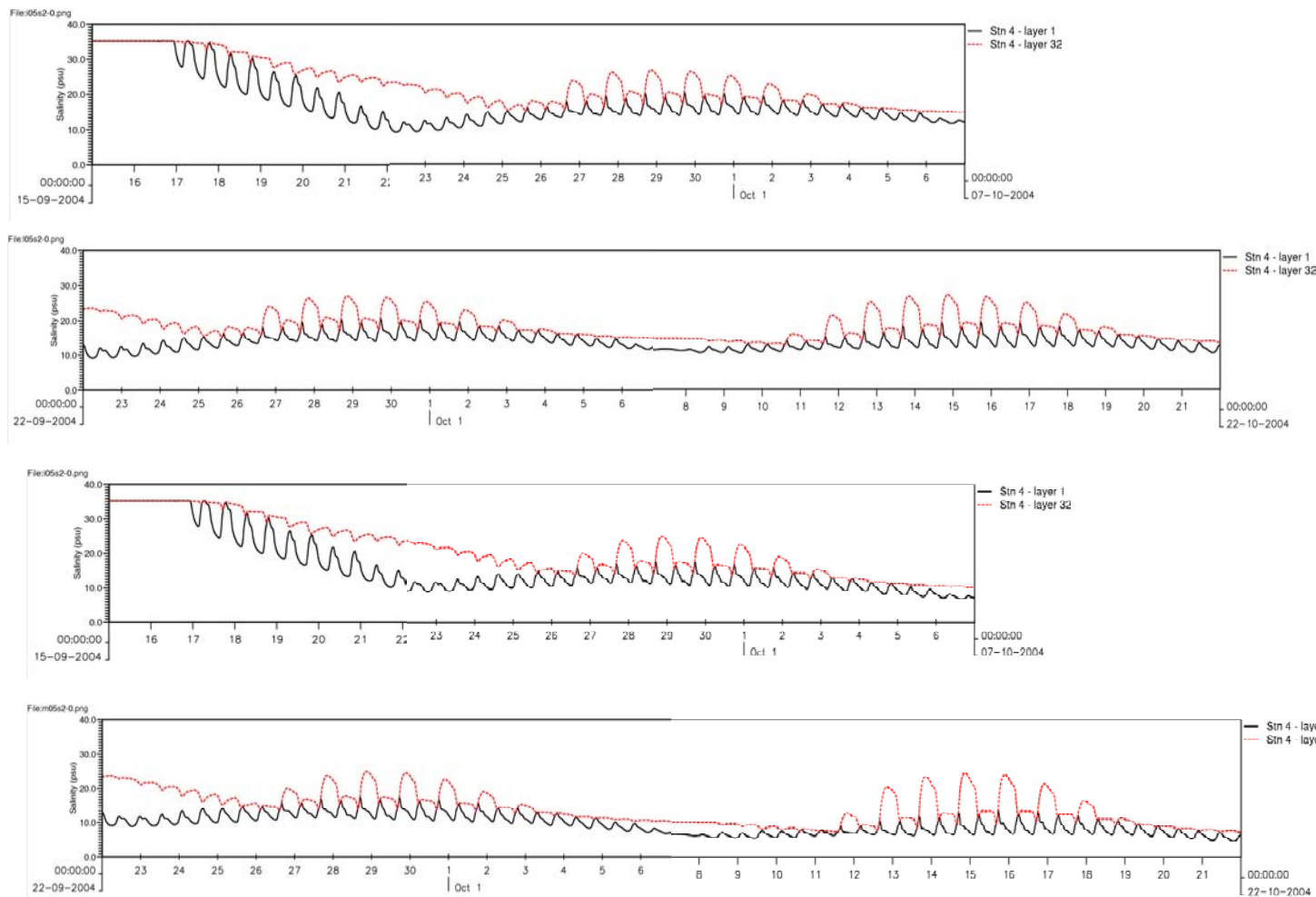


Figure 7 Sequence of simulated salinity distributions along the axis of the Kromme Estuary showing the salinity intrusions into the deeper basins (located approximately 5 km upstream of the mouth of the estuary) during spring tides (continued)

A)



B)

Figure 8 Times series of surface and bottom salinity at location S4 for : A) a 5 m³/s freshwater inflow for 6 days followed by a steady 1 m³/s freshwater inflow and B) a 5 m³/s freshwater inflow for 6 days followed by a steady 2 m³/s freshwater inflow

6. Conclusions and Recommendations

The model simulations indicated the following:

- The freshwater release of 2 million m³ presently allocated to the estuary is insufficient to achieve and/or sustain the salinity distribution required to ensure the first initial improvement in ecological functioning of the Kromme Estuary.
- Water column stratification in the estuary is generally limited due to the low freshwater inflows to the estuary and the shallow lower reaches of the estuary where turbulence due to strong tidal flows mixes the water column.
- Under these low to moderate freshwater inflows the tidal excursion of seawater up the estuary during spring tides is sufficient to inject higher salinity seawater into the deeper basins upstream, 5 km from the mouth (Station S4). The implication of this is that the salinities at a location 5 km upstream of the mouth will not consistently remain below 20 ppt for these intermediate freshwater inflows. Only for more extreme freshwater inflows will the higher salinity seawater be prevented from intruding into the estuary to the extent that seawater enters the deeper basins in the estuary approximately 5 km upstream from the mouth of the estuary.
- The Geelhoutboom tributary is a small volume tributary and requires little freshwater inflow to create low salinity conditions.
- Due to the shallowness of the Geelhoutboom tributary, should a surface layer of freshwater reach the confluence of the Geelhoutboom and the Kromme, it will rapidly flush and freshen the total water column even if the freshwater flows into the upstream section of the Geelhoutboom are limited or non-existent. Conversely, should there be no freshwater inflows into the Kromme but a reasonably strong freshwater flow into the Geelhoutboom, not only will the waters of the Geelhoutboom freshen but there will be a surface inflow of freshwater into the Kromme Estuary that is likely to result in stratified conditions in the vicinity of the confluence.

In conclusion, the nature of the Kromme Estuary (i.e. lower constricted reaches that results in a well-mixed water column, the existence of deeper basins upstream and the abrupt termination of tidal influence in deep water by the rocky sill approximately 14 km upstream of the mouth) results in the estuary being relatively “insensitive” to the nature of freshwater inflow. Unlike most other estuaries even moderately large freshwater inflows are likely to have little influence on the upstream dynamics and ecology as these flows travel across the surface of the estuary and are only mixed into the water column further downstream where the shallow waters and increased turbulence mix the surface and bottom waters. The upstream ecology is and always has been less sensitive to freshwater inflows than has been appreciated previously.

The above observation is made in greater detail in the main report where the implications of this observation to the management of this and other estuaries, is given greater consideration.

APPENDIX D

SEDIMENT DYNAMICS

Prof GR Basson and JS Beck

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1. INTRODUCTION

The Kromme Estuary is situated on the south coast of South Africa at St Francis Bay. The catchment area at the top of the estuary is 850 km² and the estuary is about 12 km long. A relatively large tributary, the Geelhoutboom, with an incremental catchment area of 60 km², enters the estuary about 8 km from the sea.

Two large dams have been constructed on the Kromme River, the Churchill Dam (1948) in the upper catchment and downstream of it the Impofu Dam (1983) near the upper end of the estuary, 16km from the sea. The Kromme River Dam has a capacity/mean annual runoff ratio (MAR) of 0.6, while the same ratio at the Impofu Dam is 1. This means that since the early 1980s the estuary has received very few floods, and is reliant mainly on the releases made from the Impofu Dam and the tributary flows from the Geelhoutboom River, which are small.

The estuary is relatively wide and shallow and the river channel meanders through numerous sand banks in the lower reaches from the mouth to the end of the sand banks (see Figure D-1 and Figure D-2). The sand banks disappear about 5 km from the sea and the river channel becomes quite deep (middle reaches up to the Geelhoutboom, see Figure D-3). In the upper reaches, from the Geelhoutboom to the top of the estuary, the river becomes very narrow with steep, rocky sides (Figure D-4).

The volume of the estuary below MSL is about 3 million m³, while at high tide the volume (taken as below +1.2 m MSL) is almost double at 5.7 million m³. In relation the volume of the marina canals (started in 1968, see Figure D-5 and Figure D-6) is about 0.15 million m³, which is very small compared to a tidal prism of about 2 million m³.



Figure D-1 Kromme Estuary – lower reaches



Figure D-2 Sandbanks in the lower estuary



Figure D-3 Sandbanks in the middle reaches of the estuary (during spring tide)



Figure D-4 Upper reaches of the Kromme Estuary



Figure D-5 Marina Glades at the Kromme Estuary (<http://www.stfrancistourism.co.za>)

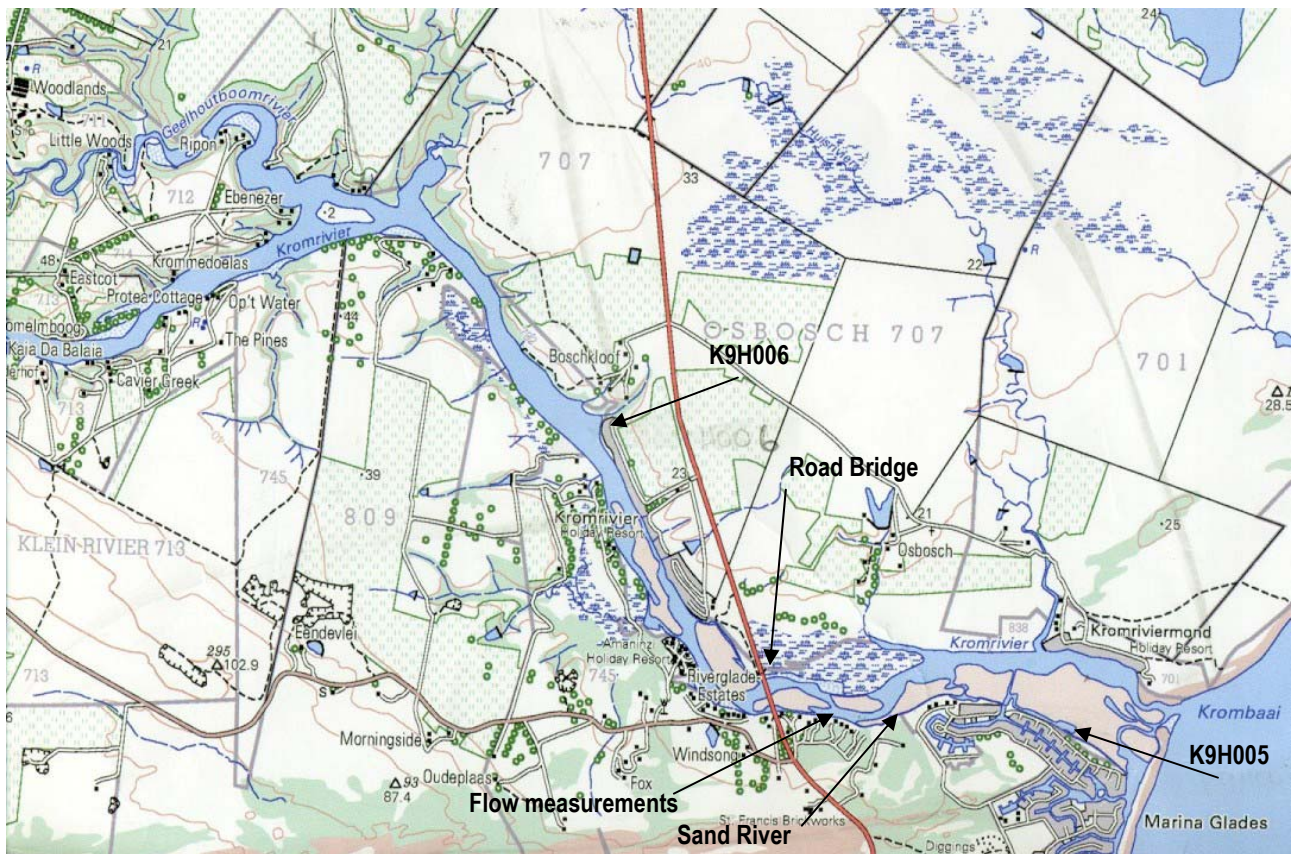


Figure D-6 Topographical (1:50 000) map of Kromme Estuary

2. FLUVIAL MORPHOLOGICAL SIMULATION SCENARIOS

In order to assess the changes in the sediment dynamics of the Kromme Estuary between the Reference and Present Conditions, mathematical modelling of the hydraulics and morphology of the Kromme Estuary was carried out. Two scenarios were selected:

- Reference Condition (natural)
- Present day

The other scenarios specified in this EFR are basically the same as the Present Scenario in terms of floods and therefore will not yield different results in terms of sediment dynamics, and were not simulated.

For the Reference Condition, data were obtained by calculating the inflows into the Churchill Dam through a dam balance, using the monthly data (e.g. evaporation and rainfall) as well as primary outflow data supplied by DWAF. This way a 10-year time series with 2-hourly time steps was obtained. The data were scaled according to a ratio of catchment areas to obtain a flow series at the top of the estuary (Figure D-7). The MAR shown in Table D-1 may differ from those listed in other sources, because the time period over which the MAR in Table D-1 was calculated, only covers a 10-year period from 1993 to 2003. The flow data used for the Present day Scenario comes from DWAF gauging station K9H003 downstream of Impofu Dam. The station recorded almost continuously from 1983 to date, except for a 2-year gap from 1996 to 1998 (Figure D-8). However, the discharge table for this station cuts off at 100 m³/s and as such, larger flows had to be calculated based on uniform flow conditions.

Table D-1 Reference Condition

Site	Catchment Area (km ²)	MAR (10 ⁶ m ³)
Kromme River Dam	357	64.9
Top of estuary	851	100.2
MAR adjustment factor	1.54	

From Figure D-7 and Figure D-8 it can be seen that while in the early 1990s the dam spilled occasionally, no more spills seemed to have taken place in the last seven years.

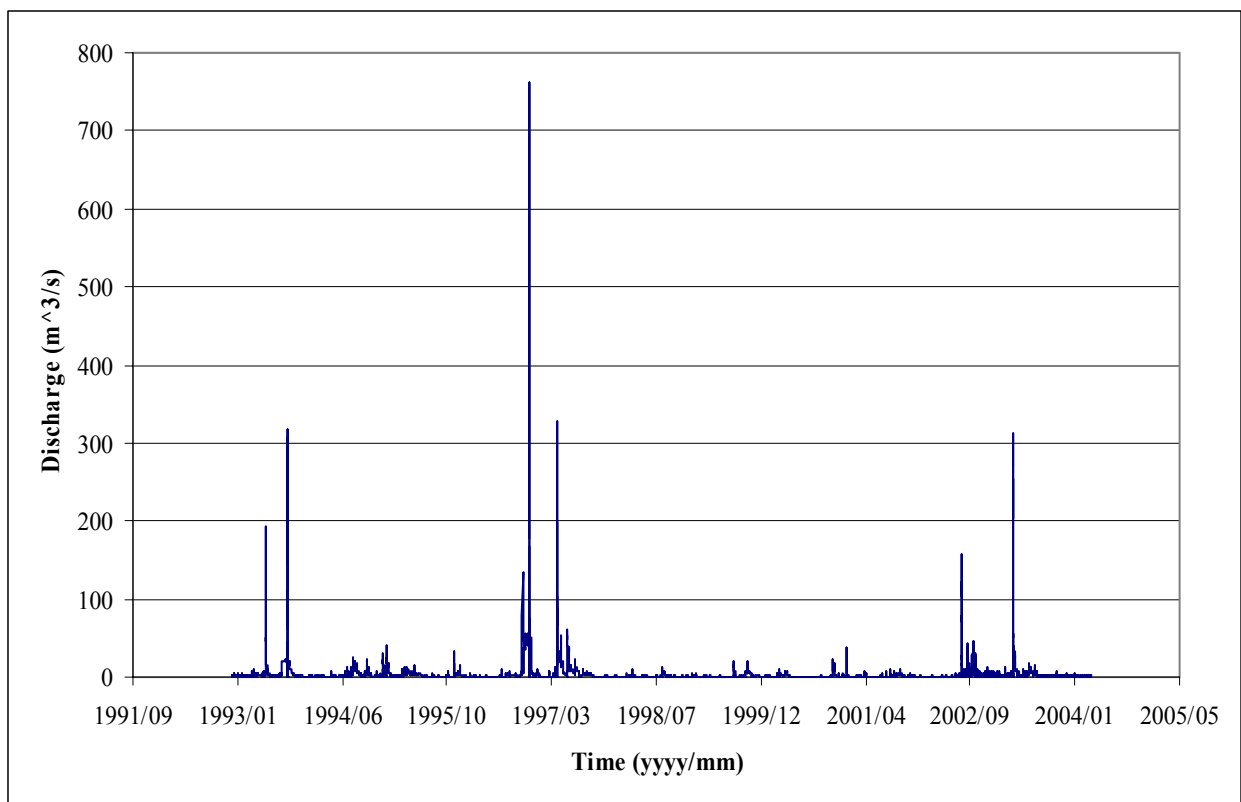


Figure D-7 Reference Condition – discharge time series at top of estuary (generated)

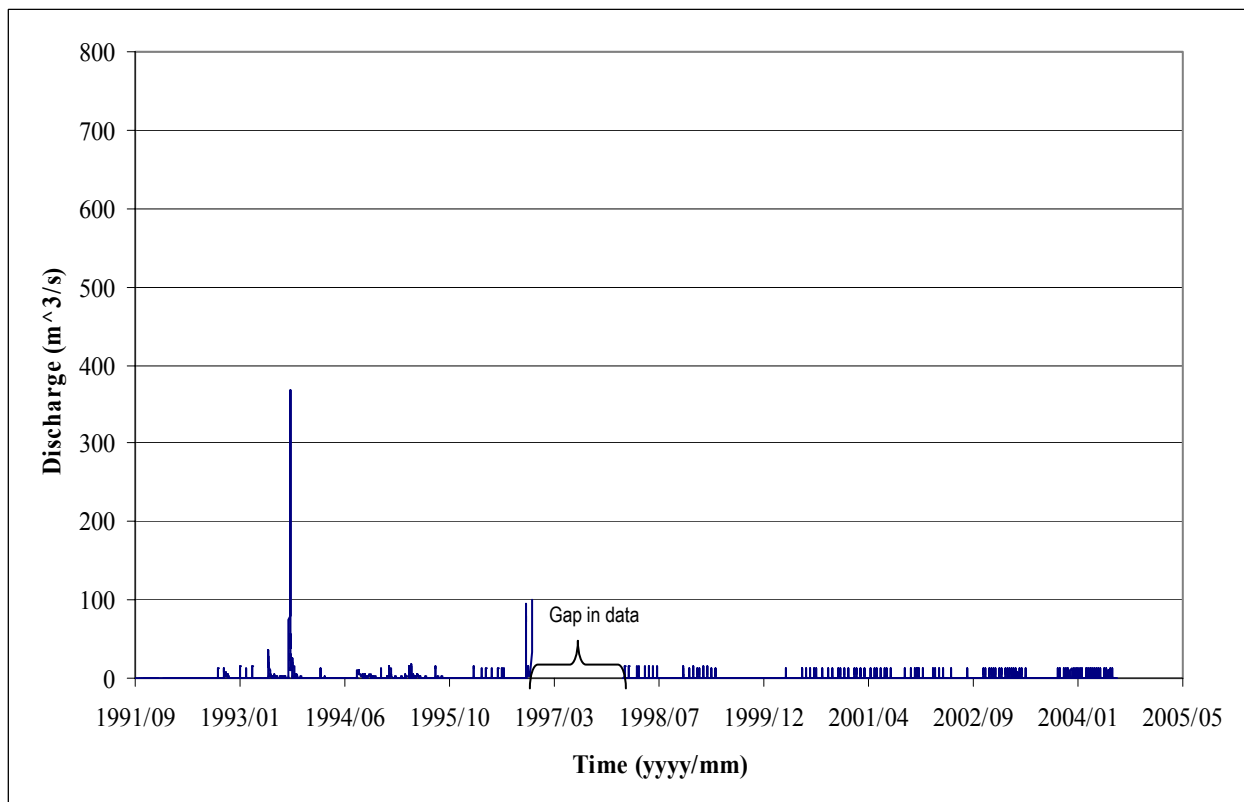


Figure D-8 Present Condition – discharge time series at top of estuary (observed)

3. KROMME ESTUARY MODEL SET-UP

3.1 Mathematical model background

For the computational modelling, the two-dimensional model MIKE 21, developed by the DHI Water and Environment (DHI, 2003), was used. MIKE 21 is a software package for simulating free-surface flows, water quality, sediment transport and waves in rivers, lakes, estuaries, bays, coastal seas and other water bodies. In particular MIKE 21C, a special module developed to simulate river morphology, was used. MIKE 21C is based on a curvilinear grid and hydrodynamics, where sediment transport and river morphology can be simulated, with modules to describe:

- Flow hydrodynamics – water levels and flow velocities over a curvilinear or rectangular grid are computed
- Helical flow (secondary currents)
- Sediment transport – based on various model types, capable of graded sediment transport computations
- Alluvial resistance due to bed material and bed forms
- Scour and deposition – large-scale movement of bed material is computed and the effect of supply limited sediment layers can be incorporated.
- Bank erosion and platform changes – bank lines as well as the curvilinear grid can be updated

The modules can run interactively, incorporating feedback from variations in the alluvial resistance, bed topography and bank line geometry to the hydrodynamics and sediment transport.

3.2 Model setup

A curvilinear grid with 150 grid cells in the flow direction and 20 grid cells across (Figure D-9) was used for the hydrodynamic and morphological simulations, with a cell size of approximately 80 m x 50 m. The 2D model was set up from just downstream of the Impofu Dam to the open sea. The model bathymetry was based on a combination of data obtained from the CSIR for the Delft 3D model used for water quality simulations (Figure D-10):

- 1988 bathymetry data of the estuary
- Shoreline
- Sandbanks and land boundary

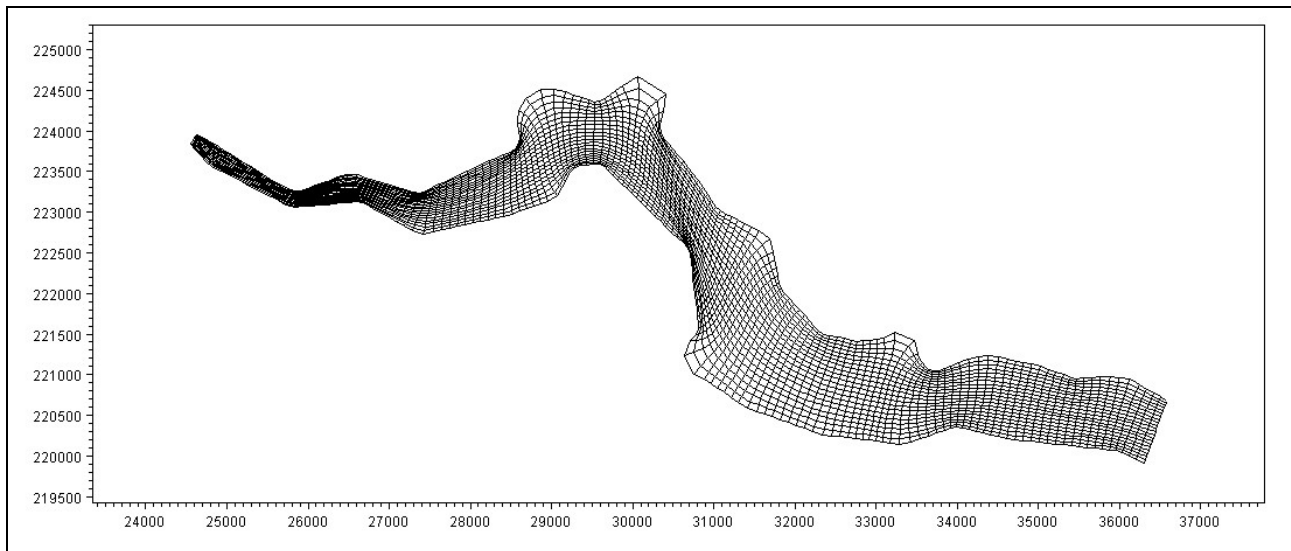


Figure D-9 Kromme Estuary grid

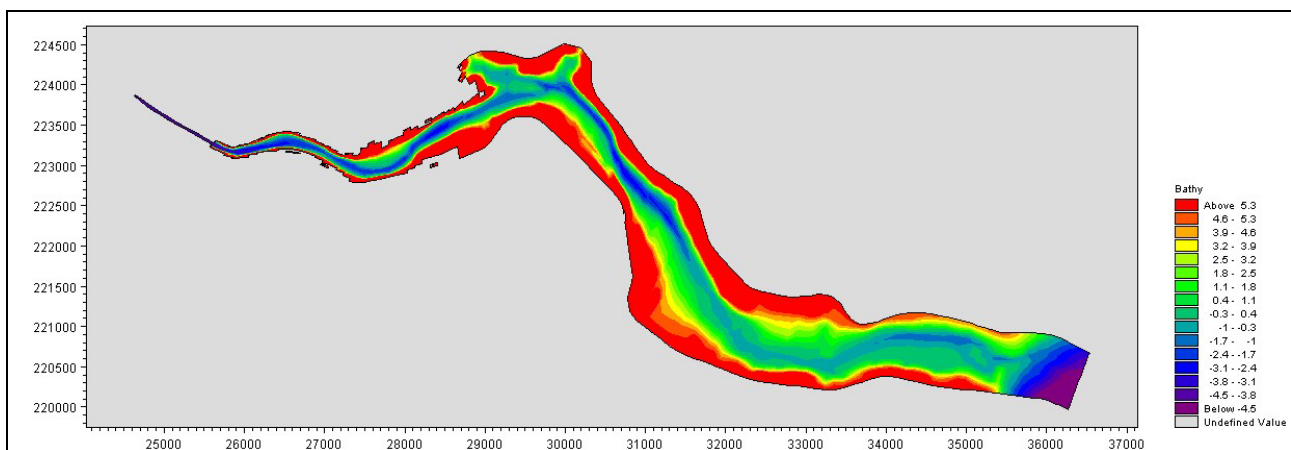


Figure D-10 Kromme Estuary bathymetry

3.2.1 Boundaries

At the upstream boundary an inflow time series was specified. A water level time series with 30-minute time steps, representing the tidal variation in the sea, was specified at the downstream boundary. The tidal variation was simulated, based on tidal constituents for Port Elizabeth (Figure D-11). No inflow from the Geelhoutboom River was specified as no data was available for this tributary, but the MAR from the Geelhoutboom is any case very small compared to the total catchment runoff (3% with a catchment area of 60 km²) and as such these flows would not have significant impacts on the sediment dynamics of the Kromme Estuary.

For both scenarios a three-month period was simulated, covering normal tidal action and, in the case of the Reference Condition, a number of medium sized floods as well (Figure D-12). In contrast, during this three-month period no floods reached the estuary for the Present Condition (Figure D-13). The flows during this three-month period (Present Condition) were generally less than 0.1 m³/s, except for one of the floods with a peak of approximately 13 m³/s that are released from the dam at regular intervals (Figure D-14). All flows used in these simulations consist of instantaneous peak flows and not daily average values.

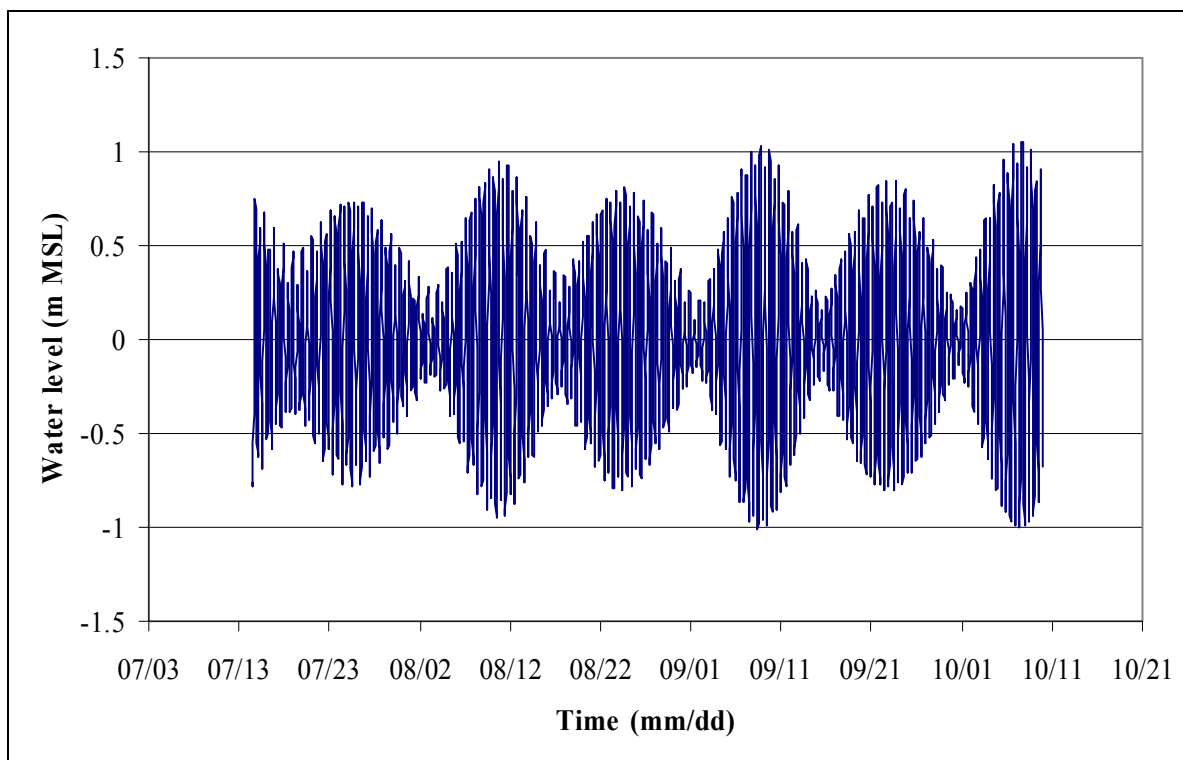


Figure D-11 Predicted tidal variation based on Port Elizabeth tidal constituents (2002)

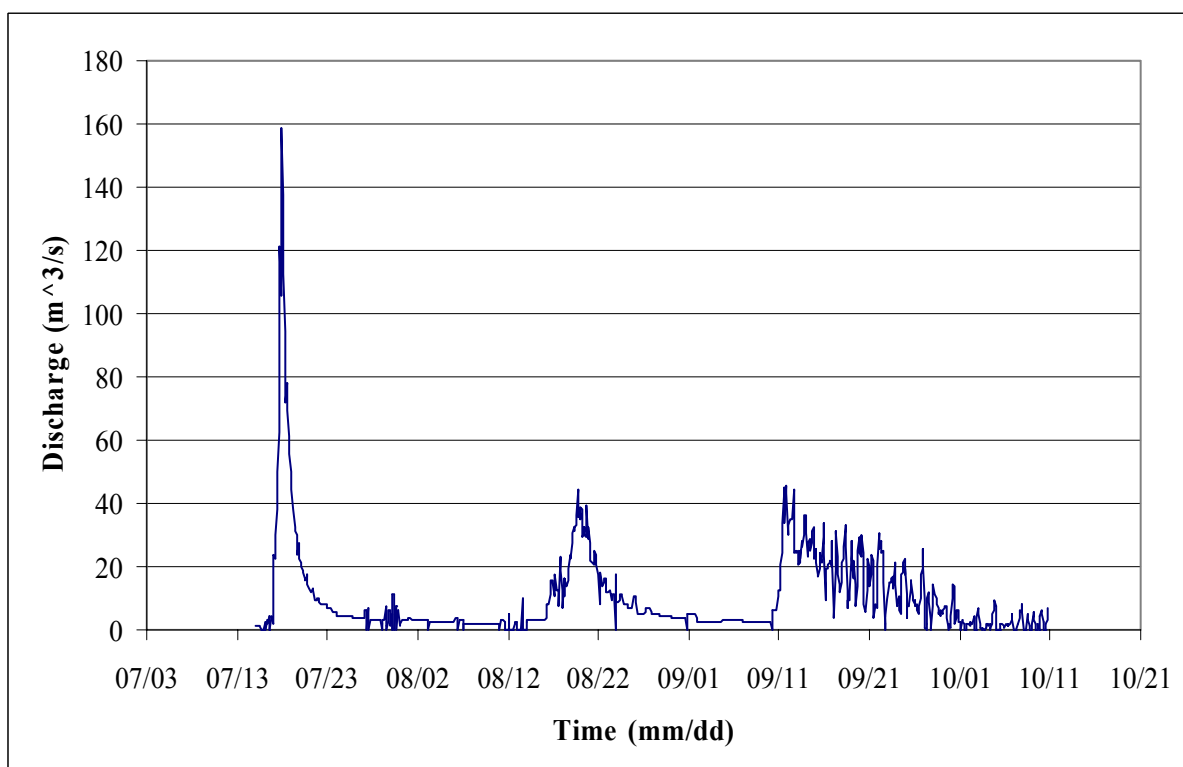


Figure D-12 Reference Condition simulation inflow time series (instantaneous peak data) (2002)

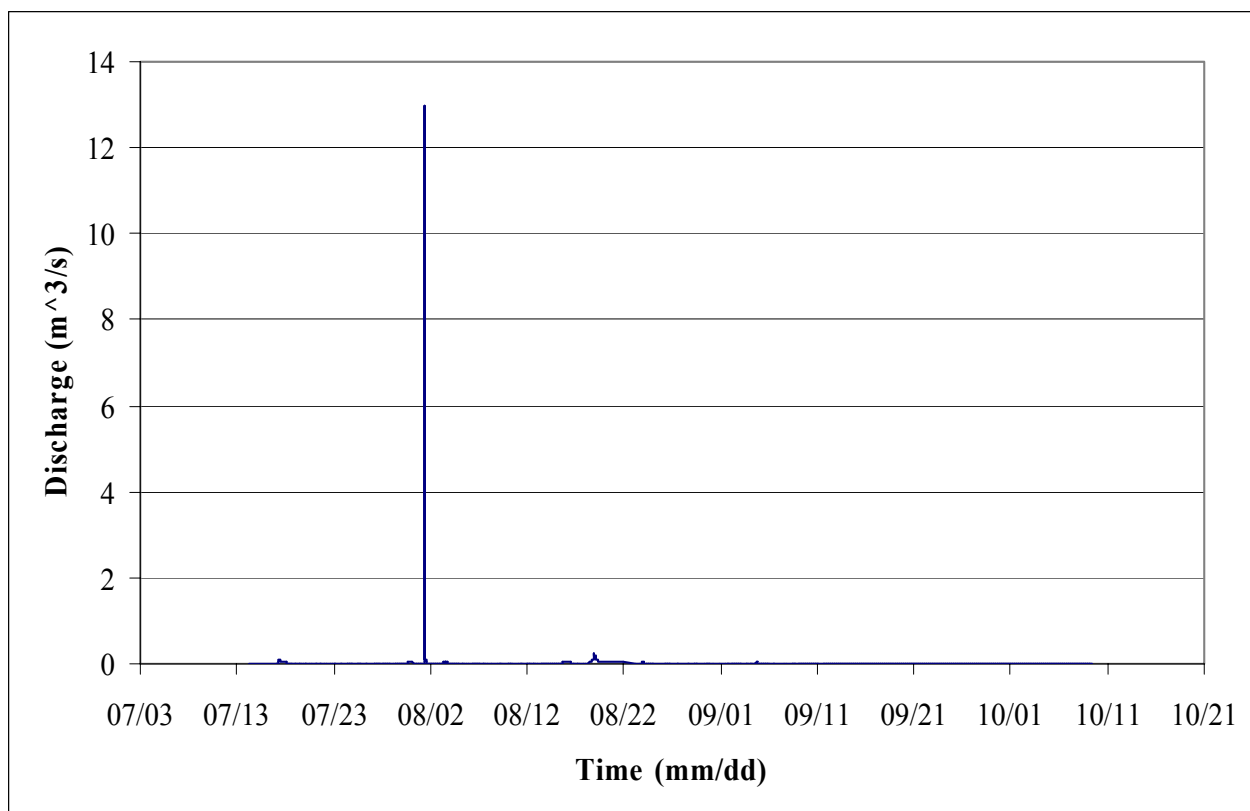


Figure D-13 Present Condition simulation inflow time series (instantaneous peak data) (2002)

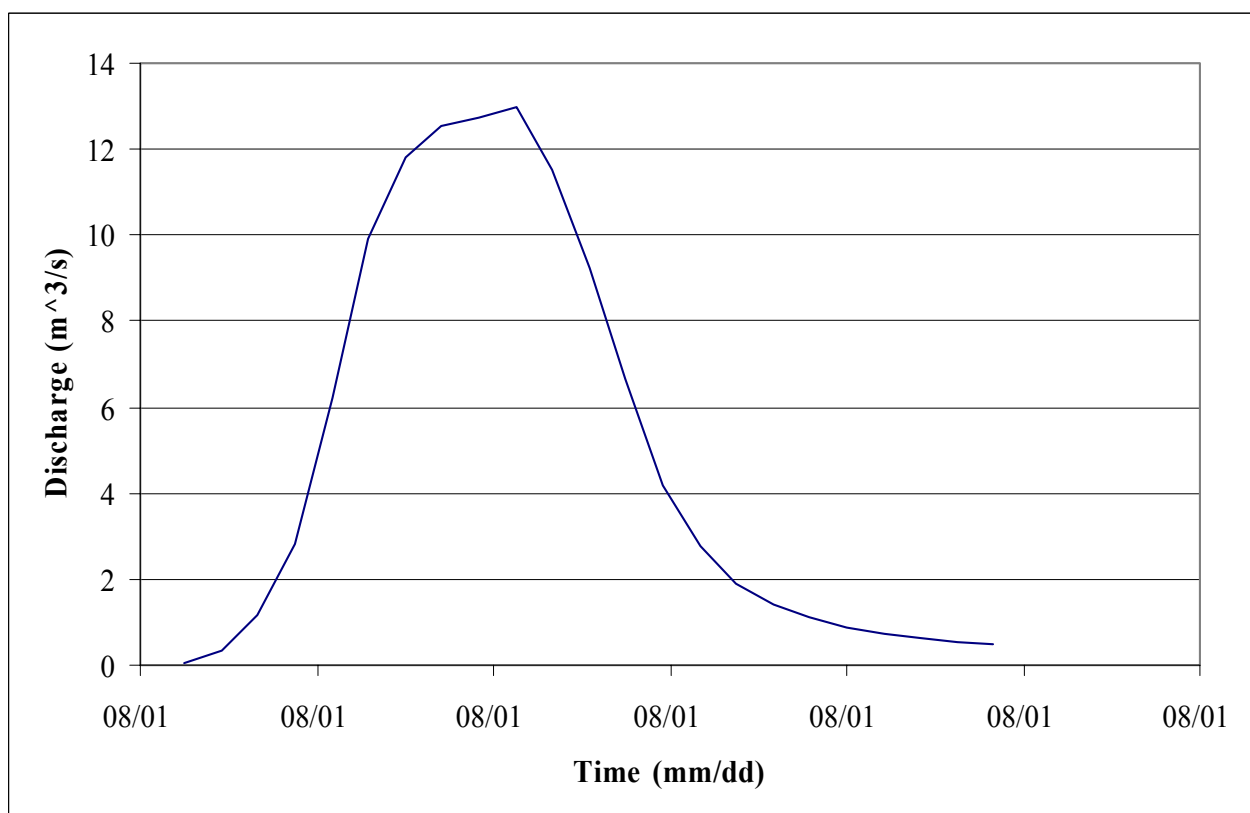


Figure D-14 Present Condition artificial flood release

3.2.2 Model parameters

The bed resistance was kept constant throughout. Other model parameters are given in Table D-2.

Table D-2 Hydrodynamic and morphological model parameters

Parameter	Value
Hydrodynamic time step	3 s
Morphological time step	3 s
Manning M	50 m ^{0.33} /s
Median grain diameter	0.21 mm
Sediment transport formula	Engelund and Fredsøe
Eddy viscosity	0.15 m ² /s
Mass density of sediment	2650 kg/m ³

3.2.3 Sediment characteristics

A uniform sediment size of 0.21 mm was specified throughout the whole model, which was based on bed sediment samples taken in the field (see Figure D-15). Figure D-12 shows that towards the top of the estuary the sediment becomes increasingly coarse, probably because much of the finer sediment is flushed away by the clear water released from the dam. In the first 4 km from the mouth the sediment size is very consistent with a median particle diameter of 0.21 mm, which is typical of marine sediments along our coasts. This seems to indicate that along those 4 km marine sediments dominate. In the area where the estuary becomes deeper the sediment is much finer, probably because all the fine material has settled in the deeper parts of the estuary due to the lower flow velocities, and is not easily flushed out. The spike in the sediment size around 6.5 km is probably due to the influx of coarser sediment from the Geelhoutboom River. Just upstream of this tributary, the sediment is again very fine, but becomes increasingly coarse further upstream, closer to the dam.

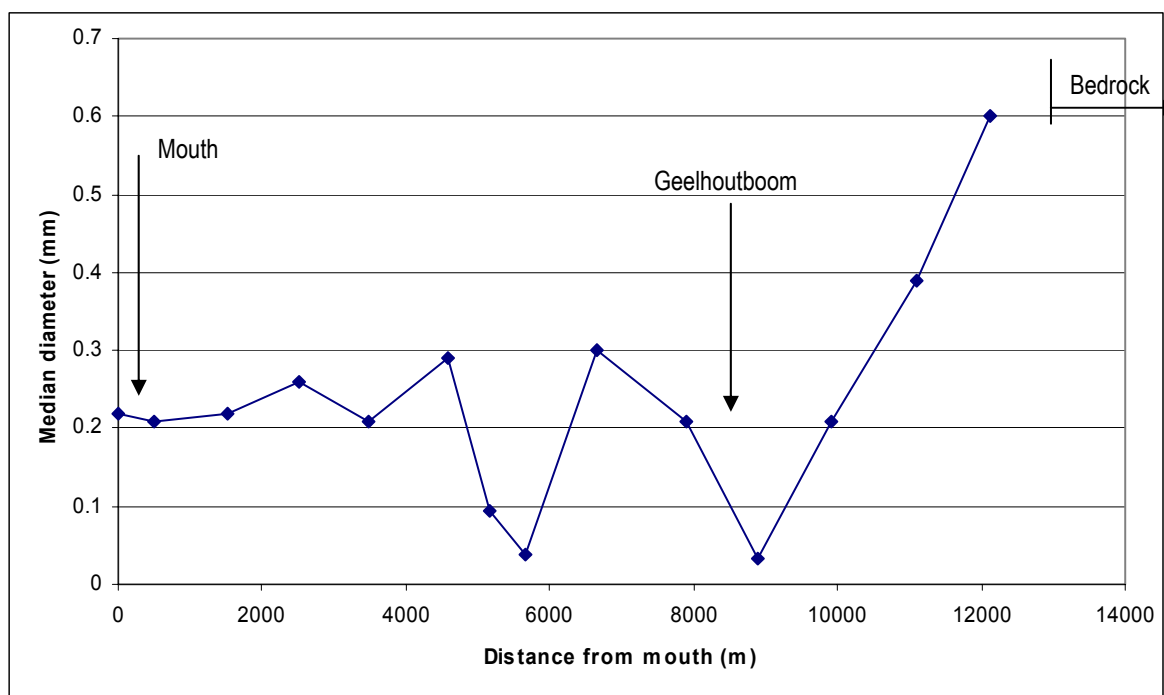


Figure D-15 Median diameter of sediment samples taken in February 2004 at the Kromme Estuary

For the Present Condition no sediment input was specified at the upstream boundary, as virtually all

the catchment sediment is trapped in the dams. For the Reference Condition the incoming sediment loads were obtained by calculating the sediment transport at the top of the estuary, based on the local hydraulic conditions. The sediment loads thus obtained are calculated for a representative sediment size of 0.21 mm and represent the total carrying capacity of the inflow. This value usually has to be scaled to account for the fact that although the river can transport a certain amount of sediment, it is not always available.

The sediment yields obtained from various sources for this catchment vary considerably:

- Sediment yield maps 170 ton/km².a (Rooseboom, 1992)
- Reservoir sediment surveys Kromme River Dam – 10 ton/km².a

The reservoir sediment surveys indicate that the sediment yield is relatively low.

No sediment input was specified at the downstream boundary since it was assumed that most of the sediment from the ocean would be scoured around the mouth of the estuary, which is included in the model, and that the sediment availability from the ocean is not limited.

The catchment area downstream of the Impofu Dam is 130 km². If the sediment input to the estuary is taken as 170 ton/km².a x 130 km², the total average annual input could be 22100 ton. The storage capacity of the farm dams in the Geelhoutboom catchment, however, traps about 80% (Churchill, 1948) of the sediment and therefore the net sediment input to the estuary is on average only 13900 ton/a. If 100% trapping of sediment in the estuary is assumed, the estimated rate of rise of the bed in the deep part of the estuary from the top of the estuary to the marine sediment area (8 km) is about 9 mm/year. This does not take into consideration that during floods most of the sediment brought in will be carried out to sea. The process of sediment accumulation in the upper estuary is therefore very small and slow.

The sporadic sediment input from the Sand River (see Figure D-6 for location, as well as Figure D-16) was taken into account through the relatively high sediment yield from the incremental catchment downstream of the Impofu Dam, which accounts for the slow rate of accretion in the deeper areas of the estuary, as explained above. Since the numerical model always assumes that the availability of sediment is not limited at the ocean boundary, the normal sediment transport in the lower reaches of the estuary is not compromised by not including the sediment input from the Sand River in the numerical modelling.



Figure D-16 Sand River in 1994 (*Photo P Huizinga*)

4. MODEL CALIBRATION

4.1 Tides

The model was calibrated based on measured water levels at the DWAF water level recorder K9H006, which is situated approximately 5 km from the mouth. The calibration was carried out for one week in 2004, by adjusting the parameters in Table D-2, with the bed roughness being the most important factor. The calibrated tidal variation is generally within 10 cm lower than the observed tidal variation, and the timing was calibrated to be within 10 to 20 minutes (see Figure D-17). The slightly greater differences at the beginning of the calibration period could be due to the fact that the real tidal variation could have been greater as a result of a small flood on the Geelhoutboom or a storm that could have temporarily increased the water levels.

Flow rates were also calibrated based on flow measurements done by DWAF during the February 2004 fieldwork. The flow rates were measured at a cross-section about 1 km downstream of the road bridge. The velocities and flow rates during the flood tide compared reasonably well, as can be seen in Table D-3. The flood tide velocities compare much better than the ebb tide velocities. The reason for this could be that the bathymetry on which the model is based has changed. The main channel might be smaller now than what it was.

Table D-3 Measured and simulated velocities and flow rates

	Measured	Mathematical model simulated
Ebb tide velocities	0.2 – 0.6 m/s *	0.2 – 0.4 m/s
Flood tide velocities	0.3 – 0.7 m/s	0.2 – 0.6 m/s
Ebb tide flow rates	52 m ³ /s	30 m ³ /s
Flood tide flow rates	91 m ³ /s	85 m ³ /s

*Range of velocities across cross-section.

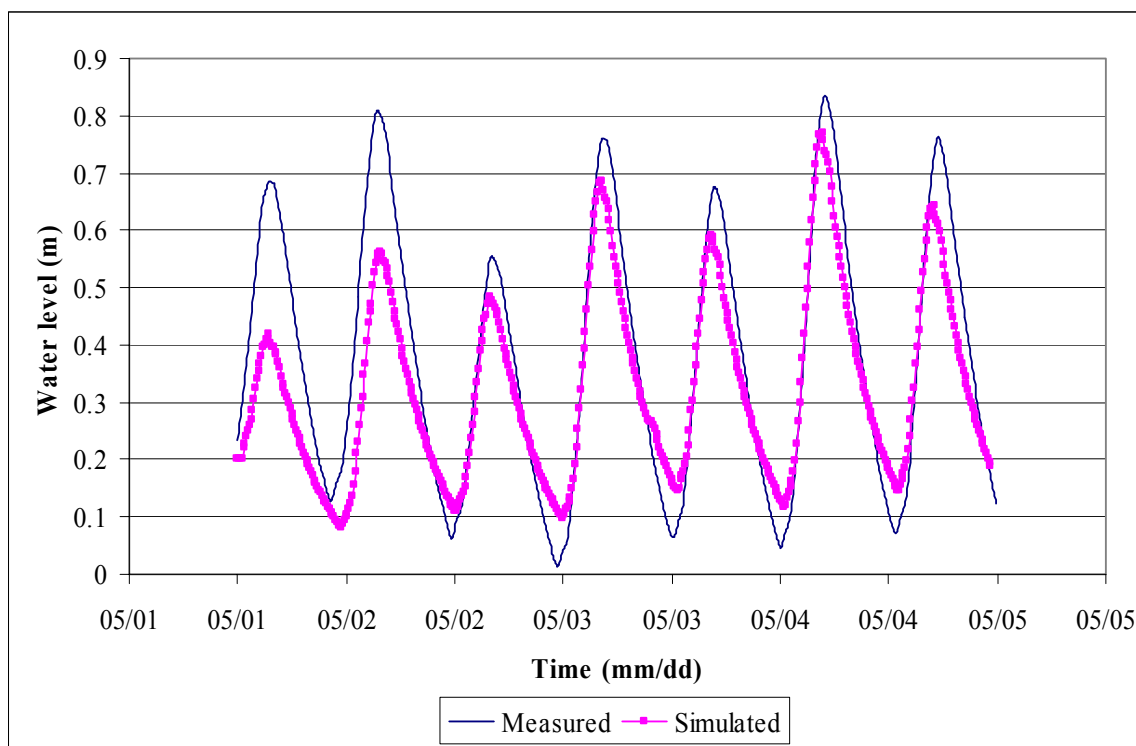


Figure D-17 Calibrated and measured water levels at K9H006

5. SIMULATION RESULTS

5.1 Reference Condition

A three-month period from mid July to October 2002 was simulated under Reference Condition. From Figure D-18 it can be seen that very little sediment movement has taken place in the upper reaches of the estuary, but becoming more widespread and pronounced in the lower reaches where the estuary is very shallow. Most of the changes have taken place in the mouth (see Figure D-19 and Figure D-20). Basically the tidal action and the occasional floods have created a deeper, more pronounced channel in the mouth and to some degree in the middles reaches as well.

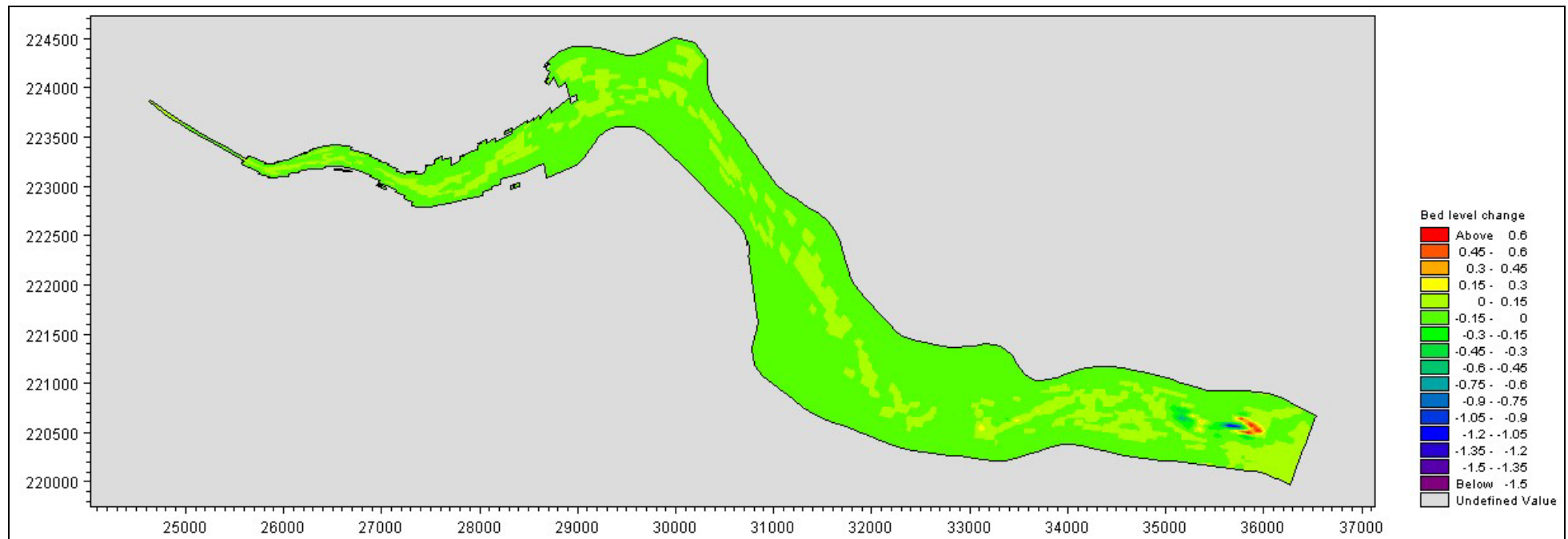


Figure D-18 Reference Condition – bed level changes after three-month simulation period

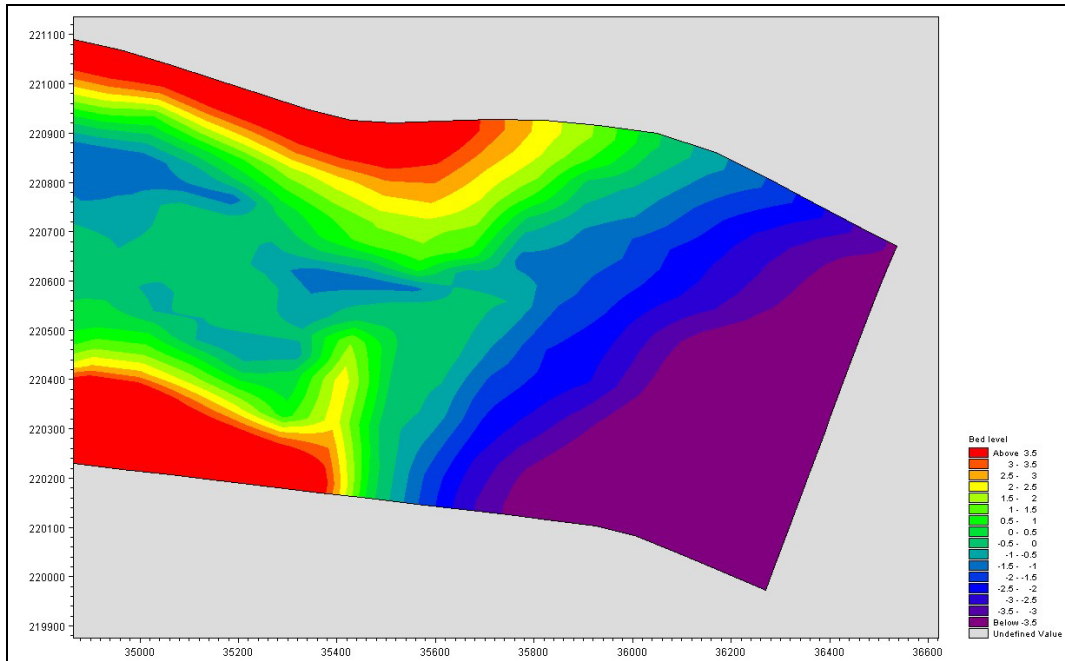


Figure D-19 Reference Condition – initial bed level

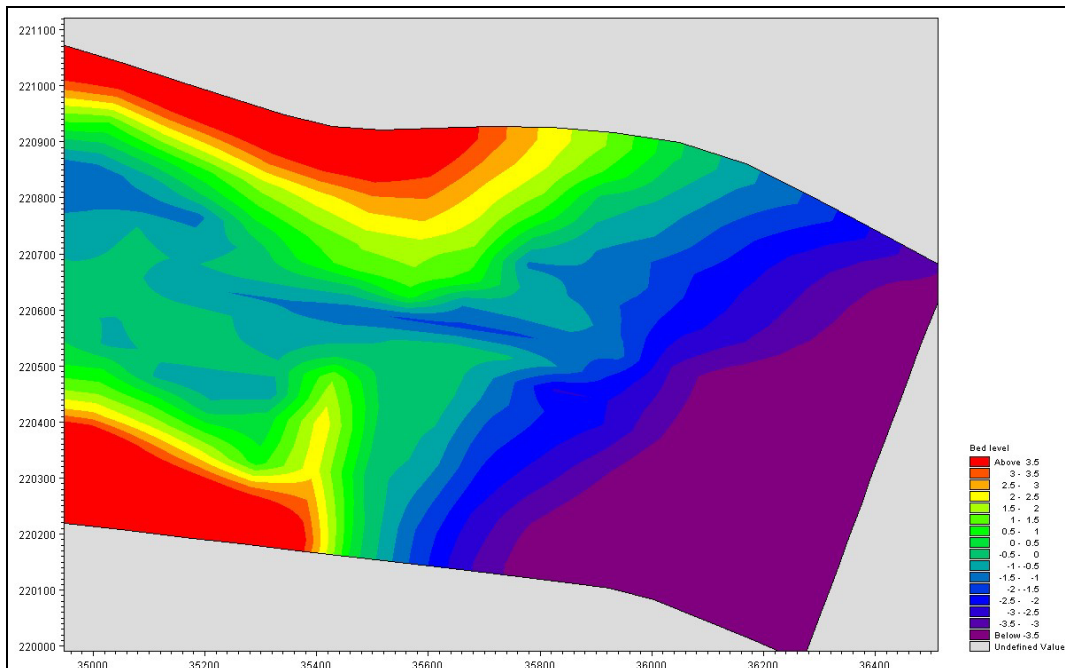


Figure D-20 Reference Condition – final bed level

5.2 Present Condition

The same three-month period as was used for the Reference Condition was simulated under Present Condition. From Figure D-21 it can be seen that similar to the Reference Condition very little sediment movement has taken place in the upper reaches of the estuary, but becoming more widespread and pronounced in the lower reaches where the estuary is very shallow. Most of the changes have taken place in the mouth (see Figure D-22 and Figure D-23), as the flow velocities in that area are much greater than anywhere else in the estuary (see Figure D-24 and Figure D-25). Basically the tidal action has created a deeper, more pronounced channel in the mouth and formed sandbars on either side of this channel towards the open sea.

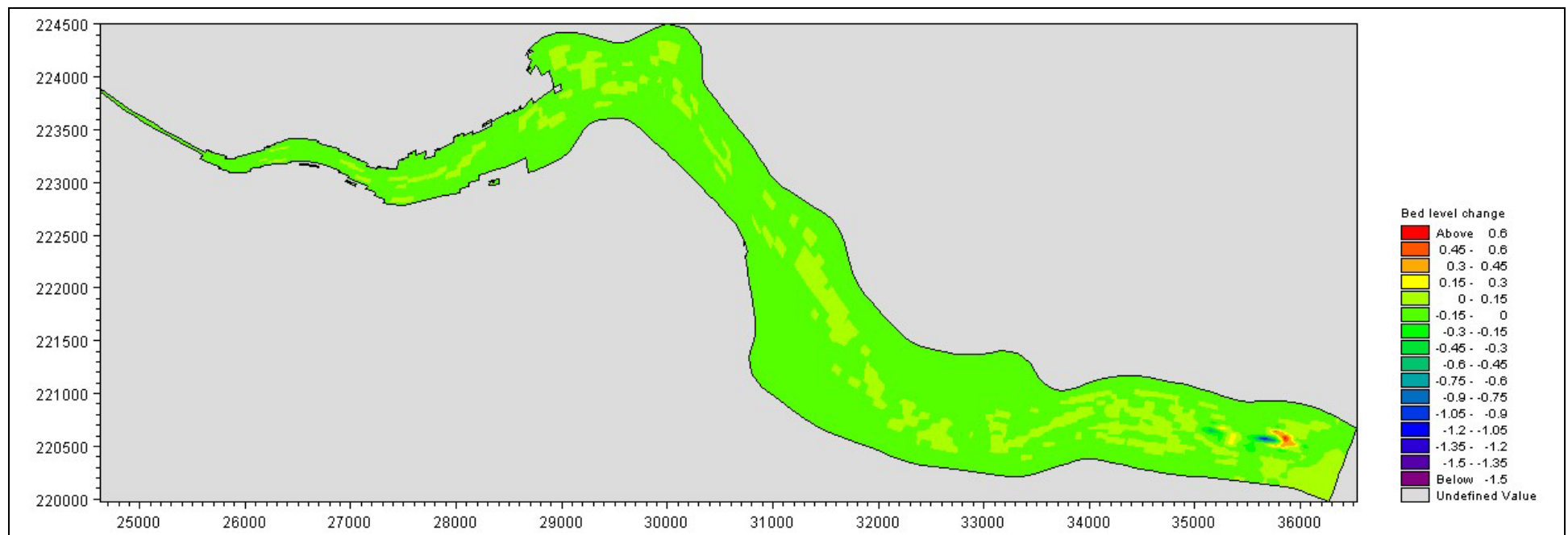


Figure D-21 Present Condition - bed level changes after three-month simulation period

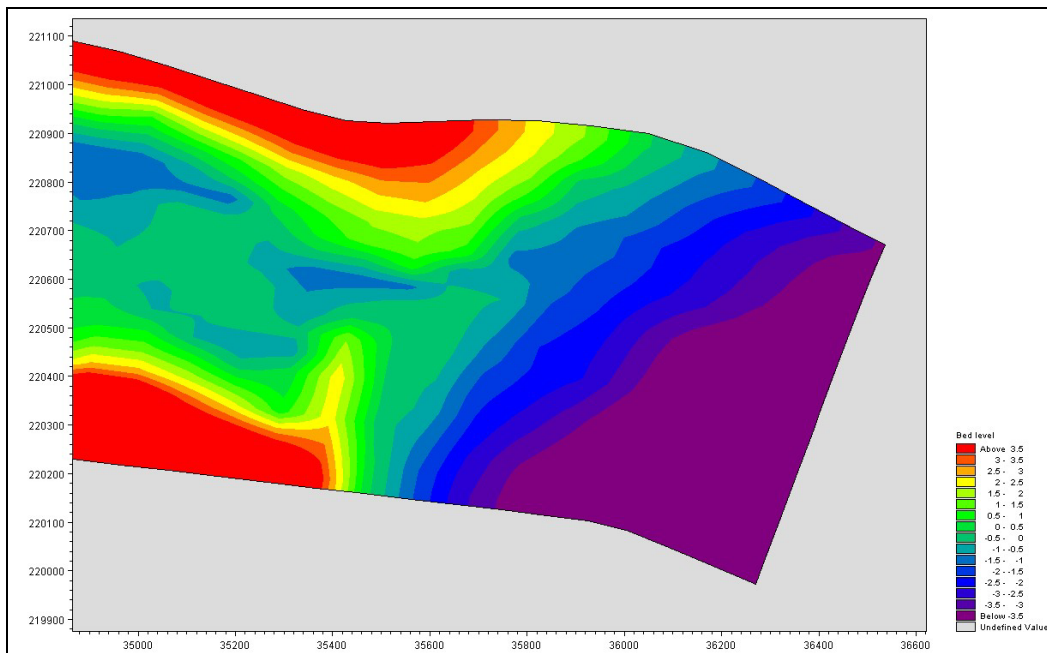


Figure D-22 Present Condition – initial bed level

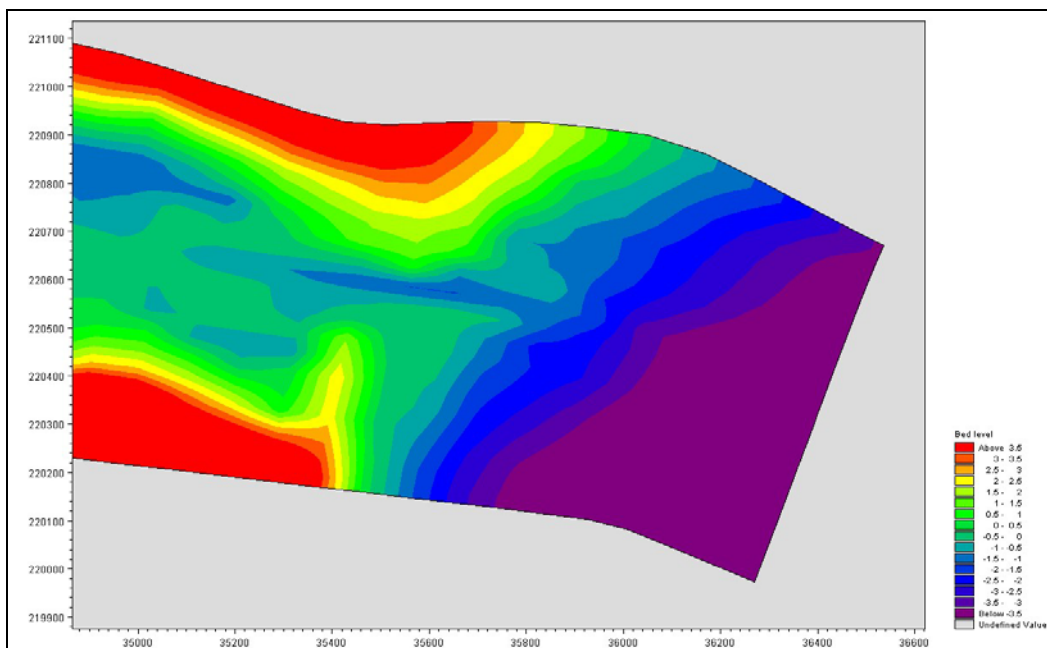


Figure D-23 Present Condition – final bed level after three-month simulation period

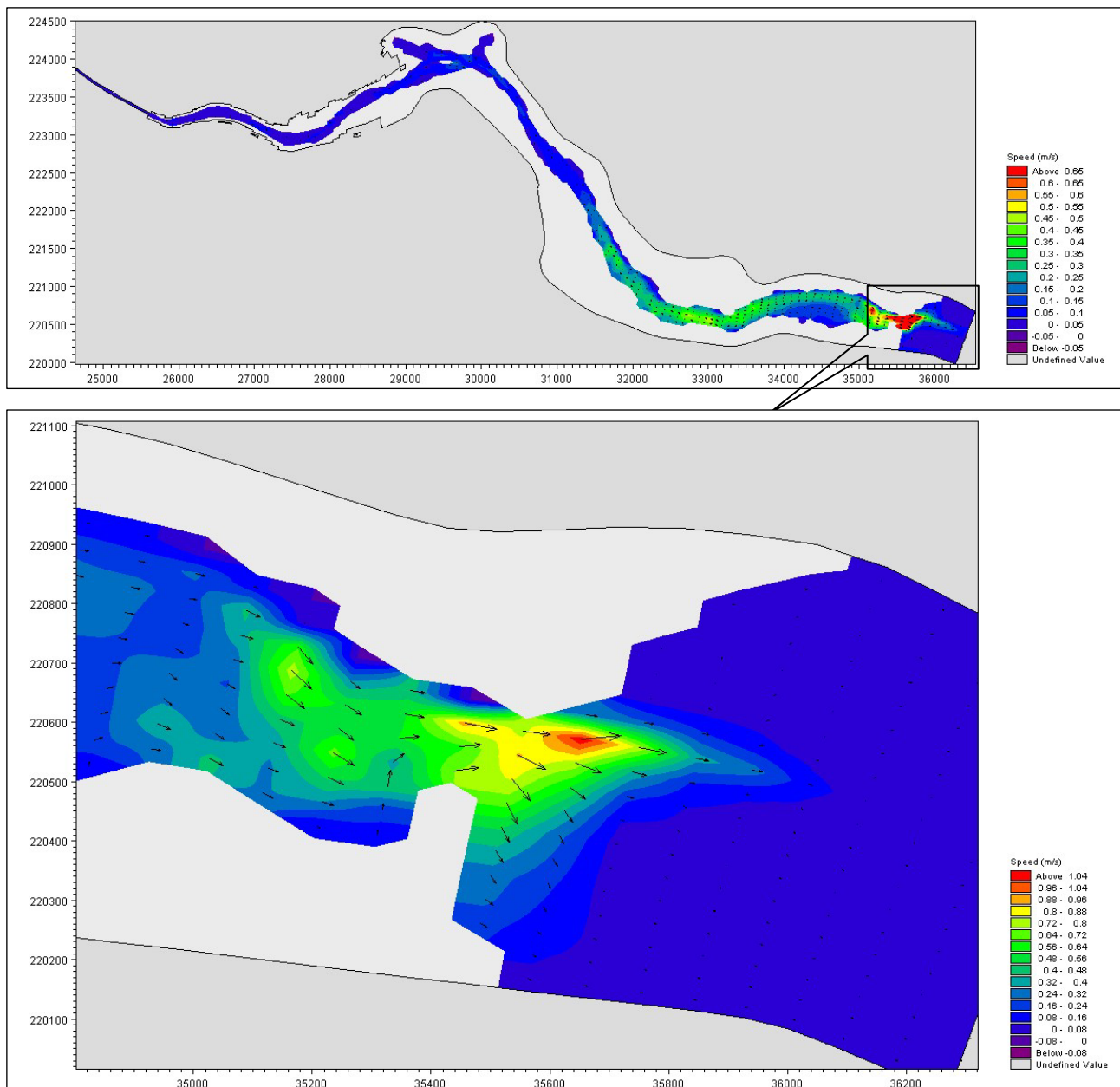


Figure D-24 Present Condition – flow velocities during ebb tide

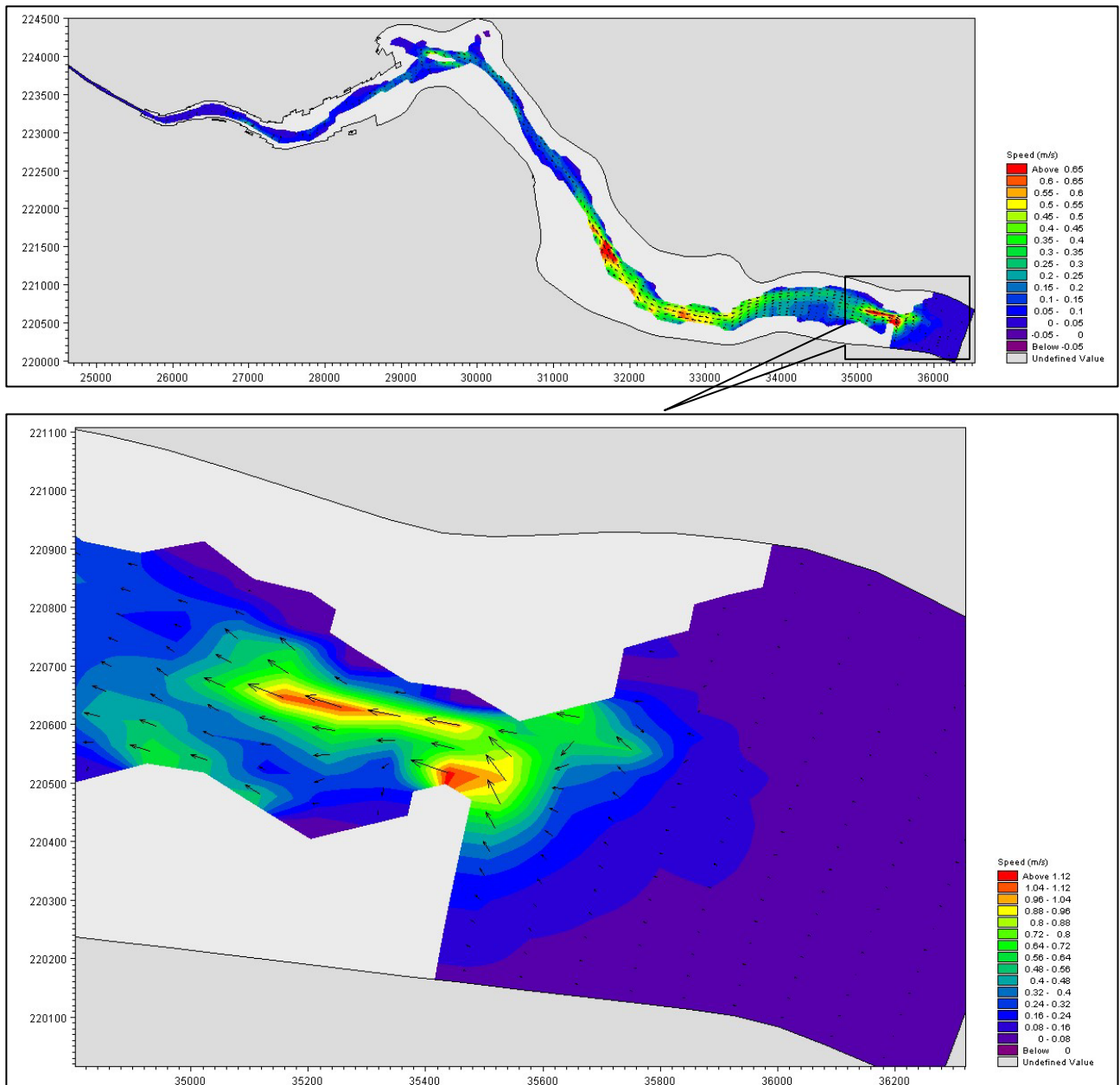


Figure D-25 Present Condition – flow velocities during flood tide

In the mouth and the lower reaches sediment movement tends to be directed towards the ocean, while further upstream at the end of the sandbanks the net sediment movement tends to be directed upstream, even though tidal flood velocities tend to be greater than ebb velocities. The volume of sediment moved during a week long tidal cycle is, however, very small (see Table D-4). The sediment flushed out during floods is much greater. For the Reference Condition, the largest flood in the 10-year period between 1993 and 2003 (peak discharge of 760 m³/s) was simulated and it was found that as much sediment was flushed from the mouth during that period as would during 15 years of normal tidal action. Therefore even with smaller floods, the volume of sediment flushed from the estuary would still be significantly greater than that brought in during normal tidal action. Aerial photography of the estuary also indicates a slow upstream movement of marine sediment.

Table D-4 Simulated sediment loads

Scenario	Location	Sediment load (m ³ /week)
Present	Mouth (1 week tidal action)	16
Present	End of sandbanks (1 week tidal action)	- 30*
Reference	Mouth (Flood – 760 m ³ /s - 1 week duration)	12200

*The negative value indicates that the direction of sediment movement is upstream.

5.3 Return period floods

The floods with return periods of 2, 10 and 20 years have been calculated for both the Reference and Present conditions with the aid of statistical methods (Table D-5). These methods are based on the maximum annual flood peaks during the 10-year period. Software developed by Alexander (1991) was used to calculate the return period floods. The probability distribution providing the best fit for all the data was Log Pearson Type 3 (LP3). Any return period floods based on a longer period of time could of course be different to the ones listed in Table D-5. However, the relative differences between the two scenarios are of importance.

It can be seen from Table D-5 that the magnitude of the return period floods are much lower at present, which is because almost all the floods from the catchment are absorbed by the Impofu Dam, which spills only rarely.

Table D-5 Return period floods for Reference and Present Conditions

Return period (yr)	Peak discharge – Reference (m ³ /s)	Peak discharge – Present (m ³ /s)
2	45	20 (55%)
10	360	185 (49%)
20	720	445 (38%)

¹Values in parentheses indicate the percentage decrease in flood peaks from Reference Condition

From Figure D-26 it can be seen that the frequency of all flows is much lower at present than for the Reference Condition. At present more than 90% of the time the flows into the estuary are less than 0.1 m³/s, whereas under Reference Condition, only 25% of the flows were less than 0.1 m³/s. The difference in frequencies of flows greater than about 10 m³/s is relatively small because small floods of about 13 m³/s are made regularly from the dam.

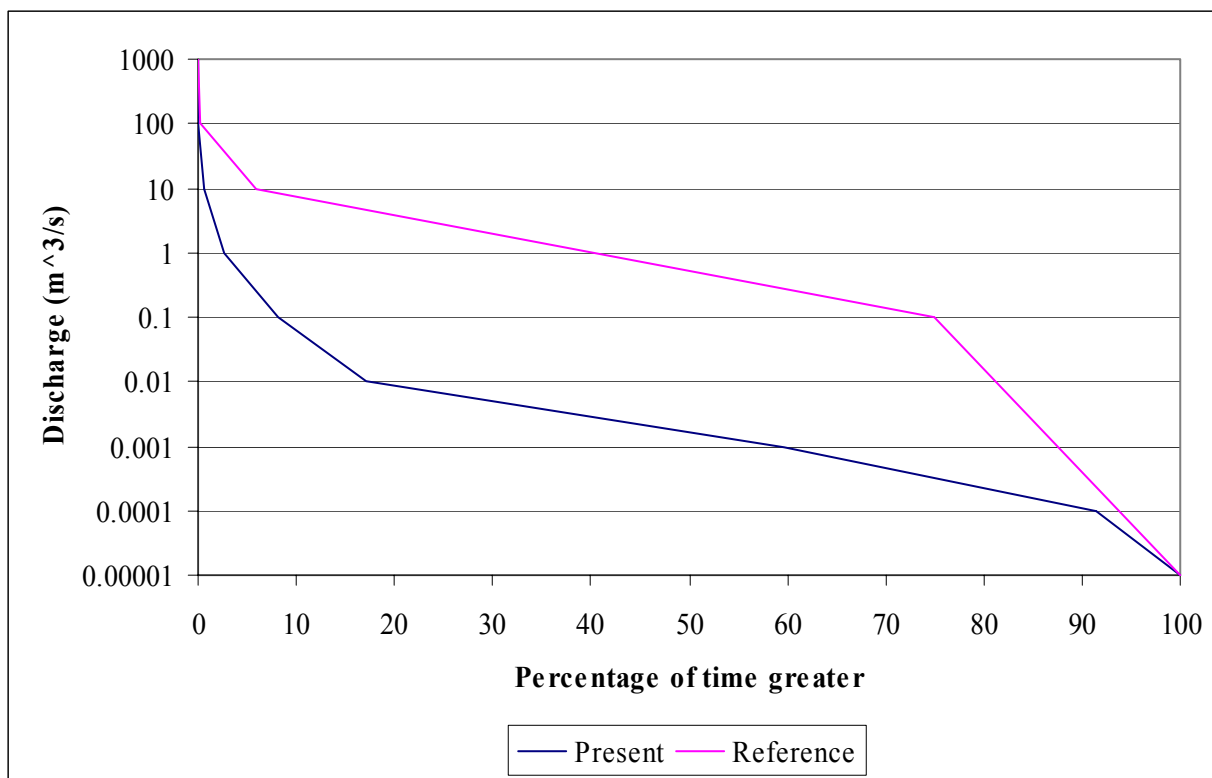


Figure D-26 Discharge – frequency graph at the top of the estuary

6. CONCLUSIONS AND RECOMMENDATIONS

The key findings are:

- The volume of the estuary below MSL is about 3 million m³, while at high tide the volume (taken as below +1.2 m MSL) is almost double that at 5.7 million m³. In relation the volume of the marina canals is about 0.15 million m³, which is very small compared to a tidal prism of about 2 million m³.
- Local scouring could occur near the mouth due to dredged channels. The dumping of the dredged material could affect the mouth morphology and tidal flow conditions.
- Flood peaks have been reduced by between 55% (1:2 year) to 38% (1:20 year) due to dam construction on the Kromme River. The dams will affect even large floods.
- The spring flood tide discharge (near bridge) was measured at 91 m³/s, which is larger than the 1:2 year flood of 45 m³/s under natural conditions.
- The largest tributary is the Geelhoutboom River. A number of farm dams have been constructed in its catchment, which attenuate the flood peaks and trap sediment.
- Marine sediment dominates the lower 4 km of the estuary, which is relatively shallow.
- Due to tidal currents and the reduced flood peaks, the marine sediment is slowly moving upstream. The rate of upstream delta growth was simulated by mathematical model at 3.5 m/year on average if there are no medium to large floods.
- The Impofu Dam has cut off sediment input to the estuary and the upper estuary sediment is therefore much coarser.
- Sediment input into the estuary from the incremental catchment downstream of Impofu Dam will lead to a very slow accretion of the deeper middle and upper reaches of the estuary at an estimated maximum rate of 9 mm/year.
- The jetties may reduce the outside bend scour effect during floods and lead to a shallower main channel.
- The road bridge has a relatively wide opening and thus has a limited impact on the flow patterns, but has cut off the flow across the floodplain and thus could lead to silting up of the floodplain areas.

7. REFERENCES

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Churchill, M.A. 1948. *Analysis and Use of Reservoir Sedimentation Data*. Discussion by L.C. Gottschalk. Proc. Federal Interagency Sedimentation Conference, Washington DC, Jan 1948, pp. 139-140.

DHI. 2003. *MIKE 21C - River Hydrodynamics and Morphology*. User Guide. DHI Water and Environment, Denmark

Rooseboom, A. 1992. *Sediment Transport in Rivers and Reservoirs – A Southern African Perspective*. South African Water Research Commission, Report No.297/1/92, South Africa.

Sediment Grading Analysis February 2004

Particle size (mm)	Distance from mouth (m)														
	3500	4600	5700	6700	7900	8900	9900	11100	12100	Geelhoutboom	5200	2500	1520	495	0
>2.36	100	100	100	100	100	100	99.64	100	100	100	100	100	100	100	100
1.18-2.36	100	100	100	100	100	100	99.64	100	95.71	100	100	100	100	100	100
0.6-1.18	100	97.06	100	98.48	96.97	96.43	99.64	89.19	48.57	100	100	100	100	100	100
0.3-0.6	87.5	57.35	98.48	96.97	72.73	91.07	80.26	33.78	18.57	100	88.33	62.5	78.95	91.67	85.14
0.15-0.3	4.17	4.41	95.45	95.45	28.79	87.5	23.53	13.51	14.29	96.67	61.67	4.17	5.26	8.33	4.05
0.075-0.15	4.17	4.41	87.88	93.94	18.18	87.5	12.45	13.51	14.29	90	43.33	4.17	3.95	2.78	2.7
0.075-0.0015	3	3.2	11	11	6	12.5	4	5.5	4	13	6.5	2	2	0	2
<0.0015	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX E

MICROALGAE

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Nelson Mandela Metropolitan University

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1. INTRODUCTION

The Kromme Estuary is located in the Eastern Cape Province, approximately 80 km west of Port Elizabeth. The estuary is relatively narrow, an average width of approximately 80 m, and extends for 14 km from a permanently open mouth to a rocky sill that forms the tidal head of the estuary. Its major tributary is the Geelhoutboom, which enters approximately 8 km from the mouth. The catchment area and length of the Kromme River are approximately 1000 km² and 100 km respectively. The rainfall over the catchment occurs throughout the year, with bimodal maxima in autumn and spring. January and February tend to have the lowest rainfall (Bickerton and Pierce, 1988).

The Kromme Estuary occurs in a relatively undisturbed and pristine area. It meanders through rural land and there is little urban, industrial and agricultural development in the area (Baird and Heymans, 1996). The substrate at the mouth area varies between medium- and coarse-grained sand with some silt. In the lower and middle reaches, mud and silt are encountered whereas the substrate of the upper reaches consists of coarse silty sand and stones. A road bridge has been constructed across the estuary, approximately 3 km from the mouth, and a marina development consisting of a number of canals with waterfront housing and mooring facilities is located on the west bank near to the mouth (Emmerson *et al.*, 1982).

There are two dams above the estuary and their combined holding capacity (Impofu Dam 107 x 10⁶ m³ and the Churchill Dam 33.3 x 10⁶ m³) exceeds the mean annual runoff (MAR) of the Kromme River (estimated to be in excess of 105 x 10⁶ m³) (Reddering, 1988). This has resulted in the water becoming saline to the head of the Kromme Estuary. In addition to reduced river flow, the dams have also affected the frequency and magnitude of flood events, and the availability of riverine material replenishing the estuarine nutrient pool (Scharler *et al.*, 1997). A release policy, which provides 2 x 10⁶ m³ per annum (EMATEK (CSIR) 1994), was proposed to account for the evaporative loss of the estuary (Jezewski and Roberts, 1986). However, flow records and personal communication with the Impofu Dam managers indicate that very few or no releases have been made for a number of years (2002-2005). The construction of farm dams and a weir, together with abstraction of water for agriculture have significantly reduced the flow of water input from the Geelhoutboom River.

The primary aims of this report are to determine the present status of microalgae (phytoplankton and microphytobenthos) in the Kromme Estuary, determine how this has changed from the reference condition (before anthropogenic influences) and then to predict changes in response to varying freshwater release patterns. These represent the future scenarios assessed in the main report of the RDM study and included:

- i) 5 x 10⁶ m³ release during November,
- ii) 5 x 10⁶ m³ release during November and another in January,
- iii) Maintain present flow in the Kromme but increase flow in the Geelhoutboom tributary (river class C/D),
- iv) 5 x 10⁶ m³ release during November and increased flow from the Geelhoutboom tributary (river class C/D), and
- v) 7.5 x 10⁶ m³ release over a two month period (October-November).

2. MATERIALS & METHODS

2.1 Study site

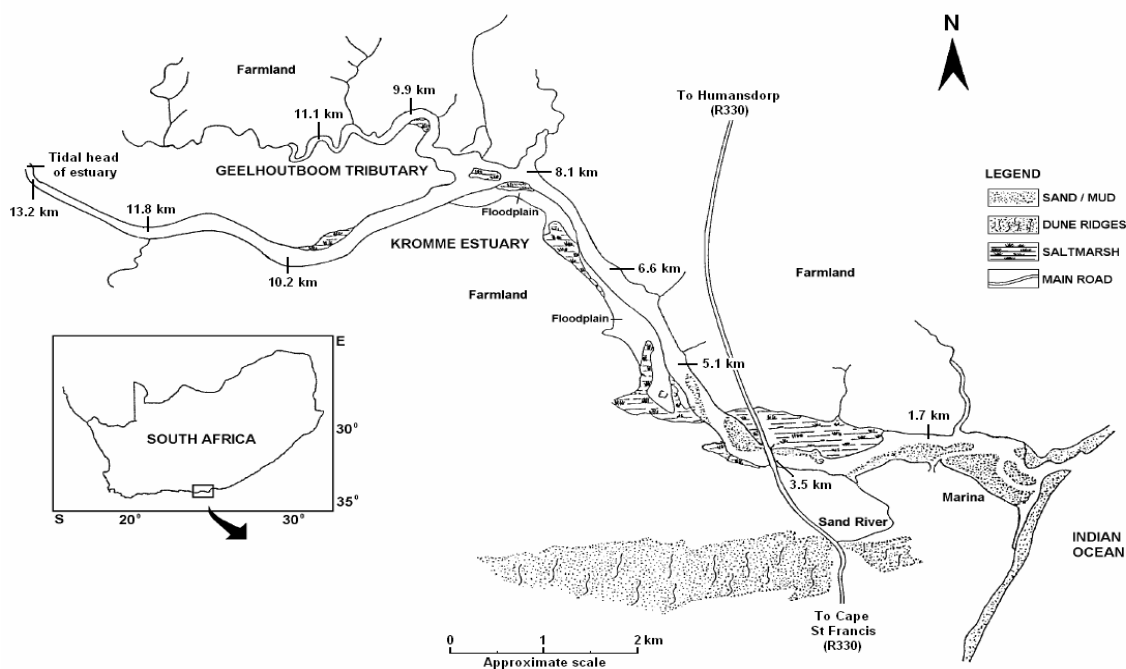


Figure E-1 Map of the Kromme Estuary and Geelhoutboom tributary, showing distances of the sampling stations (km from the mouth) for the 2004 surveys (modified from Bickerton and Pierce 1988).

Samples were collected at similar locations to sites used by Scharler *et al.* (1997) during the two sampling trips in this study (Figure E-1). During November 2003, two sampling sites were located below the confluence of the Kromme Estuary and the Geelhoutboom tributary, 1.7 and 8.1 km from the mouth, and two sites were located within the Geelhoutboom, 9.9 and 11.1 km from the mouth. An additional site was located near to the head of the estuary but only physico-chemical measurements were taken there. On 30 July 2004 there were 10 sites in total, all matching the locations of Scharler *et al.* (1997).

2.2 Physico-chemical factors

Physical parameters (conductivity, salinity, dissolved oxygen content, total dissolved solids and pH) were measured using a YSI multiprobe. Measurements were taken every half a meter from the surface at each site. Water transparency was measured with a Secchi disc.

2.3 Phytoplankton biomass

Water column samples were collected from the surface and bottom and then gravity filtered through plastic Millipore towers using Whatman (GF/C) glass fibre filters. The samples were collected using a 500ml weighted pop-bottle. Chlorophyll a was extracted by placing the filters into glass vials containing 10 ml of 95% ethanol (Merck 4111). The samples were then stored overnight at 1-2°C. The contents of the vials were filtered and the light absorbance at 665 nm of the supernatant was determined, before and after the addition of 0.1N HCL, using a spectrophotometer within 24 hours. The equation used was that of Hilmer (1990), derived from Nusch (1980):

$$\text{Chlorophyll } a \text{ biomass } (\mu\text{g l}^{-1}) = (E_{b665} - E_{a665}) \times 29.6 \times (v/(V \times l))$$

Where: E_{b665} = absorbance at 665 nm before acidification

E_{a665} = absorbance at 665 nm after acidification

v = volume of solvent used for the extraction (ml)

V = volume of the sample filtered (l)

L = path of spectrophotometer cuvette (cm)

29.6 = constant calculated from the maximum acid ratio (1.7) and the specific absorption coefficient of chlorophyll-a in ethanol ($82\text{g.l}^{-1} \cdot \text{cm}^{-1}$).

2.4 Microphytobenthos biomass

Microphytobenthos biomass was estimated using benthic chlorophyll *a* ($\mu\text{g chl-a}$ per gram of freeze dried sediment; expressed as $\mu\text{g/g}^{-1}$). Four 1 cm deep intertidal and subtidal sediments cores were collected from each site, then frozen and kept in the dark before being freeze-dried in the Secfroid Lausanne Suisse freeze-drier. The process of freeze drying eliminates the error related to the water holding capacity of different sediment types and organic content. Once freeze-dried, 4 ml of 95% ethanol (Merck 4111) was added to approximately 100 mg of sample and the pigment was left to extract in a fridge for 24 hours.

After extraction the samples were well mixed using a whirlmixer (WM/250/SC/P) and the extract injected into a high performance liquid chromatograph (HPLC) attached to Waters-Lambda-Max 481 LC spectrophotometer and Waters LM-45 solvent delivery system for chlorophyll-a analysis. A 30% methanol and 70% acetone mixture was used as a carrier. The system was calibrated using the chlorophyll *a* of red seaweed, (*Plocamium collorhiza*) because it contains no chlorophyll *b* that might interfere with the chlorophyll *a* reading. Chlorophyll *a* absorbance was measured at 665 nm. The chlorophyll *a* concentration was determined from the absorbance reading using the modified equation of Nusch (1980):

$$\text{Chl-a biomass } (\mu\text{g g}^{-1}) = [(E_{Ploc665} - (E_{Ploc665}/1.7)) \times 29.6] \times (V/M) \times E_{HPLC}$$

Where: $E_{Ploc665}$ = *Plocamium collorhiza* chlorophyll *a* absorbance measured using the spectrophotometer at 665 nm (calibration formula in squared brackets)

29.6 = constant calculated from the maximum acid ratio (1.7) and the specific absorption coefficient of chlorophyll *a* in ethanol ($82\text{g l}^{-1} \cdot \text{cm}^{-1}$)

V = volume of ethanol used to extract pigment (ml)

M = mass of freeze-dried sample (g)

E_{HPLC} = HPLC absorbance value

Surface and bottom water (500 ml) were collected from each site and preserved with one drop of Glutaraldehyde solution for 25% for phytoplankton identification. The filtrate from phytoplankton chlorophyll *a* was preserved using mercuric chloride and frozen for use in nutrient analysis.

2.5 Phytoplankton identification

Two drops of Rose Bengal were added to 60 ml of the preserved water samples and poured into a 26.5 mm internal diameter settling chamber. The cells were left to settle for 24 hours before identification with a Zeiss IM 35 inverted microscope at the maximum magnification of X630. A minimum of 200 cells was counted for each sample and the cells were classified according to different microalgal groups; i.e. small flagellates ($3.5\mu\text{m} \times 2.8\mu\text{m}$), big flagellates ($6.7 \times 4.2\mu\text{m}$), diatoms, dinoflagellates, cyanophytes (blue-green algae), chlorophytes (green algae), euglenoids and coccolithophorids. The numbers of cells were calculated in 1 ml using the formula:

$$\text{Cells ml}^{-1} = ((\pi r^2)/A) \times C/V$$

Where: A = area of each frame (mm^2)

C = number of cells in each frame

V = volume of sample in settling chamber (ml)

Nitrate concentration was determined using the reduced copper-cadmium method described by Bate and Heelas (1975). Nitrate was collected from surface and bottom water at each site using a weighted pop-bottle. The nitrate in the filtered (Whatman GF/C filters) water samples was reduced to nitrite then determined as NO_2^- -N plus NO_3^- -N. Nitrite was quantitatively incorporated into a diazo-couple (red/purple) compound and then the concentration determined at 540 nm using a GBC UV-VIS spectrophotometer. All results were expressed in μMolar values as these units obviate any problems of interpretation between N and other oxidised nitrogen (NO_x) compounds.

2.6 Ash free dry weight (AFDW) and water content (WC)

Three sediment samples were taken from the intertidal and subtidal zones at a depth of 1 cm. Once in the laboratory the wet sediments were weighed and 9 placed into pre-dried (24 hours at 105°C) and pre-weighed crucibles. The sediments were dried in the oven for 24 hours at 105°C and were weighed again (dry weight). The crucibles were placed into a furnace at 550°C for an hour and were weighed again (ash weight).

3. RESULTS

3.1 30 July 2004

Results from sampling on 30 July 2004 indicate that water quality and microalgal chlorophyll *a* remained relatively constant throughout the Kromme Estuary and Geelhoutboom tributary, suggesting that there was a weak and insignificant freshwater input at the head of the estuary and in the Geelhoutboom tributary. There was a gradual decrease in temperature, electrical conductivity (EC) and redox potential (ORP) from the mouth to the head of the Kromme Estuary (Figure E-2). Temperature and EC were particularly low in the Geelhoutboom tributary, 11.1 km from the mouth (13.2°C and 41.1 mS.cm⁻¹ respectively). Factors such as salinity, total dissolved solids (TDS), pH and turbidity remained relatively constant throughout the estuary with just a slight decrease at the site nearest to the head of the estuary. Salinity, TDS and pH were lowest in the Geelhoutboom tributary, 11.1 km from the mouth (35 ‰, 34.5 g.l⁻¹ and 8.15 respectively). In contrast, turbidity and light attenuation through the water column were highest in the Geelhoutboom, with maxima of 100.7 NTU's and 3.04 m⁻¹ respectively.

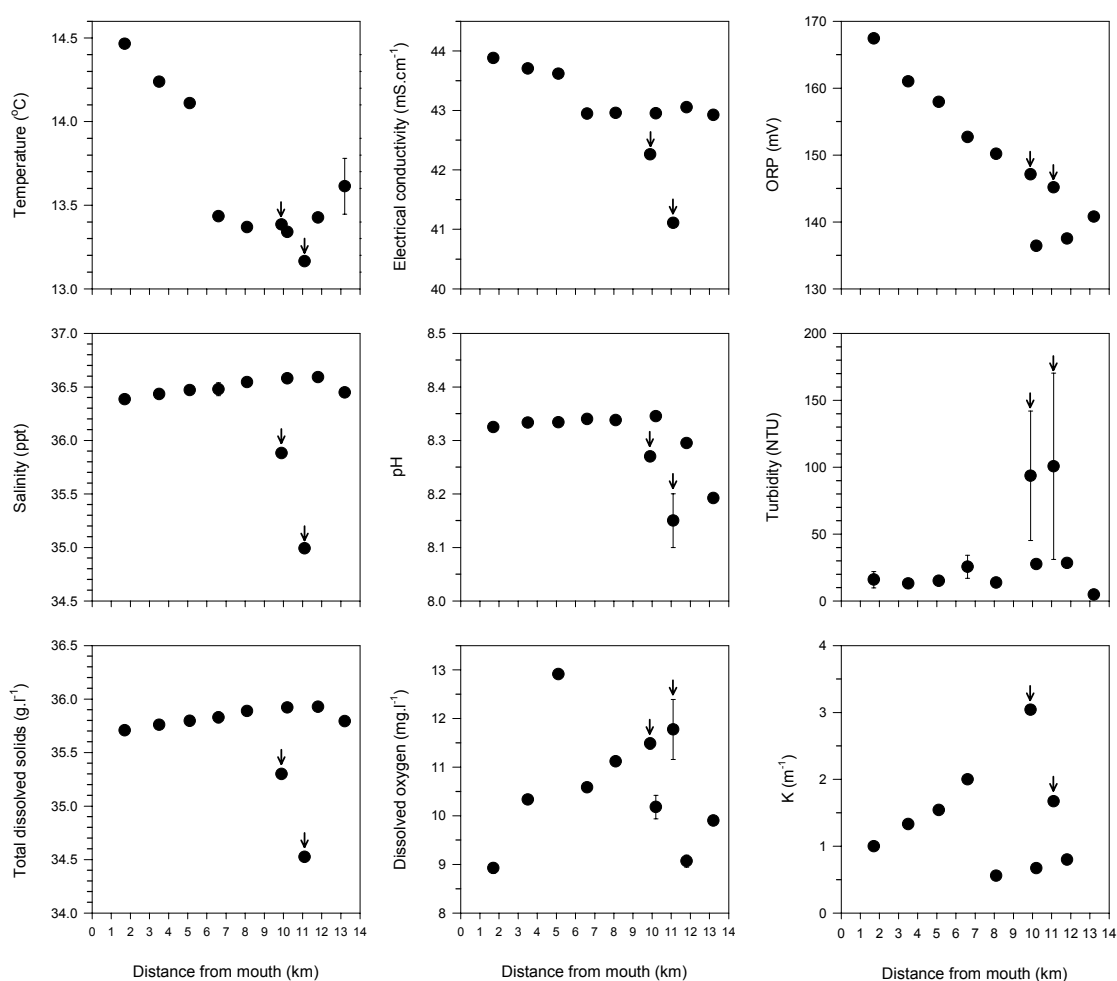


Figure E-2 Physico-chemical variables measured in the Kromme Estuary (30 July 2004) in relation to distance from the mouth. Arrows indicate measurements recorded in the Geelhoutboom tributary. Vertical bars represent $\pm$ SE mean.

Phytoplankton chlorophyll *a* remained relatively constant throughout the estuary with only a slight decrease at the site nearest to the head of the estuary. The highest average phytoplankton chlorophyll *a* was 5.0 ± 1.5 ($n = 2$), 9.9 km from the mouth in the Geelhoutboom tributary (Figure E-3), but there were no significant differences in phytoplankton chlorophyll *a* between all sites ($P >$

0.05). There was no significant correlation between chlorophyll *a* and any of the physico-chemical variables ($P > 0.05$). Total dissolved solids in the estuarine water followed a similar pattern to salinity, with a narrow range of between 35.7 g.l^{-1} and 35.9 g.l^{-1} in the estuary, and were slightly lower (minimum of 34.5 g.l^{-1}) in the Geelhoutboom tributary.

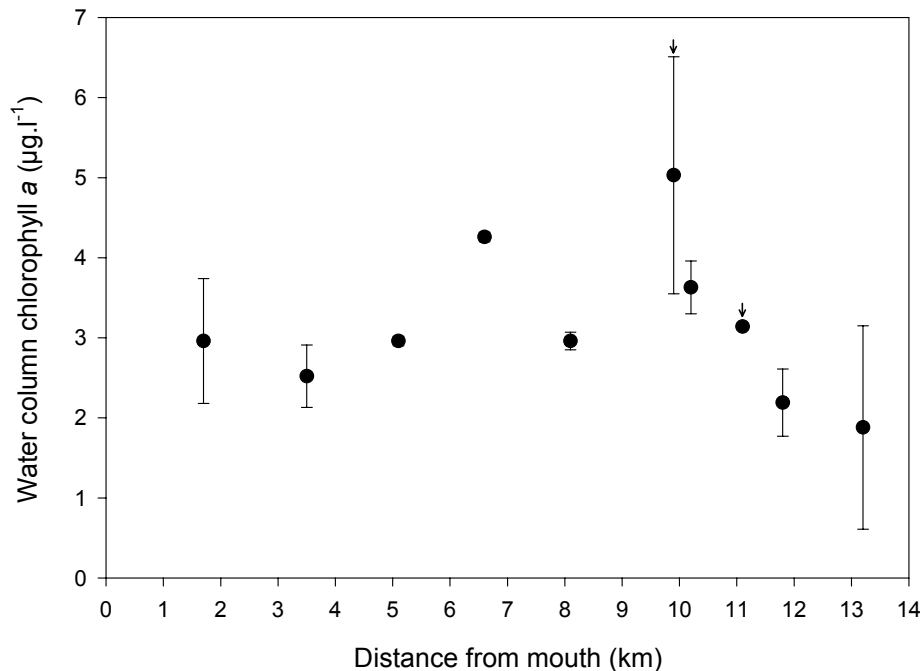


Figure E-3 Water column chlorophyll *a* in the Kromme Estuary (30 July 2004). Arrows indicate measurements recorded in the Geelhoutboom tributary. Vertical bars represent $\pm$ SE mean.

Average phytoplankton chlorophyll *a* in the Kromme Estuary has consistently been lower than the nearby eutrophic Gamtoos estuary (Table E-1). Average concentrations in the Kromme have ranged from 0.6 ± 0.1 to $5.6 \pm 0.3 \mu\text{g.l}^{-1}$. Average salinity during this study (November 2003 and July 2004) was generally similar or greater than sea water and low standard error values indicate weak salinity gradients throughout the estuary. During these extended periods of low freshwater input, average phytoplankton chlorophyll *a* has been particularly low ($3.0 \mu\text{g.l}^{-1}$ or less). After a $2 \times 10^6 \text{ m}^3$ pulse of freshwater in the 1998/1999 study (Snow *et al.*, 2000a), average chlorophyll *a* concentration increased to a maximum of $5.6 \pm 0.3 \mu\text{g.l}^{-1}$, almost a month after the release.

Table E-1 Average salinity and phytoplankton chlorophyll *a* during this study (*italics*) and previous studies (Snow *et al.*, 2000 a&b; Snow, 2000; Scharler *et al.*, 1997) in the Kromme and nearby Gamtoos estuaries

Estuary	Sampling date	Average salinity (‰)	Average phytoplankton chl <i>a</i> ($\mu\text{g.l}^{-1}$) $\pm$ SE
Kromme	<i>24 November 2003</i>	35.0 ± 0.4	0.6 ± 0.1
	<i>30 July 2004</i>	36.3 ± 0.2	3.0 ± 0.2
	16 November 1998	34.2 ± 0.1	4.2 ± 1.1
	18 November 1998	21.5 ± 2.1	1.7 ± 0.2
	20 November 1998	23.7 ± 1.3	2.1 ± 0.2
	22 November 1998	29.4 ± 0.6	4.4 ± 0.5
	3 December 1998	31.9 ± 0.4	4.3 ± 0.3
	17 December 1998	34.1 ± 0.2	5.6 ± 0.3
	5 January 1999	35.4 ± 0.1	5.2 ± 0.7
	June 1993 – June 1994	28.7 ± 0.5	4.2 ± 3.3
	4 November 1996	12.5 ± 2.1	17.2 ± 1.6
	11 February 1997	9.8 ± 1.9	44.8 ± 6.1
Gamtoos	12 November 1996	10.8 ± 2.1	7.4 ± 0.5

Intertidal benthic chlorophyll *a* ranged from $1.8 \pm 0.2 \mu\text{g.g}^{-1}$ to $12.4 \pm 0.7 \mu\text{g.g}^{-1}$, displaying a gradual increase in sediment from near the mouth to upstream of the Geelhoutboom tributary, 11.1 km from the mouth (Figure E-4). Subtidal benthic chlorophyll *a* was significantly higher than intertidal chlorophyll *a* ($P = 0.007$), and ranged from $3.6 \pm 0.7 \mu\text{g.g}^{-1}$ (1.7 km from the mouth) to $12.7 \pm 0.8 \mu\text{g.g}^{-1}$ (5.1 km from the mouth) (Figure E-4).

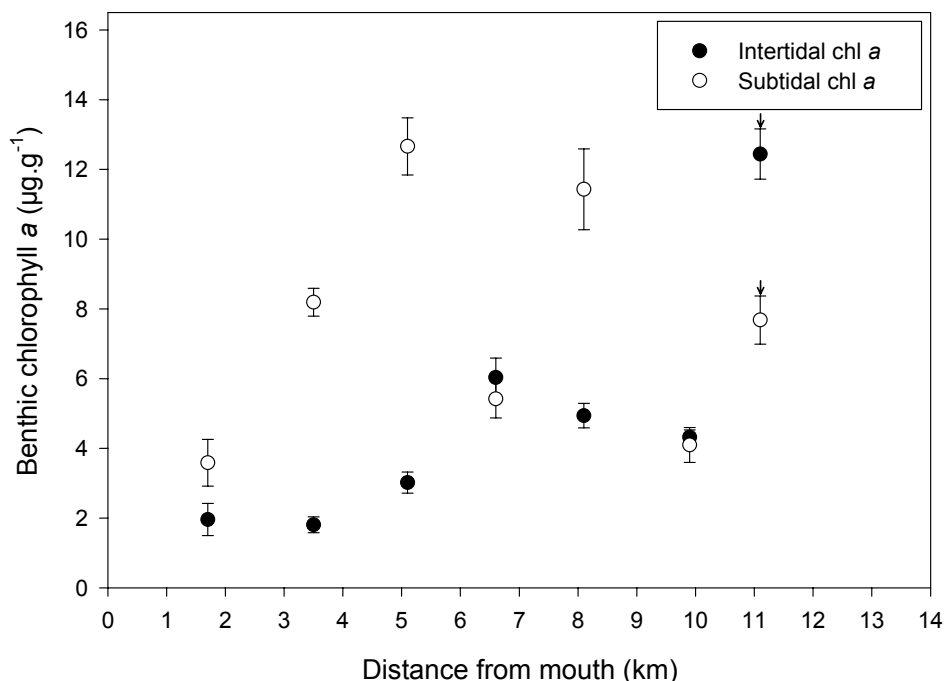


Figure E-4 Intertidal and subtidal benthic chlorophyll *a* in the Kromme Estuary (30 July 2004). Arrows indicate measurements recorded in the Geelhoutboom tributary. Vertical bars represent $\pm$ SE mean.

Average intertidal chlorophyll *a* was $12.9 \pm 2.5 \mu\text{g.g}^{-1}$ and $4.9 \pm 0.4 \mu\text{g.g}^{-1}$ in the Kromme Estuary during November 2003 and July 2004 of this study respectively. These concentrations are comparable to those found in intertidal sediments in other South African estuaries (Table E-2), which could indicate that intertidal microalgal biomass in the intertidal zone is not severely limited by the low freshwater inputs.

Table E-2 Average intertidal benthic chlorophyll *a* during this study (*italics*) and studies of other South African estuaries (Snow, unpublished data)

Estuary	Sampling date	Intertidal Chl <i>a</i> ($\mu\text{g.g}^{-1}$)
Kromme	<i>24 November 2003</i>	12.9 ± 2.5
	<i>30 July 2004</i>	4.9 ± 0.4
Gamtoos	7 August 2002	27.7 ± 3.0
	21 February 2003	10.4 ± 0.9
Keurbooms	25 August 2002	9.5 ± 0.8
Mngazana	22 June 2003	27.2 ± 2.3
	25 January 2003	16.4 ± 2.5
Mngazi	26 January 2003	12.9 ± 0.9

Estuary	Sampling date	Intertidal Chl a ($\mu\text{g.g}^{-1}$)
Sundays	19 February 2003	9.1 ± 1.0
	25 July 2002	10.2 ± 1.0
Swartkops	5 December 2002	3.7 ± 0.6
	12 February 2002	11.2 ± 0.9
	15 August 2003	22.5 ± 1.9
	28 November 2001	5.9 ± 0.9
	30 October 2001	8.2 ± 0.8

3.2 24 November 2003

There was a weak longitudinal salinity gradient in the estuary (Figure E-5). Water column salinity at the mouth of the estuary was 36.2 ± 0.0 ‰, which was significantly higher than 9.9 km from the mouth of the estuary (33.9 ± 0.1 ‰), in the Geelhoutboom tributary, and at the head of the estuary (34.4 ± 0.0 ‰) ($P < 0.05$). However, both the longitudinal and vertical salinity gradients (< 2 ‰ and < 1 ‰ respectively) in the estuary were small suggesting that the water column was well mixed and that the volume of freshwater entering the estuary was low. (Figure E-5). Total dissolved solids and electrical conductivity followed a similar pattern to salinity, with ranges of 33.5 to 35.5 g.l^{-1} and 51.6 to 54.6 mS.cm^{-1} respectively.

Light attenuation was highest ($K = 2.83 \text{ m}^{-1}$) at the two sites nearest to the mouth due to the high turbulence. Lower values were found at the sites in the Geelhoutboom tributary, 9.9 km from the mouth ($K=2.3 \text{ m}^{-1}$) and at 11.1 km from the mouth ($K=2.1 \text{ m}^{-1}$). No significant correlation was found between light attenuation and depth of the water column ($P > 0.05$) (Figure E-5).

There was a gradual increase in water column temperature with distance from the estuary mouth. The highest temperature was in the Geelhoutboom tributary (24.5 ± 0.3 °C), 11.1 km from the mouth, and the lowest temperature was 1.7 km from the mouth (20.5 ± 0.3 °C) (Figure E-5).

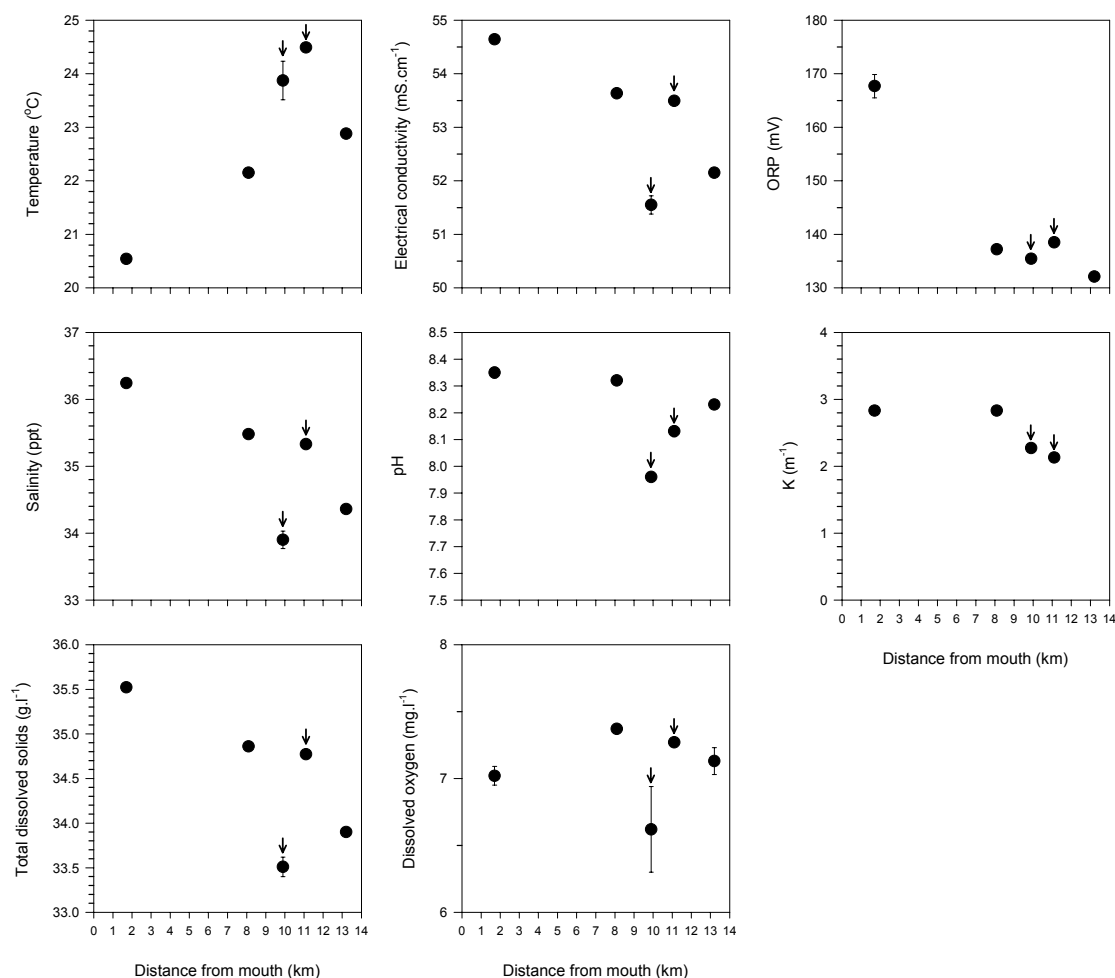


Figure E-5 Physico-chemical variables measured in the Kromme Estuary (24 November 2003) in relation to distance from the mouth. Arrows indicate measurements recorded in the Geelhoutboom tributary. Vertical bars represent $\pm$ SE mean.

Average phytoplankton chlorophyll *a* was particularly low during this sampling session ($< 1.0 \mu\text{g.l}^{-1}$) (Figure E-6) and was significantly higher in the surface water compared to the bottom water ($P < 0.05$). Highest chlorophyll *a* concentration was in the surface water of the Geelhoutboom tributary ($0.9 \pm 0.2 \mu\text{g.l}^{-1}$), 9.9 km from the mouth of the estuary. Nitrate concentration was below detectable limits throughout the estuary, possibly indicating that microalgal biomass was nutrient limited on this occasion.

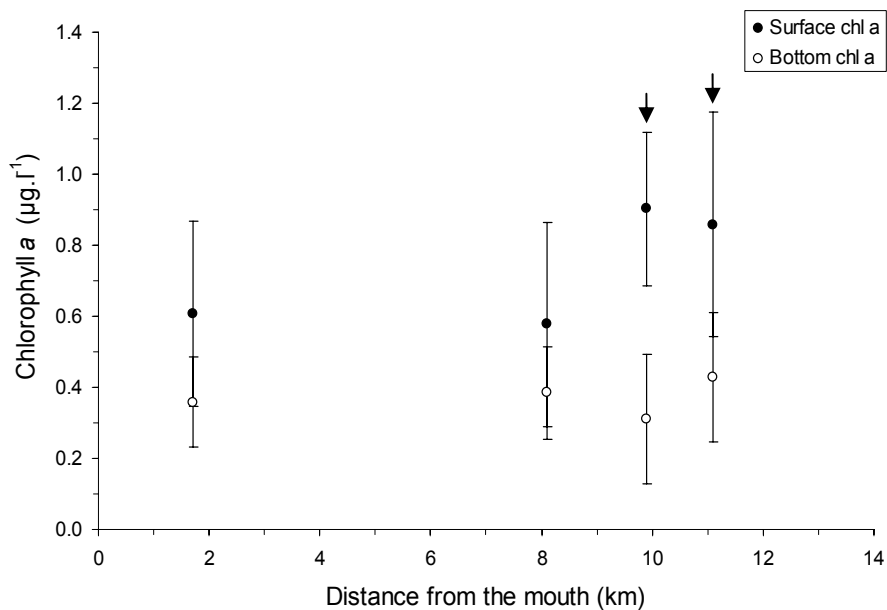


Figure E-6 Water column chlorophyll *a* in the Kromme Estuary (24 November 2003). Arrows indicate measurements recorded in the Geelhoutboom tributary. Vertical bars represent $\pm$ SE mean.

Average intertidal chlorophyll *a* ($12.9 \pm 2.5 \mu\text{g.g}^{-1}$) was significantly higher ($P < 0.05$) than subtidal chlorophyll *a* ($5.2 \pm 1.5 \mu\text{g.g}^{-1}$) and was particularly high at the site nearest to the mouth of the estuary ($27.1 \pm 7.0 \mu\text{g.g}^{-1}$) (Figure E-7). This could be the result of influence of the close proximity to the entrance of the St Francis marina canals. Chlorophyll *a* at most sites was below $10 \mu\text{g.g}^{-1}$, which can be regarded as low in comparison to concentrations in studies of other estuaries (Table E-2).

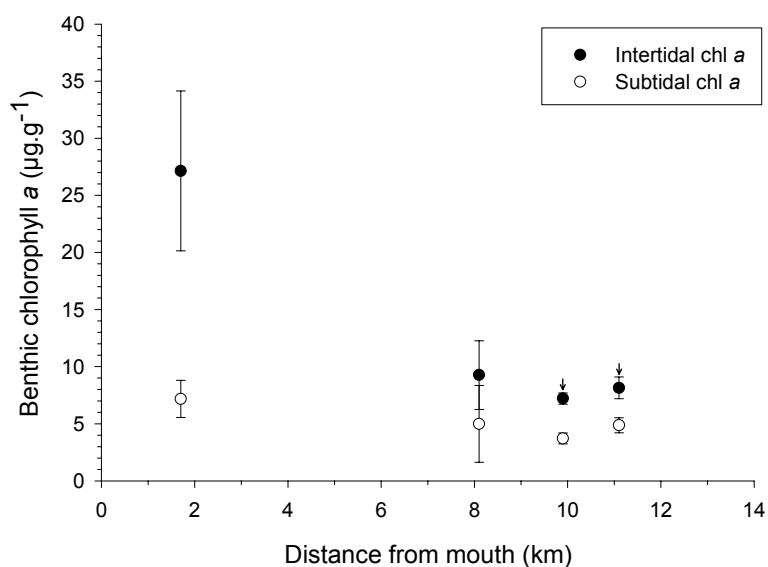


Figure E-7 Intertidal and subtidal benthic chlorophyll *a* in the Kromme Estuary (24 November 2003). Arrows indicate measurements recorded in the Geelhoutboom tributary. Vertical bars represent $\pm$ SE mean.

On 24 November 2003 the flagellates made up the most dominant group of phytoplankton. Small flagellates (3.5 x 2.8 µm) in particular had the highest relative abundance, exceeding 60 % in surface and bottom water throughout the estuary and Geelhoutboom tributary (Figure E-8). Diatoms, dinoflagellates, cyanophytes, euglenophytes, chlorophytes and coccolithophorids showed no distinct patterns in the estuary but all groups were represented in water near the mouth of the estuary.

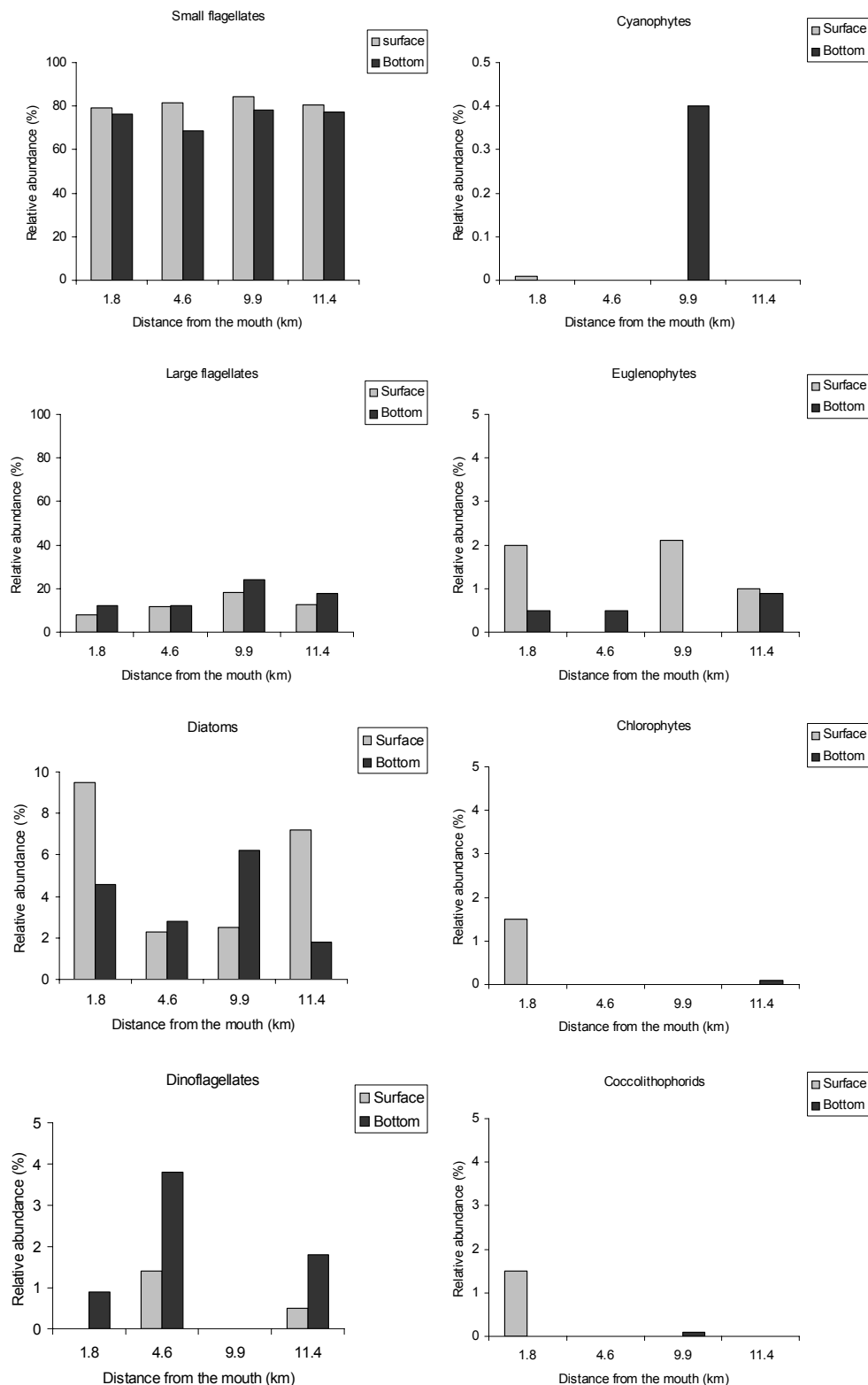


Figure E-8 Relative abundances of phytoplankton groups in surface and bottom water in the Kromme Estuary (1.8 and 4.6 km from mouth) and Geelhoutboom tributary (9.9 and 11.4 km from the mouth) on 24 November 2003.

Phytoplankton in the Impofu Dam, collected prior to the release of $2 \times 10^6 \text{ m}^3$ freshwater in November 1998 were dominated by diatoms ($>1500 \text{ cells.ml}^{-1}$) and flagellates ($>500 \text{ cells.ml}^{-1}$). Chlorophytes were present throughout the water column ($>100 \text{ cells.ml}^{-1}$) but dinoflagellates were totally absent (Figure E-9).

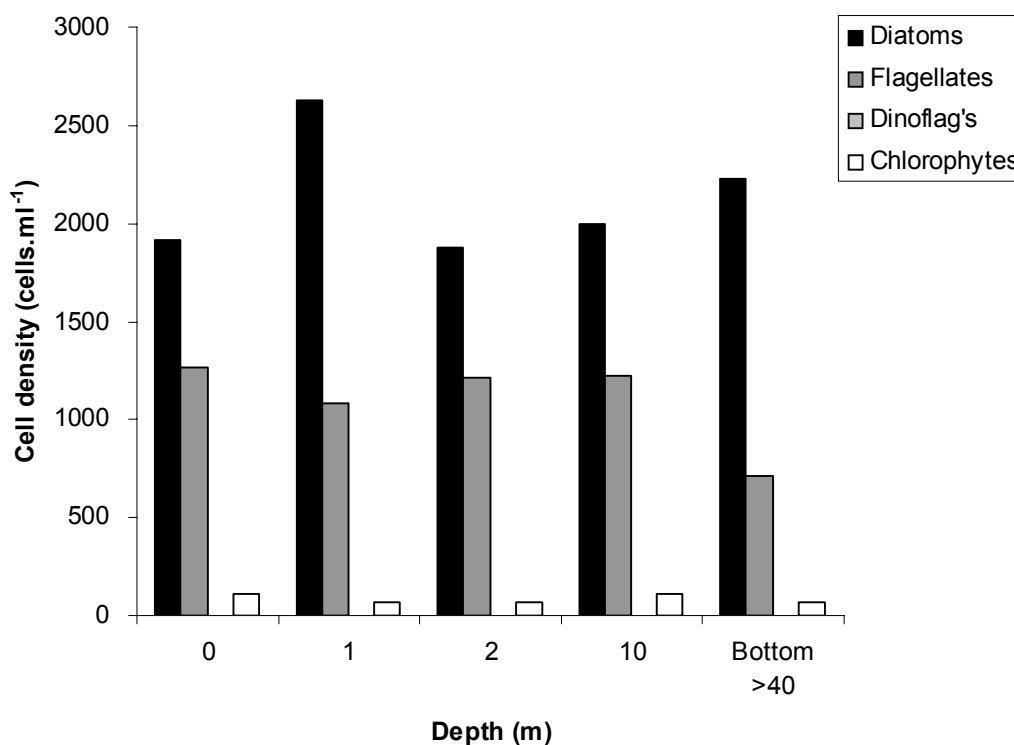


Figure E-9 Cell densities of diatoms, flagellates, dinoflagellates and chlorophytes in the Impofu Dam prior to the $2 \times 10^6 \text{ m}^3$ release of water (16 November 1998).

Phytoplankton in the Kromme Estuary during the freshwater release study of 1998/1999 (Snow *et al.*, 2000a) was dominated by flagellates prior to the release and for a few days afterwards. Up to 80 % of cells were flagellates and the bulk of the remaining cells were diatoms. By the 17th day after the release a bloom of *Extubocellulus* and *Leptocylindrus* spp. had developed resulting in diatoms becoming the dominant group with cell densities of $>11000 \text{ cells.ml}^{-1}$ being recorded 11.8 km from the mouth of the estuary. The bloom was short-lived and flagellates dominated the phytoplankton by the 31st day again.

4. DISCUSSION

The Impofu and Churchill dams have severely reduced the river flow into the Kromme Estuary and flows of $< 0.2 \text{ m}^3\text{s}^{-1}$ are often encountered over a number of months resulting in hypersaline conditions in the upper reaches of the estuary (van Niekerk and Taljaard, 2005). During these conditions, which are regarded as Present State conditions, chlorophyll *a* in the water column seldom exceeds $5 \mu\text{g.l}^{-1}$ and small flagellates dominate the phytoplankton. There was no clear pattern with regards to chlorophyll *a* in the estuarine sediments but concentrations did exceed $20 \mu\text{g.g}^{-1}$ in the sandy sediment near to the entrance of the St Francis marina canals.

Recently built farm dams, abstraction and a weir appear to have reduced flow entering the estuary from the Geelhoutboom tributary. During this study, salinity in the tributary was slightly lower and turbidity slightly higher than that measured in the Kromme Estuary. This suggests that there was some freshwater input from the Geelhoutboom River and may have been the cause of the maximum chlorophyll *a* concentrations in the water column and sediment occurring in the Geelhoutboom tributary.

Scharler *et al.* (1997) reported an increase in all nutrients in the Kromme Estuary and Geelhoutboom tributary during periods of freshwater input. During extended periods of low or no flow, phosphate showed a negative gradient of concentration from the mouth to the head of the estuary. Following a freshwater release, there was no gradient in phosphate concentration, which suggests that phosphate concentration in the Kromme River water is low and similar to marine water in St. Francis Bay. If the freshwater input is low or non-existent then the estuary can become marine in nature. Nutrient concentrations of estuaries dominated by marine water are generally lower than those experiencing a higher and more regular freshwater supply (Scharler *et al.*, 1997). The construction of dams in the catchment of the Kromme River have resulted in the pulses of freshwater becoming reduced in frequency and intensity so the regeneration of 'trapped' nutrients in fine sediment from erosion and subsequent resuspension is unlikely and could limit microalgal biomass in the estuary.

During a recent study of the nearby Gamtoos Estuary (Snow, 2000; Snow *et al.*, 2000b), the river-estuary interface zone (REI) was defined as the distance from the mouth of the estuary where a maximum phytoplankton chlorophyll *a* concentration occurred. This generally occurred where vertically averaged salinity was less than 10 ‰. The REI zone is a concept developed in estuaries with a classical "cone-shaped" bathymetry. The upper reaches are narrow and shallow and become deeper and wider towards the lower reaches of the estuary. This means that as freshwater enters an estuary, a longitudinal salinity gradient develops from 0 ‰ at the head of the estuary to marine (~35 ‰) near the mouth under average flow conditions. This bathymetry allows the 'fresh' water to flow over the denser saline water with gradual mixing.

Results from the study in the Gamtoos Estuary showed that the chlorophyll *a* concentration in the REI was particularly high at a flow of $1 \text{ m}^3\text{s}^{-1}$ or residence time of 3 tidal cycles (42 days). This region of the estuary is generally the most turbid due to the flocculation of particles (fine sediment, organic matter, nutrients and microalgae), which settle out and are an essential source of nutrients (for subtidal benthic microalgae in particular) during periods of low flow/poor nutrient input.

In the case of the Kromme Estuary, the bathymetry is reversed (i.e. shallow at the mouth and deepest at the head of the estuary). Freshwater from the Kromme River pours off of a rocky sill onto a generally saline ($>30 \text{ ppt}$) water column with limited mixing. The large volume of water in this reach of the estuary probably limits the effectiveness of freshwater input unless the input was over an extended period. A persistent flow of $4\text{--}8 \text{ m}^3\text{s}^{-1}$ would scour saline waters from deeper areas but residence time would only be 3–7 days under these conditions (van Niekerk and Taljaard, 2005). If it were possible for a REI zone to develop, phytoplankton biomass would most probably be limited by the low concentration of nutrients and suspended particles in the river water. This in turn limits the amount of particles that flocculate and settle out of suspension, limiting benthic microalgal biomass and recycling of nutrients.

Scharler *et al.* (1997) calculated that the demand for nutrients by primary production in the estuary exceeded the supply from the Kromme River. Regeneration of nutrients within the Kromme Estuary and supply from the Geelhoutboom tributary may act as additional sources. The Kromme Estuary was described as being nutrient poor due to the reduced freshwater inflow. This means that a continuous nutrient supply and favourable hydrodynamic conditions do not exist in the estuary. These are factors that are essential for a stratified water column and a long enough residence time to enable the development of algal blooms.

It is likely that the river flow during medium rainfall conditions from the Kromme River prior to the construction of dams in the catchment and other anthropogenic influences (the reference condition) would have been in excess of $1 \text{ m}^3 \cdot \text{s}^{-1}$ for about 8 months of the year (CSIR, 2005, this study). During these conditions, the upper reaches of the estuary could have been regularly flushed of high saline waters during freshwater pulses. Dams would not have been present so the higher concentration of suspended solids would most probably have flocculated and settled out of suspension once the fresh river water and saline estuarine water mixed. An increase in phytoplankton biomass would be expected but this would have been limited by the low nutrient concentrations and residence time of water in the estuary. In addition, a pulse of freshwater has been shown to result in a rapid increase in mysids and copepods, which would exert grazing pressure on the phytoplankton population (Jerling and Wooldridge, 1994). It is likely that the river water was co-dominated by diatoms and flagellates and there would be a gradual change in community structure to flagellate dominated water near to the mouth of the estuary.

A study of a freshwater release (Snow *et al.*, 2000a) found that freshwater entering the estuary did not mix well with water in the deep upper reaches of the estuary. Instead, a strong halocline developed in the upper reaches of the estuary for less than a week after the release and water in the lower reaches of the estuary was well-mixed from tidal exchange. Nitrate concentration increased at the head of the estuary in particular and this also persisted for a period of < 1 week. However, nitrate concentration in the estuary was higher than before the release for up to 2 months after the release. Phytoplankton chlorophyll *a* decreased from $4.3 \pm 0.7 \mu\text{g} \cdot \text{g}^{-1}$ to a minimum of $1.8 \pm 0.2 \mu\text{g} \cdot \text{l}^{-1}$ two days after the release. Average phytoplankton chlorophyll *a* then increased to a maximum concentration of $5.7 \pm 0.3 \mu\text{g} \cdot \text{l}^{-1}$ 31 days after the release. There was no significant change in average subtidal chlorophyll *a* in the estuary, probably as a result of the well developed halocline. Intertidal chlorophyll *a* did increase significantly, reaching and maintaining concentrations of $> 50 \text{ mg} \cdot \text{m}^2$ for at least 50 days following the release. Flagellates were the dominant phytoplankton group in the estuary during periods of low or no flow. A diatom bloom of *Extubocellulus* sp. and *Leptocylindrus* sp. developed 17 days after the release, making diatoms the dominant group in the estuary but this was short-lived and flagellates became dominant again after 31 days.

Reddering and Esterhuysen (1983) describe the Kromme River catchment as being dominated by Table Mountain Quartzite and Bokkeveld shale. Eroded, these are sources of sand and mud but in low quantities. The high residence time in the Impofu and Churchill dams result in even less sediment reaching the Kromme Estuary, but the Geelhoutboom River is still a source of sediment and has resulted in the higher turbidity associated with the Geelhoutboom tributary during this study. Turbidity in the estuary is best described as relatively low in the steep-sided and wind-protected upper reaches, turbid in and near to the Geelhoutboom tributary in the middle reaches and clear during high tide in the lower reaches but fairly turbid and well-mixed during low tide.

Microalgae associated with fine sediment (silt and mud) are dependent on the continual input and sedimentation of fine sediment in estuaries. These 'epipellic' communities, generally dominated by diatoms, are capable of colonising fine sediments and tend to stabilise the sediment through their carbohydrate exudates used for migration within the surface layers of the sediment. Coarser sediments (sand) are generally colonised by 'episammic' microalgae that attach themselves to the sand particles to resist resuspension during periods of high energy (e.g. tidal currents). Chlorophyll *a* is generally lower in sand and is not as stable as colonised fine sediments.

5. CONCLUSION

River inflow has been severely decreased into the Kromme Estuary primarily due to dam construction. Flow has also been reduced into the Geelhoutboom tributary. This has resulted in a reduction in nutrient and sediment loads entering the estuary. Phytoplankton chlorophyll *a* has been consistently low in the estuary ($< 10 \mu\text{g.l}^{-1}$) even after a pulse of freshwater, probably as a result of low ambient nutrient concentrations and high levels of herbivory from zooplankton. The morphology and hydrology of the estuary are unsuitable for the formation of algal blooms because the formation of strong salinity stratification and a long enough residence time is unlikely to occur. Water from the Impofu Dam had a high ($> 50\%$) relative abundance of diatoms prior to a freshwater release in 1998 (Snow *et al.*, 2000a) and small flagellates dominate the estuary during periods of low or no flow. It is likely that a release of freshwater from the dam will introduce water that is dominated by diatoms, causing a slight shift in community composition shortly after the release. Benthic chlorophyll *a* can reach concentrations in excess of $12 \mu\text{g.g}^{-1}$ and this is most likely to occur in the finer sediment located in the middle reaches of the estuary and in the Geelhoutboom tributary. Pulses of freshwater are unlikely to have an effect on subtidal benthic biomass but intertidal chlorophyll *a*, particularly in the middle to upper reaches of the estuary, should increase by up to a third following a release. This is the result of inflowing freshwater 'floating' above the denser saline water.

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APPENDIX F

MACROPHYTES

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EXECUTIVE SUMMARY

This study investigated the species richness, present and past distribution and area covered by the different plant community types in the Kromme Estuary. The distribution of vegetation along elevation gradients and in relation to controlling environmental factors was investigated at two sites in the upper reaches of the Kromme Estuary and Geelhoutboom tributary using transects.

The transects extended from the submerged *Zostera* beds to a narrow band of supratidal salt marsh. Supratidal and intertidal areas were clearly defined in the Kromme salt marsh but overlapping of species occurred in the Geelhoutboom salt marsh. Canonical Correspondence Analysis (CCA) showed that vegetation distribution in the Geelhoutboom and Kromme salt marshes was significantly affected by distance from the estuary channel, groundwater electrical conductivity and depth to groundwater ($p = 0.001$). *Salicornia virginicus* was associated with high groundwater electrical conductivity and the supratidal salt marsh species, *Sporobolus virginicus* and *Disphyma crassifolium* were associated with low groundwater electrical conductivity. Supratidal salt marsh species were associated with a greater depth to groundwater compared to intertidal species. These data indicate the influence of the estuary channel on the physico-chemical conditions of the salt marsh. The salinity of the estuary water and the influence of the tides are important factors controlling the edaphic salinity. Soil conductivity was higher in summer than winter as a result of increased evaporation and accumulation of salt during the summer months.

Correlation matrices showed that soil electrical conductivity, groundwater electrical conductivity and depth to groundwater all decreased with an increase in rainfall and a change of season (winter) in the Geelhoutboom salt marsh. Similar relationships were found for the Kromme salt marsh except that soil electrical conductivity did not change with season because of lower elevations and increased tidal inundation. Because of reduced freshwater flooding in the Kromme Estuary, rainfall probably plays a more important role than it did in the past in reducing soil and groundwater salinity in the salt marshes.

There was a decrease in groundwater electrical conductivity with an increase in depth to groundwater in both the Kromme and the Geelhoutboom salt marsh. Soil- and groundwater electrical conductivity was generally higher than the electrical conductivity of the water column. Groundwater and soil electrical conductivity were correlated and soil with a high clay fraction was associated with low electrical conductivity. These sites occurred furthest from the estuary channel and were associated with supratidal salt marsh.

There has been a steady increase in the area covered by *Zostera capensis* since 1942 (10.8 ha), 1980 (13.7 ha), 1989 (21.7 ha) to 30.98 ha recorded in this study. This was related to reduced freshwater inflow, lack of scouring and sedimentary disturbances, stable salinity and reduced turbidity. The attenuation of floods has reduced the dynamic nature of the estuary and the associated increase in stability has favoured encroachment by *Zostera*. Marine macroalgae are also common and in some quiet backwater areas appear to be outcompeting *Zostera*.

Salt marsh covers 81.237 ha and extends into the upper reaches of the Kromme Estuary and the Geelhoutboom tributary. The construction of the road bridge and numerous resort developments in the floodplain has resulted in the loss of 17 ha of salt marsh since 1942. Reeds and sedges occupy 12.952 ha and occur at sites of freshwater seepage into the estuary. The total area covered by reeds and sedges has decreased by 0.07% over the last 62 years. This is due to the loss of a large area (7.2 ha) of *Phragmites* near the village of St Francis as a result of the construction of the marina. If this loss is ignored there has actually been an increase of over 6 ha in the estuary itself. This can be related to stable sediment conditions and increased nutrient and freshwater run-off from surrounding developments.

1. INTRODUCTION

The demand for freshwater in South Africa for domestic, agriculture and industrial use is growing (Siegfried, 1978; Adams *et al.*, 1992). Over 40% of the total river run-off is already impounded. Large pristine permanently open estuaries in South Africa have a regular flow of river water, interspersed at intervals by droughts and floods. They have an unblocked link to the river inland, a continuous connection with the sea and occasional floods. An estuary that is deprived of this freshwater input loses the physical characteristics of an estuary (Bate and Adams, 2000). This can be expected to threaten estuarine ecosystems, since the flora and fauna of estuaries are uniquely adapted to varying freshwater inputs. Freshwater serves to lower the salinity of the estuary, to control the hydrodynamics and to initiate flocculation and sedimentary processes (Adams *et al.*, 1992).

In the Kromme Estuary regular flow is absent (Adams *et al.*, 1992; Bate and Adams, 2000; Scharler and Baird, 2000) because of the construction of two large impoundments, the Churchill and the Impofu dams. The Churchill dam was constructed in 1943 approximately 36 km above the tidal reach of the estuary and has a capacity of $33.3 \times 10^6 \text{ m}^3$. In 1982 the Impofu dam was constructed below the Churchill Dam, only 4 km above the tidal reach of the estuary. It has a capacity of $100 \times 10^6 \text{ m}^3$. If the capacities of these dams ($133 \times 10^6 \text{ m}^3$) are compared with the mean annual run-off ($123 \times 10^6 \text{ m}^3$) of the Kromme catchment, it is apparent that very little freshwater reaches the estuary. The dams dampen the effect of all floods smaller than the 1:30 year flood (Bickerton and Pierce, 1988; Fromme and Badenhorst, 1987; Adams *et al.*, 1992; Bate and Adams, 2000; Scharler and Baird, 2000).

Lack of freshwater input because of dam construction upriver has reduced the longitudinal salinity gradient between the mouth and the head of the estuary. The Kromme Estuary now functions more as a marine embayment than an estuary (Bate and Adams, 2000). Freshwater impoundment can result in hypersaline conditions. Salt marsh plants predominate at salinities between 10-35 ppt and at salinities outside this range, growth and productivity are reduced (Adams and Talbot, 1992; Adams *et al.*, 1992). It is important that small tributaries and other freshwater seepage sites leading into the Kromme Estuary are conserved as they provide nodes of plant and animal diversity. Plants at these sites can range from salt tolerant to brackish species, e.g. *Phragmites australis* (Adams and Bate, 1994).

There is therefore a need to determine the importance of freshwater in estuaries and the extent to which the macrophytes require it. It is also important to know whether freshwater affects the distribution of macrophytes within the estuary.

The objectives of this study were:

1. to identify vegetation patterns along an elevation profile,
2. to investigate the spatial and temporal variations in vegetation cover and soil characteristics,
3. to produce accurate maps of the vegetation of the estuary, and
4. to determine the species richness, present and past distribution and area covered by the different plant community types.

This data would in turn be used in the RDM protocol. See main report.

2. A. FIELD STUDY: SALT MARSH TRANSECTS

2.1 Methods and materials

Four permanent transects were established in the marsh area along the estuary, two in the Geelhoutboom tributary and two along the main channel of the Kromme Estuary (Figure F-1). Global Positioning System (GPS) coordinates at the first and last markers in each transect were recorded. Sites selected in the Kromme Estuary were situated in close proximity to the sites used by Adams (1991) so that the data could be compared. During 1990, salt accumulation was evident in the salt marshes in the middle-upper reaches of the Kromme Estuary. Sites were selected in the Geelhoutboom tributary to establish whether salt marsh structure and the controlling environmental variables were similar to that of the Kromme Estuary. The profile and elevation above mean sea level for each transect was determined using a theodolite (Sokkisha TM 6). Vegetation changes were analysed by determining the percentage cover in two duplicate permanent quadrates (1 m²) located every 5 m along the transects. The permanent quadrates were used to determine whether seasonal changes in vegetation cover were occurring.

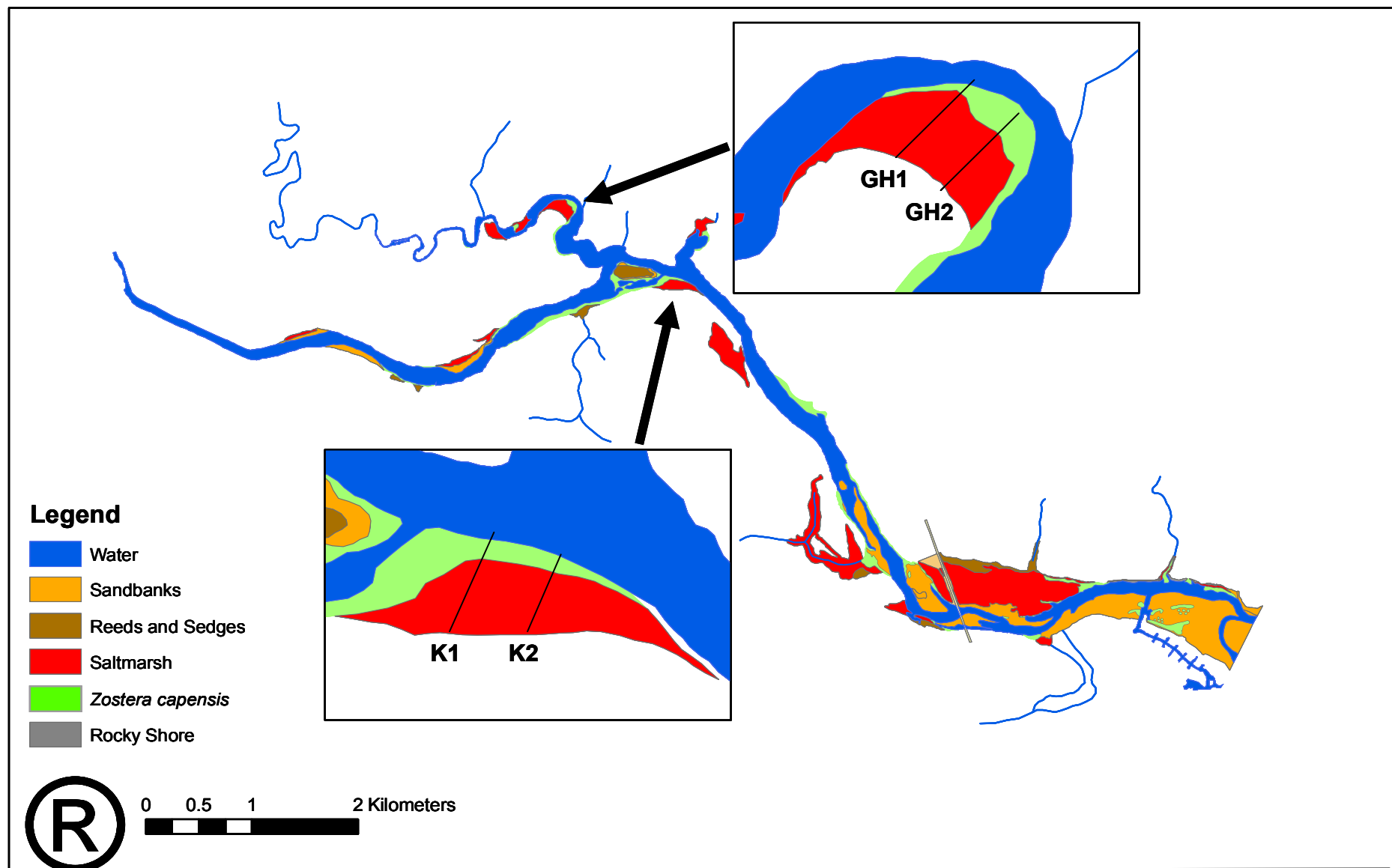


Figure F-1 The location of transects in the Kromme Estuary and the Geelhoutboom tributary. (GH1= Geelhoutboom transect 1; GH2= Geelhoutboom Transect 2; K1= Kromme Transect 1; K2= Kromme Transect 2)

2.1.1 Vegetation analysis

The percentage vegetation cover was determined along four transects during two field trips in February 2004 and July 2004. The vegetation data collected every 5 m along each transect was analysed using Detrended Correspondence Analysis (DCA) to determine if vegetation changes occurred over the two sampling periods. Only the vegetation cover at 30 m, 80 m and 120 m along the transects in the Geelhoutboom tributary and 10 m, 50 m and 90 m along the transects in the Kromme Estuary were used in the Canonical Correspondence Analysis (CCA) to determine the influence of environmental variables on the vegetation distribution because these were the only sites where soil variables were examined.

2.1.2 Soil analysis

During each of the two field trips, soil samples were collected at three zones along each transect. At each site, samples were collected from three depths, i.e. 0 – 0.05 m, 0.05 – 0.15 m and 1.0 – 1.2 m. Three replicates of each sample were collected. Samples were sealed and transported to the laboratory where analyses of soil moisture content, soil organic content, soil electrical conductivity and soil particle size were undertaken.

2.1.3 Soil moisture content

Soil moisture content was determined according to the methods set out by Black (1965). Into a crucible, 10 g of each soil sample was weighed and placed in a drying oven for 48 hours at 100 °C. The samples were reweighed and the moisture content was determined using the following equation:

$$\left(\frac{M_w - M_d}{M_w} \right) * 100$$

Where M_w is the initial wet mass and M_d is the mass after drying.

2.1.4 Soil organic content

The soil organic content was determined according to the method of Briggs (1977). The dried soil samples from the soil moisture content experiment were placed in a muffle furnace (ashing oven) for 8 hours at 550 °C. The crucibles were removed from the ashing oven and placed in a desiccator containing anhydrous silica crystals until cool. The percentage organic matter was calculated as a loss of mass during ashing as a percentage of the initial mass using the following equation:

$$\left(\frac{M_d - M_a}{M_d} \right) * 100$$

Where M_d is the initial dry mass and M_a is the mass after ashing.

2.1.5 Soil electrical conductivity

Soil electrical conductivity (mS.cm^{-1}) of the soil rather than salinity (ppt) was measured because, although seawater and saline groundwater are dominated by sodium and chloride, salts normally precipitate out as calcium sulphate and sodium chloride, both contributing to the ion concentration of the soil. Soil electrical conductivity increases proportionally with the salt concentration (Egan and Ungar, 1999; Bornman, 2002). Although only soil electrical conductivity was recorded, salinity and electrical conductivity are used interchangeably where exact values are not of importance, e.g. general discussions.

Soil electrical conductivity of a saturated paste was determined according to the method by Barnard (1990). An air-dried soil sample (250 g) was placed in a beaker and de-ionised water was added until saturated. The soil was tested for the properties of a saturated paste, i.e. no excess water on the surface of the soil, and if too dry more de-ionised water was added. The amount of de-ionised water used to attain saturation for each sample was recorded. The saturated paste was allowed to stand for at least one hour. The saturated paste was then filtered through a Bachman filter using Whatman No. 40 filter paper. The electrical conductivity of the filtrate was measured using a YSI 30M/10FT hand held conductivity meter.

2.1.6 Soil particle size

The hydrometer method, as set out by Gee and Bauder (1986) and ASTM (1985), was used. Approximately 40 g of soil, previously air-dried, was accurately weighed out in a pre-weighed beaker and allowed to equilibrate with the atmosphere overnight. To this sample was added 100 ml of a 50 g.l⁻¹ solution of Sodium hexametaphosphate (NaPO₃)₆ and 250 ml distilled water. The beakers were placed on a mechanical shaker for 1 hour prior to the start of the experiment. The soil mixture was then placed in a 1 l measuring cylinder and the volume made up to 1 l with distilled water. The cylinder was closed off at the mouth and shaken by hand for at least 1 minute. Two drops of amyl alcohol were added to remove the foam on top of the sample. A hydrometer was inserted after 30 seconds, 60 seconds, 3 minutes, 1.5 hours and 24 hours. A blank containing a similar solution was also prepared but without soil. The temperature of the solutions was taken using a mercury thermometer. The readings were then used in the following equations to calculate the percentage size fractions in the sample.

Determine C, the concentration of soil in suspension in g.l⁻¹, using:

$$C = R - RL$$

Where R is the uncorrected hydrometer reading (in g.l⁻¹) and RL is the hydrometer reading of the blank solution.

The determination of P, the summation percentage for the given time interval, using:

$$P = \left(\frac{C}{C_o} \right) * 100$$

Where C_o is the oven dried weight of the sample.

Determine X, the mean particle diameter in suspension in µm at time *t* using:

$$X = \theta t^{-1/2}$$

Where θ is the sedimentation parameter (µm min^{1/2}) and is a function of the hydrometer settling depth, solution viscosity and particle and solution density.

$$\theta = \left(\frac{18\eta h'}{[g(\rho_s - \rho)]^{1/2}} \right)$$

Where *h'* is the hydrometer settling depth (cm), *p_s* = soil particle density (g/cm³), *p_l* = solution density (g/cm³), *g* = gravitational constant (cm/s²) and *η* = fluid viscosity in poise (g.cm⁻¹.s⁻¹).

The relationship of the settling depth to the hydrometer dimensions were approximated by:

$$h' = -0.164R + 16.3$$

Where *R* is the uncorrected hydrometer reading.

The summation percentage was calculated as follows:

$$P_{2\mu m} = m \ln \left(\frac{2}{X_{24}} \right) + P_{24}$$

Where X_{24} is the mean particle diameter in suspension at 24 hours, P_{24} is the summation percentage at 24 hours, and m was determined using the following equation:

$$m = \frac{P_{1.5} - P_{24}}{\ln(X_{1.5} - X_{24})}$$

Where m is the slope of the summation percentage curve between X at 1.5 hours and X at 24 hours. $X_{1.5}$ is the particle diameter in suspension at 1.5 hours, and $P_{1.5}$ is the summation percentage at 1.5 hours. This procedure was repeated for the 30 second and 60 second readings.

2.1.7 Water table analysis

Bornman (2002) suggested the possibility of groundwater as a source of moisture for supratidal vegetation. It was therefore decided to include depth to the water table and groundwater electrical conductivity in the analysis of environmental variables that might influence the distribution of the salt marsh plants. Depth to groundwater and groundwater electrical conductivity were determined by manually auguring down to the water table. Readings were taken at the same sites from where the soil samples were collected. Three replicate holes were augured at each site.

2.1.8 Correlation analysis

Correlation analysis were run, one for the Geelhoutboom tributary and one for the main channel of the Kromme Estuary, using Statistica (Statistical software developed by Statsoft, Inc.) on all variables tested at all sites over both sampling periods. Variables included in the analysis were: season (to determine if any variables changed over time); distance inland from the estuary channel; depth below the soil surface (soil samples were collected along three depths); percentage soil moisture; soil electrical conductivity; percentage soil organic content; percentage sand fraction of the soil; percentage silt fraction of the soil; percentage clay fraction of the soil; rainfall; depth to groundwater and groundwater electrical conductivity.

2.1.9 Statistical analysis

The seasonal species and environmental data for both the Geelhoutboom tributary and the main channel of the Kromme Estuary were analysed using CANOCO for Windows (version 4.0, ter Braak 1997). Detrended Correspondence Analysis (DCA) was used to identify patterns in species distribution and cover over time. Canonical Correspondence Analysis (CCA) was used to obtain an ordination of the vegetation data constrained by environmental variables. Monte Carlo permutation tests (999 permutations) were performed to assess the significance of the canonical axis showing the relationship between species and the selected environmental variables. The result of the CCA was plotted as a two-dimensional graph using CANODRAW (version 3.1, 1997). The environmental variables were plotted as arrows originating from the center of the graph. The origin represents the mean value of each separate variable and the direction of the arrow line represents an increase in the value of that particular variable. The length of the environmental arrow indicates the importance of the variable and is equal to the multiple correlation of the variable with the displayed ordination axes. Statistical results were displayed in a table below each CCA ordination diagram. This information is required for the correct interpretation of the ordination diagram. The correlation matrixes were run using Statistica (version 6, 2001), Statsoft, Inc.

2.2 Results

The mean monthly rainfall for the year 2004, as well as the mean monthly rainfall over a 45 year period for the St Francis Bay area is given in Figure F-2. The Kromme Estuary receives its highest rainfall in winter. According to the data collected by the South African Weather Services, the study area received below average rainfall during 2004 (mean monthly rainfall from 1960-2003 was 54.3 mm $\pm$ 5.1 mm SE).

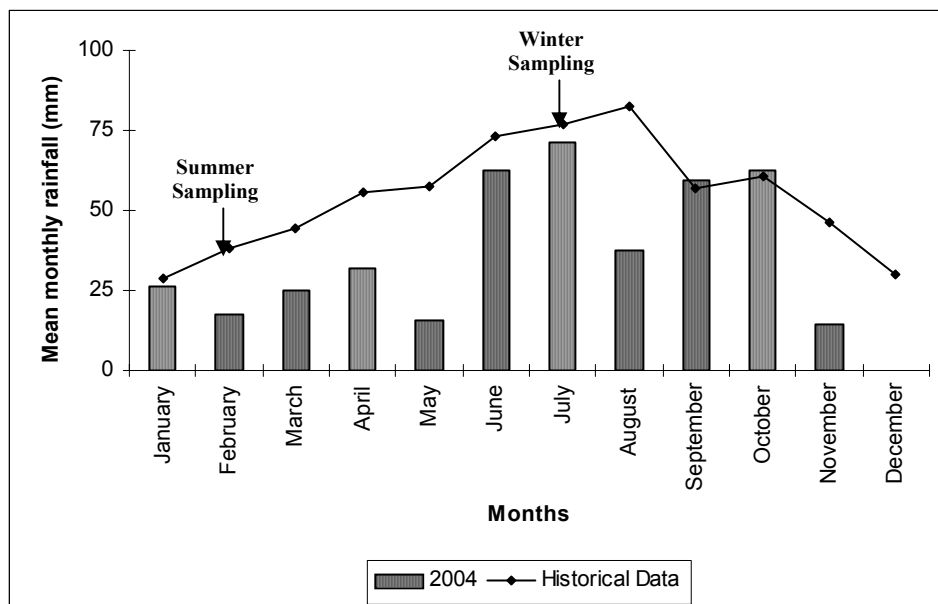


Figure F-2 Mean monthly rainfall for the St Francis Bay area (1960-2004).

2.2.1 Transect data

Transect 1 and 2 in the Geelhoutboom tributary were both 140 m long and extended from the submerged *Zostera* beds to the end of the supratidal salt marsh and terrestrial fringe (Figure F-3). These two transects were situated parallel to each other and had a similar species composition and cover, probably due to similar elevation profiles. During summer (Figure F-5 and Figure F-7) the first 20 m of the transect consisted of the submerged macrophyte, *Zostera capensis*. *Sarcocornia decumbens* was dominant throughout most of the intertidal salt marsh area along the transects except between 20 - 40 m and 100 - 130 m where the co-dominant species, *Triglochin* spp. and *Chenolea diffusa* had the highest cover respectively. *Triglochin* is a low intertidal salt marsh species and is generally associated with high soil electrical conductivity and thus occurs closest to the estuary channel. *Chenolea diffusa*, however, is associated with low groundwater electrical conductivity and therefore occurred higher up the transects. A thin band (15 m) of supratidal salt marsh occurred along the top of the transects with *Sarcocornia pillansii* as the dominant species. Along both of these transects the supratidal and intertidal areas were not clearly defined and overlapping of species occurred at certain points.

During winter (Figure F-6 and Figure F-8) only slight differences in vegetation cover was observed. Between 40-70 m there was an increase in the percentage of dead *Sarcocornia decumbens*. These patches of *Sarcocornia* probably died back due to extended water inundation. Rainfall caused the pools to fill up (Figure F-4). There was also a decrease in *Triglochin* species; however, it was not as pronounced as the patches of *Sarcocornia*. In the Knysna Estuary salt marsh around Thesen Island, Muir (2000) showed that there was an increase in the area covered by *Triglochin bulbosa* in summer. This lower intertidal species colonised new areas that were formed as a result of sedimentation and the shifting in creeks and channels.

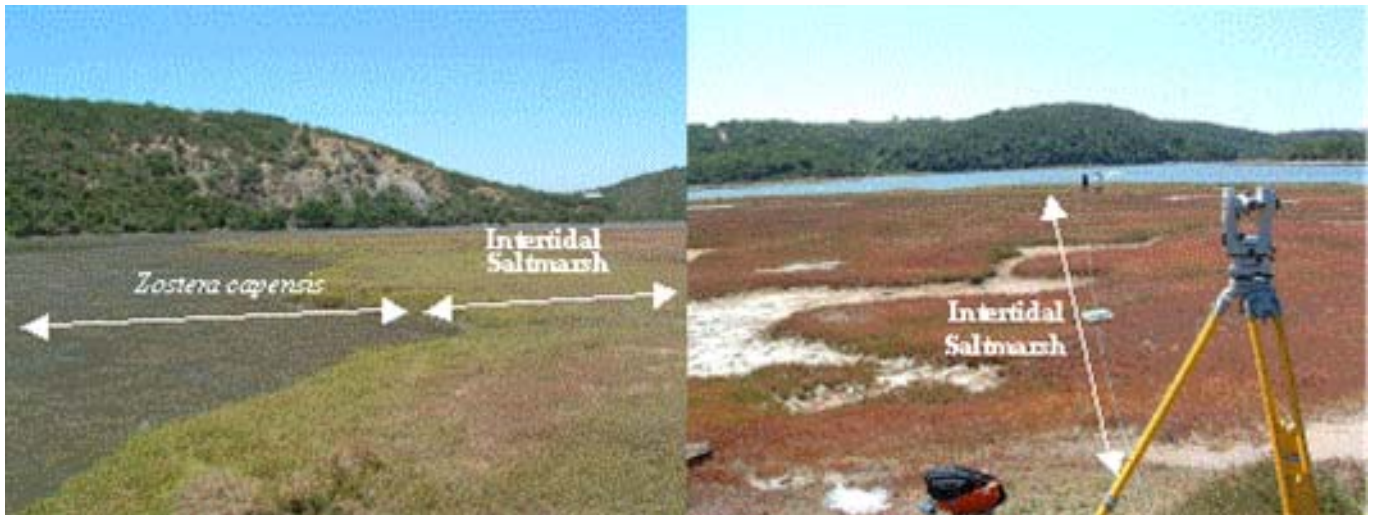


Figure F-3 Zonation at the sampling sites in the main channel of the Geelhoutboom tributary. (A) The lower part of the sampling site. (B) The upper part of the sampling site.



Figure F-4 An example of a depression filled with rainwater in the Geelhoutboom tributary.

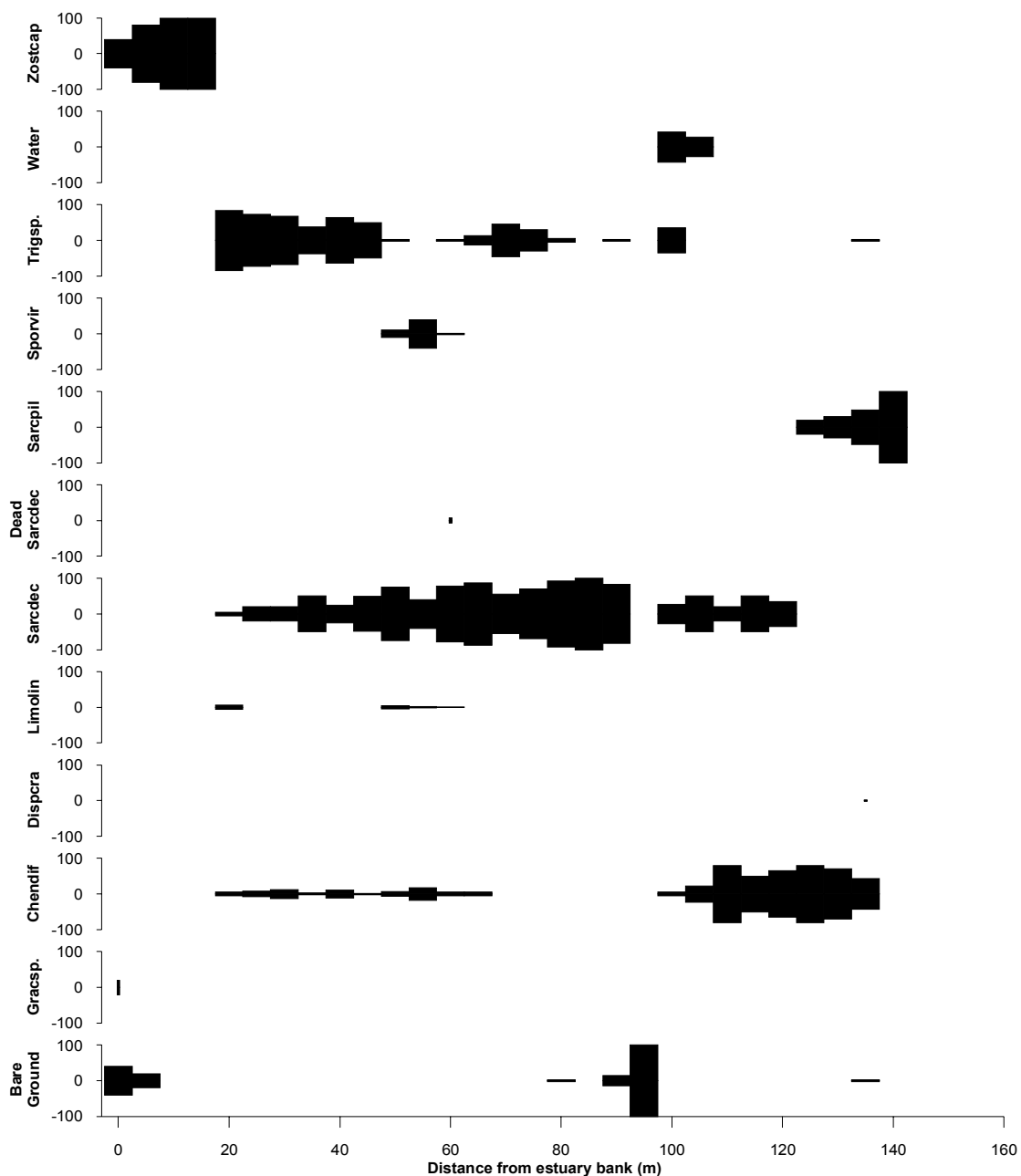


Figure F-5 Kite diagram showing the distribution of vegetation along Transect 1 in the Geelhoutboom tributary during summer (full species names are available in Attachment A^F).

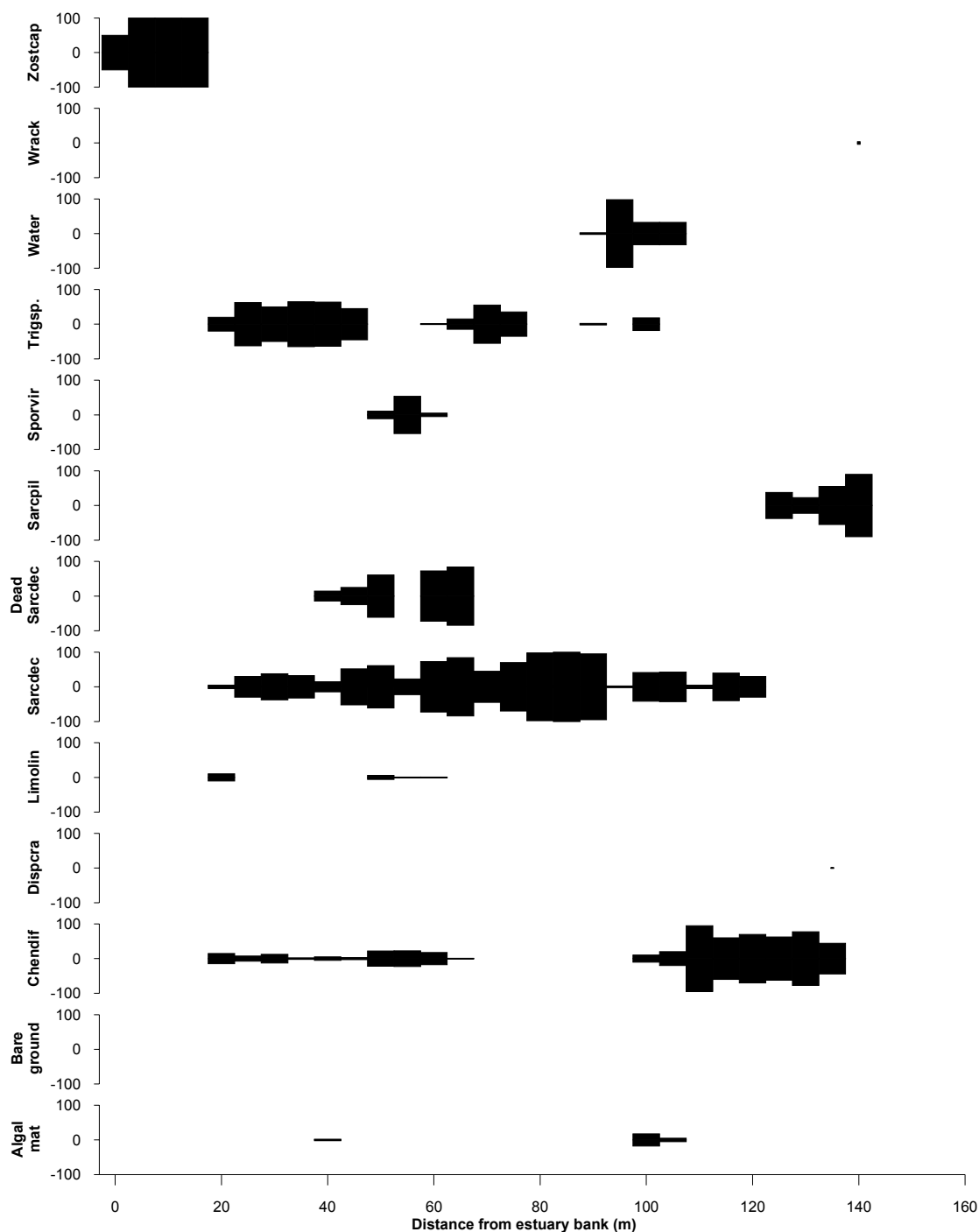


Figure F-6 Kite diagram showing the distribution of vegetation along Transect 1 in the Geelhoutboom tributary during winter (full species names are available in Attachment A^F).

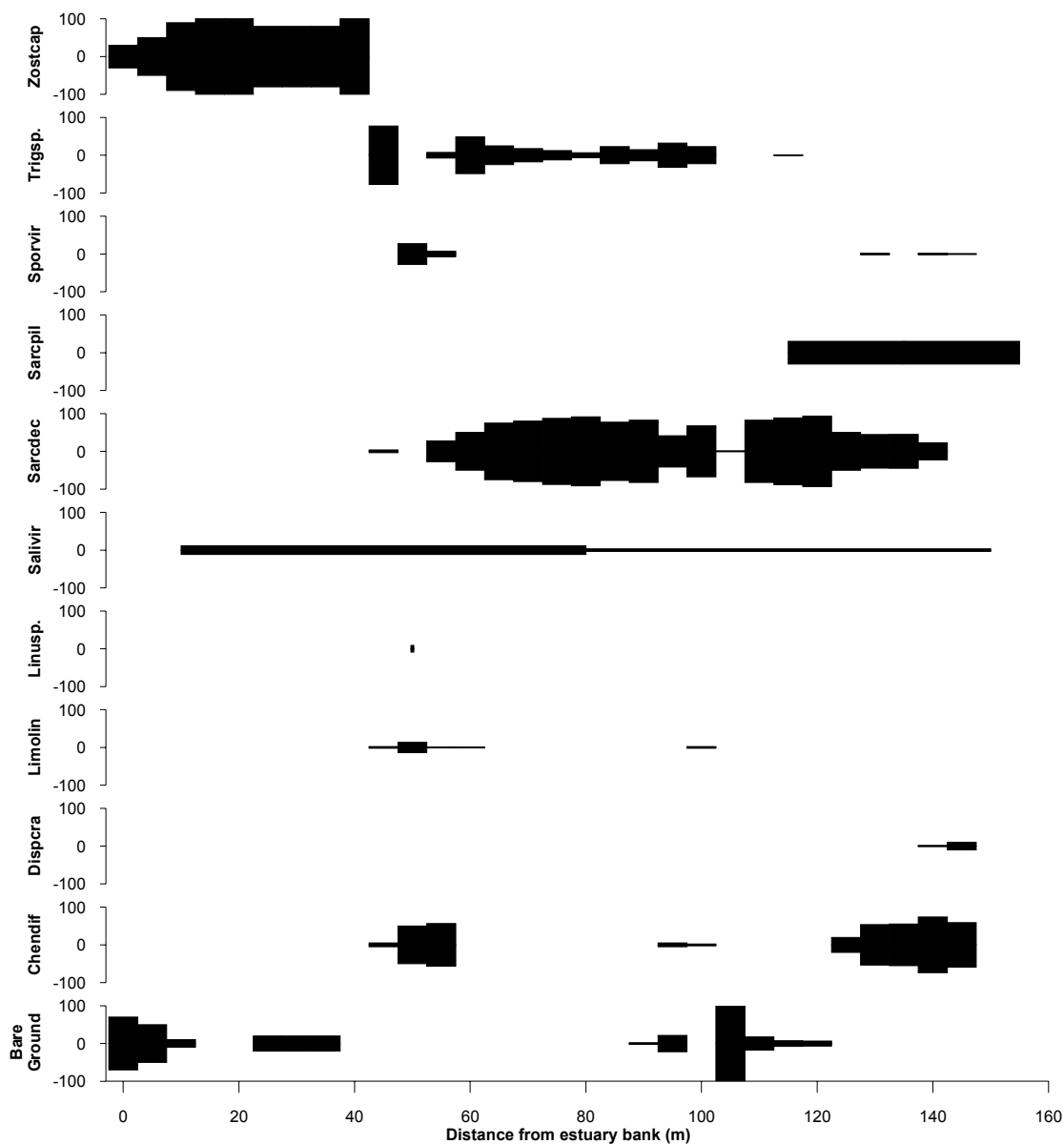


Figure F-7 Kite diagram showing the distribution of vegetation along Transect 2 in the Geelhoutboom tributary during summer (full species names are available in Attachment A^F).

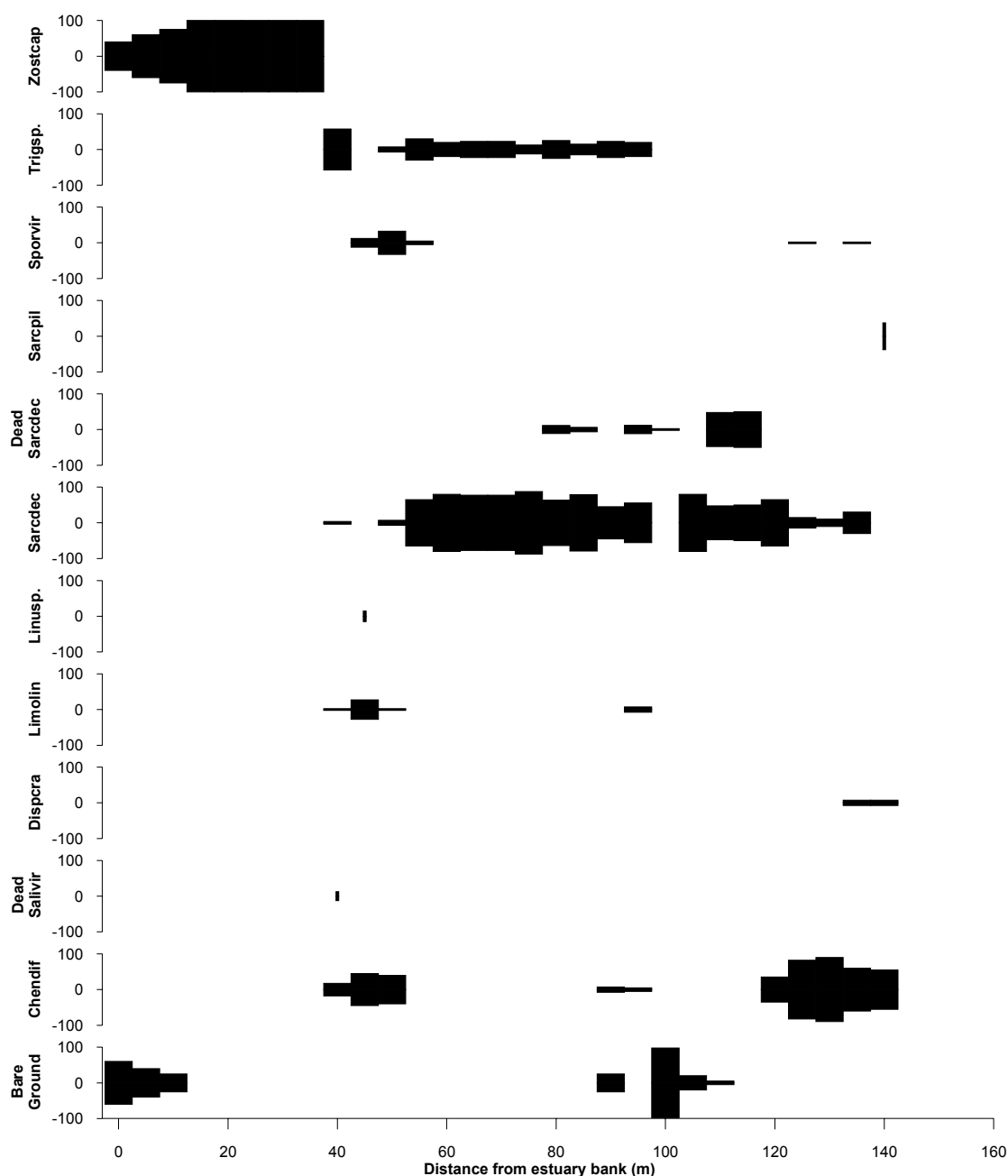


Figure F-8 Kite diagram showing the distribution of vegetation along Transect 2 in the Geelhoutboom tributary during winter (full species names are available in Attachment A^F).

Transect 1 and 2 in the Kromme Estuary were shorter than those in the Geelhoutboom tributary and were only 95 m and 110 m in length respectively. These transects extended from the submerged *Zostera* beds to the end of the supratidal salt marsh (Figure F-9). The transects were situated parallel to each other and were similar in species composition and cover, probably due to similar elevation profiles. During summer (Figure F-11 and Figure F-13) the first 15 m of the transect consisted of the submerged macrophyte, *Zostera capensis*. *Sarcocornia decumbens* was dominant throughout the intertidal salt marsh. *Triglochin* species also occurred throughout the intertidal area, but at a lower percentage cover than *Sarcocornia decumbens*. *Spartina maritima* occurred in monospecific stands (Figure F-10) between 30 - 40 m. This species was absent from the transects sampled in the Geelhoutboom tributary. Both *Triglochin* species and *Spartina maritima* are lower intertidal salt marsh species and are generally associated with high moisture content. The Kromme salt marsh had a higher soil moisture content than the Geelhoutboom tributary and may explain the occurrence of *Spartina maritima* and the higher percentage cover of *Triglochin* species. A thin band (5 m) of supratidal salt marsh occurred along the top of the

transects with *Sarcocornia pillansii* as the dominant species. Along both of these transects the supratidal and intertidal areas were clearly defined and no overlapping of species occurred.

During winter (Figure F-12 and Figure F-14) only slight differences in vegetation cover were observed. *Salicornia virginicus* died back and only small patches were observed during winter. There was also a decrease in cover of *Triglochin* spp and *Zostera capensis*.

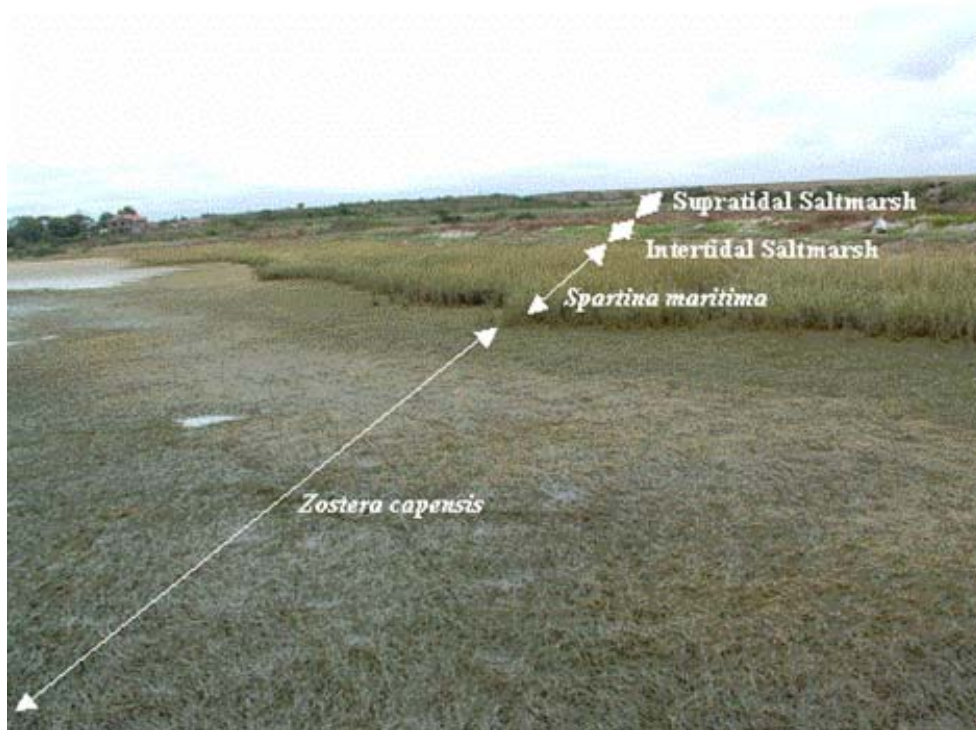


Figure F-9 Zonation at the sampling sites in the main channel of the Kromme Estuary.



Figure F-10 Monospecific stands of *Spartina maritima* in the Kromme Estuary.

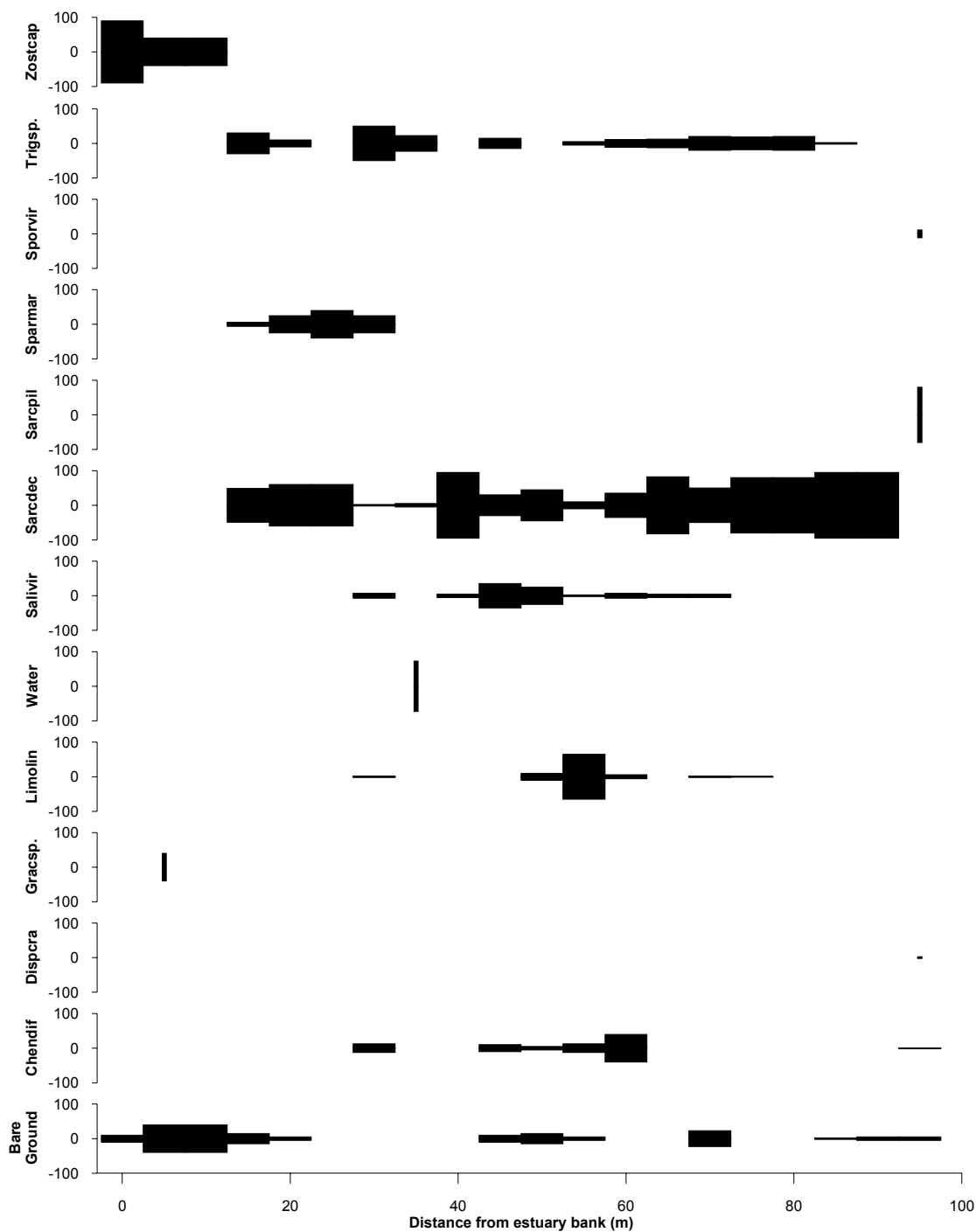


Figure F-11 Kite diagram showing the distribution of vegetation along Transect 1 in the Kromme Estuary during summer (full species names are available in Attachment A^F).

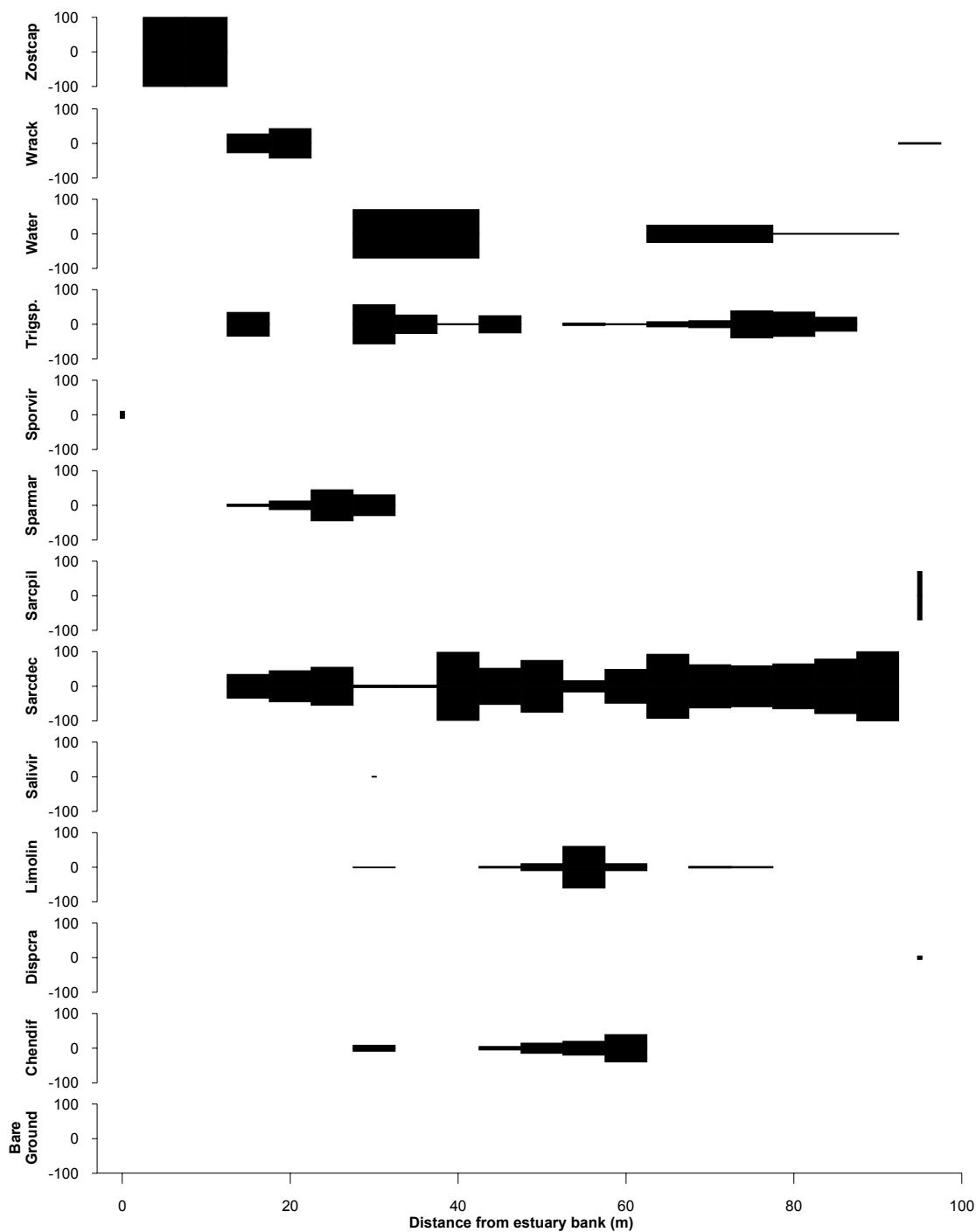


Figure F-12 Kite diagram showing the distribution of vegetation along Transect 1 in the Kromme Estuary during winter (full species names are available in Attachment A^F).

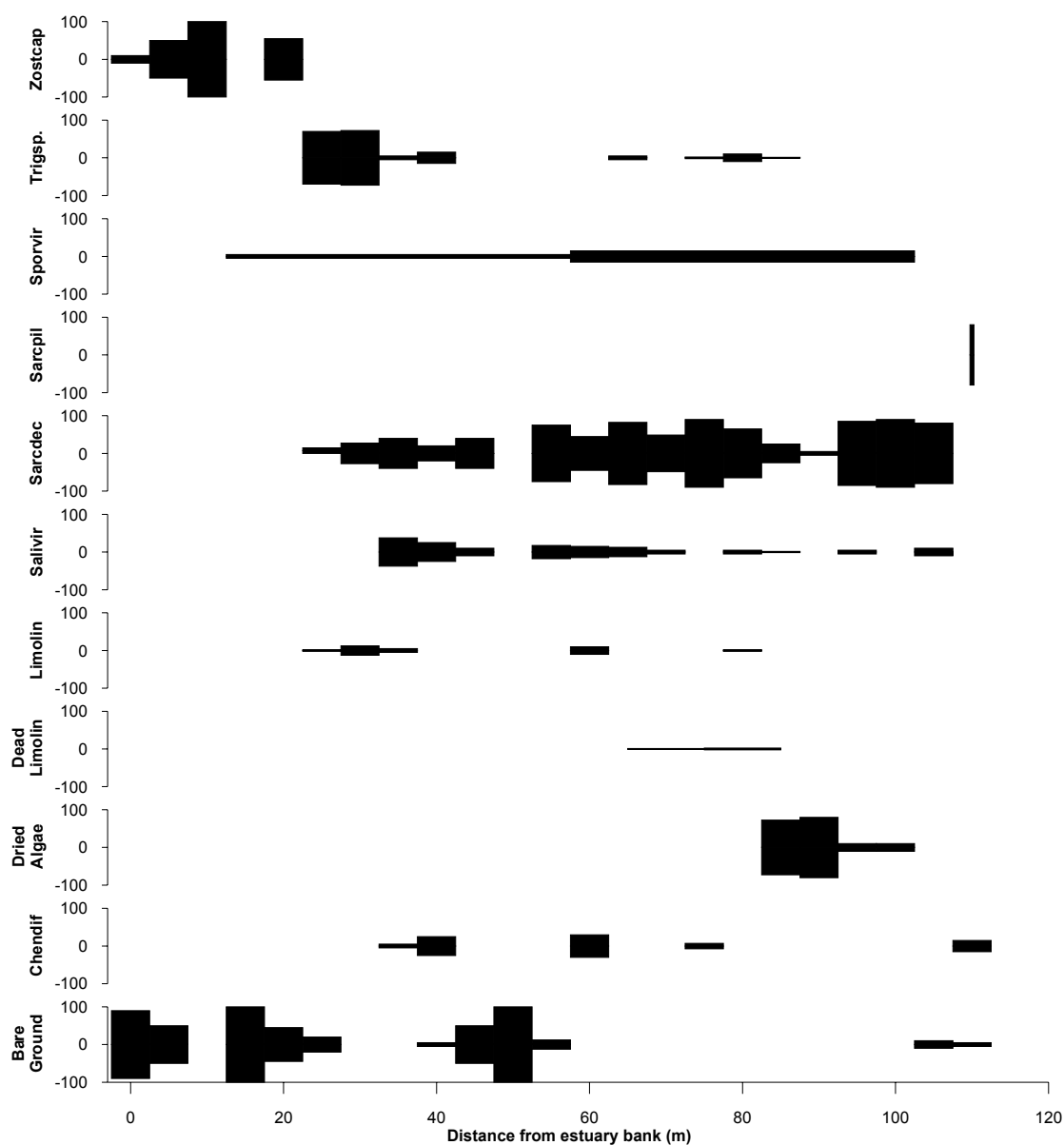


Figure F-13 Kite diagram showing the distribution of vegetation along Transect 2 in the Kromme Estuary during summer (full species names are available in Attachment A^F).

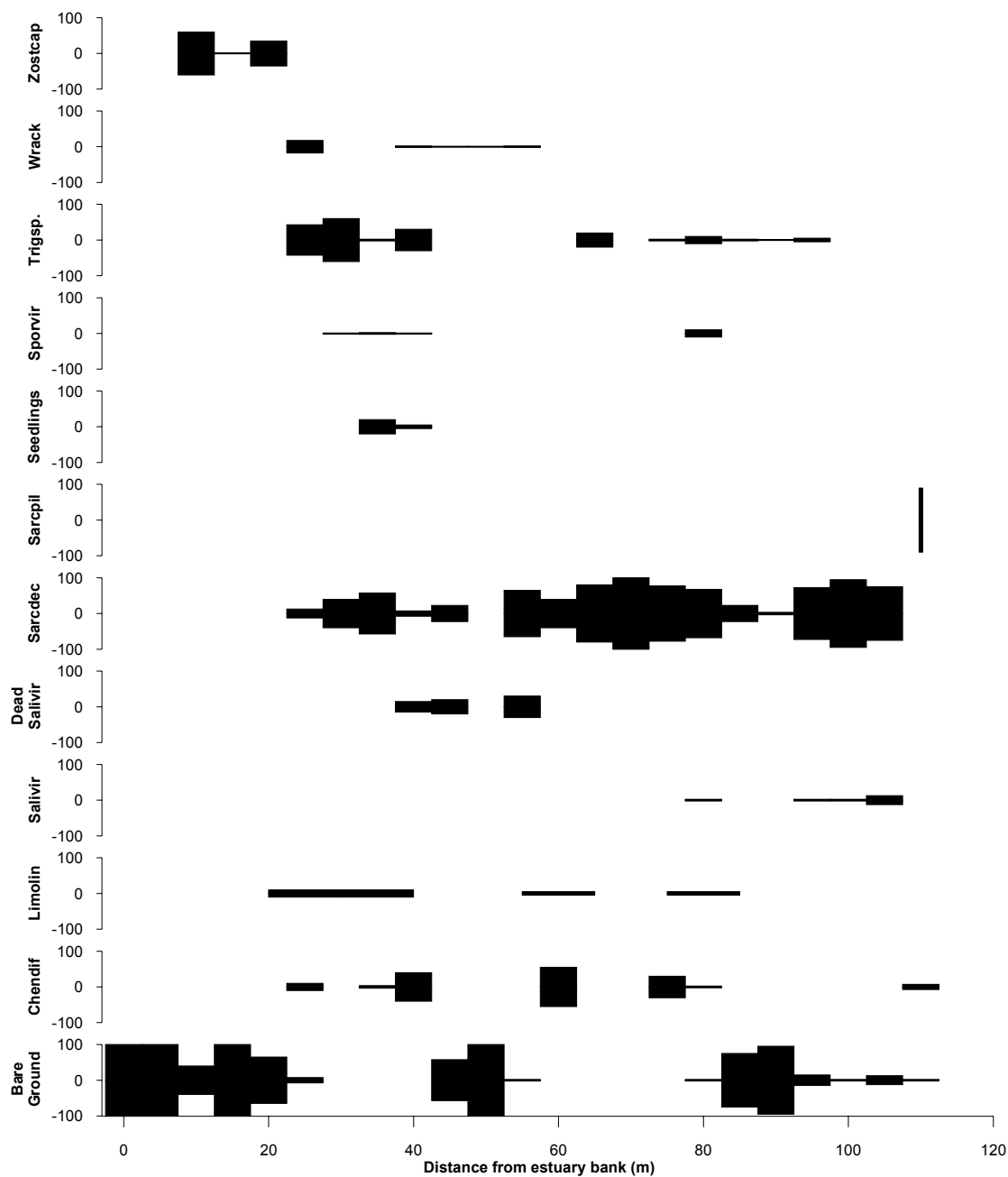


Figure F-14 Kite diagram showing the distribution of vegetation along Transect 2 in the Kromme Estuary during winter (full species names are available in Attachment A^F).

2.2.2 Vegetation distribution (Figures F-15 to F-16)

Vegetation distribution in both the Kromme Estuary and the Geelhoutboom tributary were analysed using Detrended Correlation Analysis (DCA). Vegetation in the Kromme Estuary was separated into three distinct zones: submerged vegetation, intertidal salt marsh and supratidal salt marsh (Figure F-16), whereas the Geelhoutboom tributary was separated into two distinct zones: submerged vegetation and salt marsh vegetation (Figure F-15). This indicates that there is distinct zonation between supratidal and intertidal salt marsh in the Kromme Estuary, whereas, in the Geelhoutboom tributary, the change from intertidal to supratidal salt marsh is less distinct. The reason for this is that in the Kromme Estuary there is a sudden increase in elevation between the intertidal and supratidal salt marsh, whereas in the Geelhoutboom tributary, the increase in elevation is gradual.

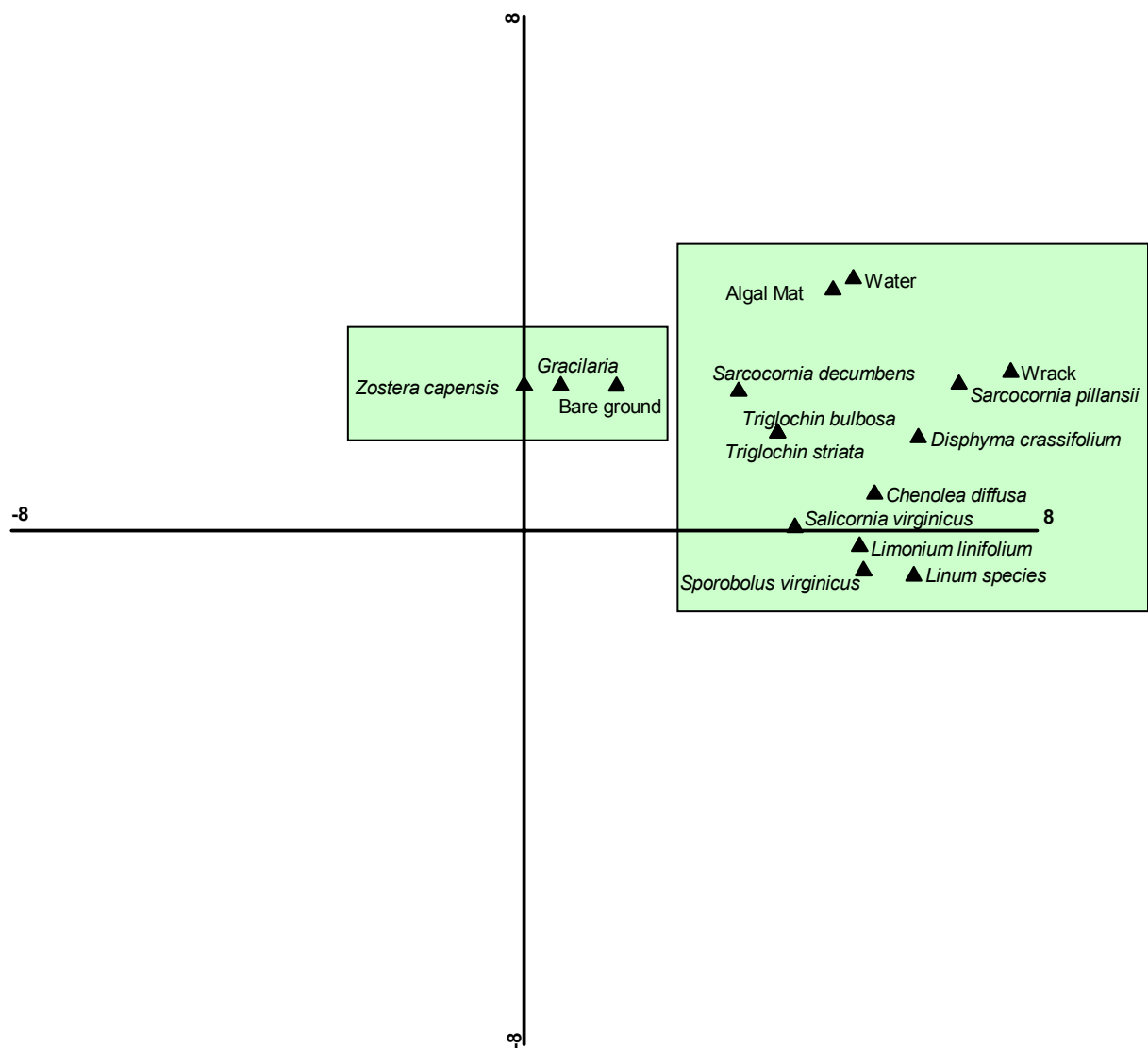


Figure F-15 DCA ordination of sites for the Geelhoutboom tributary over the 2 sampling periods. Eigenvalues: axis 1 = 0.961; axis 2 = 0.075.

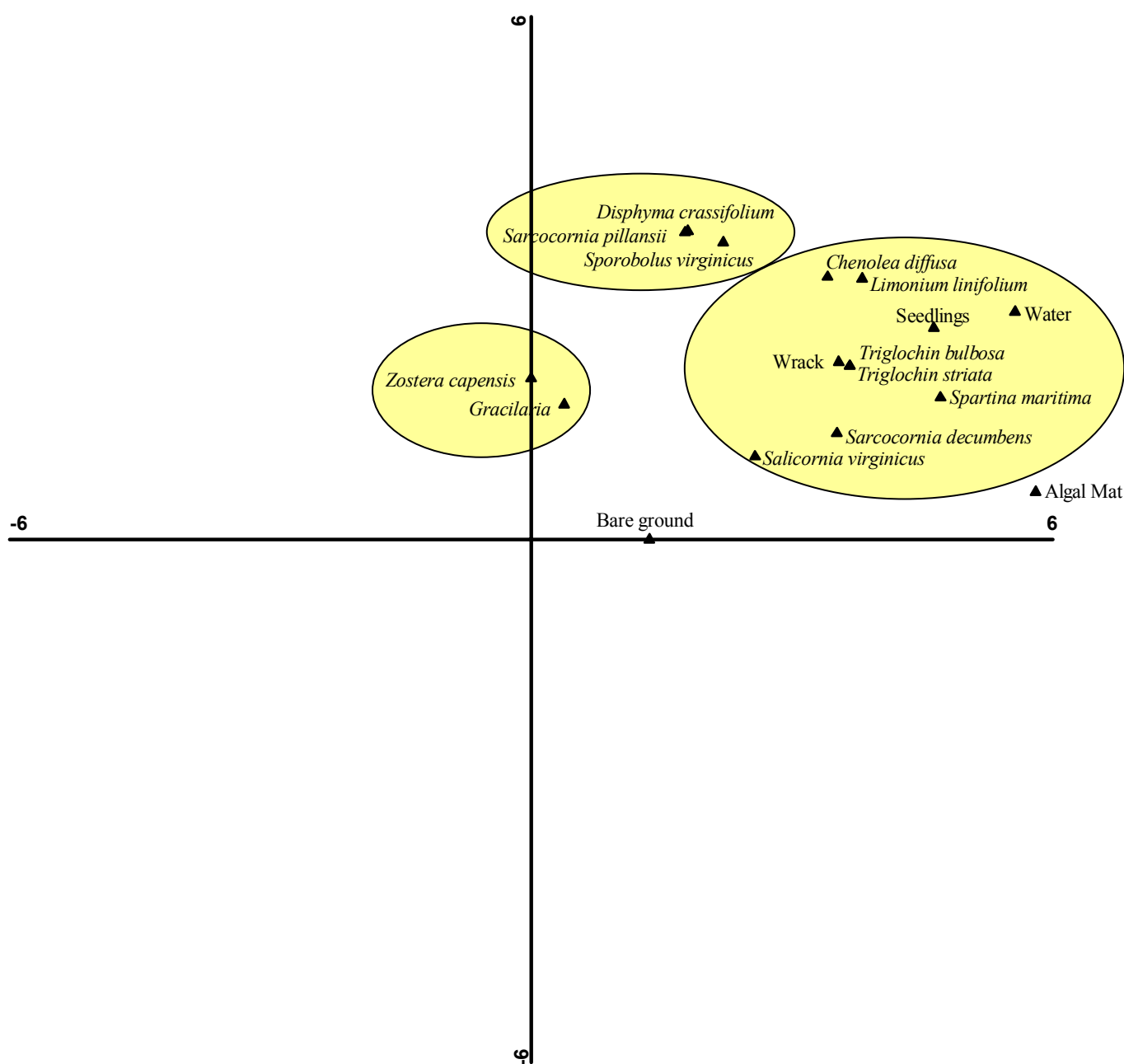


Figure F-16 DCA ordination of sites for the Kromme Estuary over the 2 sampling periods. Eigenvalues: axis 1 = 0.881; axis 2 = 0.497.

2.2.3 Influence of environmental variables on vegetation distribution (Figures F-17 to F-18)

The numerical results of the Canonical Correspondence Analysis (CCA) are shown in the tables F-1 and F-2 below the ordination diagrams for both the Geelhoutboom tributary and the Kromme Estuary. A Monte Carlo permutation test of the trace (sum of eigenvalues of all canonical axis; 999 permutations) showed that vegetation distribution in the Geelhoutboom tributary and Kromme Estuary was significantly affected by distance from the estuary channel, groundwater electrical conductivity ($p = 0.001$) and depth to groundwater. Therefore the controlling environmental factors are similar for both study sites. The same statistical test indicated that in the Geelhoutboom

tributary rainfall ($p < 0.01$) and the percentage clay fraction ($p < 0.05$) were also important, whereas in the Kromme Estuary seasonality was important ($p = 0.001$).

In the Geelhoutboom tributary (Figure F-17) the first canonical axis (horizontal) described 50% of the variation of the species – environment relation. This axis was negatively correlated with soil electrical conductivity (-0.43) and positively correlated with rainfall (0.18), seasons (0.18) and distance from the estuary channel (0.88).

In the Kromme Estuary (Figure F-18) the first canonical axis described 54% of the variation of the species – environment relation. This axis was negatively correlated with rainfall (-0.26), and seasons (-0.26) and positively correlated with soil organic content (0.34), soil moisture content (0.57) and the percentage clay and silt particle fractions.

The ordination diagram for the Geelhoutboom salt marsh (Figure F-17, Table F-1) indicates three distinct groups, a lower intertidal salt marsh group close to the estuary channel and associated with high sediment electrical conductivity, a supratidal salt marsh group (*Sarcocornia pillansii*) occurring furthest from the channel and associated with low sediment electrical conductivity and a upper intertidal (*Chenolea diffusa*) supratidal salt marsh group (*Sporobolus virginicus* and *Disphyma crassifolium*) associated with low groundwater electrical conductivity. In the Kromme Estuary, however, *Chenolea diffusa* was associated with high groundwater electrical conductivity. The reason for this is that the lowest groundwater electrical conductivity (70-80 mS/cm⁻¹) values in the Geelhoutboom tributary were very similar to the highest groundwater electrical conductivity (80-90 mS/cm⁻¹) values in the Kromme Estuary, therefore what is low in the one is high in the other. If all values for both systems are combined then it can be said that *Chenolea diffusa* occurred optimally at intermediate levels of groundwater electrical conductivity. The Kromme salt marsh was wetter than the Geelhoutboom salt marsh and therefore rainfall would probably have a greater effect on groundwater electrical conductivity in the Geelhoutboom.

Salicornia virginicus was influenced by high soil electrical conductivity in both systems. This is an annual that often colonises open areas and dried out pools of water where evaporation would result in high salinity. *Spartina maritima* was associated with high moisture content in the Kromme Estuary, while it was absent from the transects sampled in the Geelhoutboom tributary. This species is dependent upon frequent tidal exchange, therefore it is natural that it would be restricted to the salt marsh closest to the mouth (main channel of the Kromme Estuary). If the mouth were to close, *Spartina maritima* would disappear. Lower intertidal salt marsh species, *Triglochin striata* and *Triglochin bulbosa*, in the Geelhoutboom tributary were associated with high soil electrical conductivity and were situated closest to the estuary channel.

The ordination diagram for the Kromme salt marsh (Figure F-18, Table F-2) indicates two distinct groups, a lower intertidal salt marsh group close to the estuary channel that is associated with a shallow water table and a supratidal group (*Sarcocornia pillansii*, *Sporobolus virginicus* and *Disphyma crassifolium*) occurring furthest from the channel and associated with a greater depth to the water table.

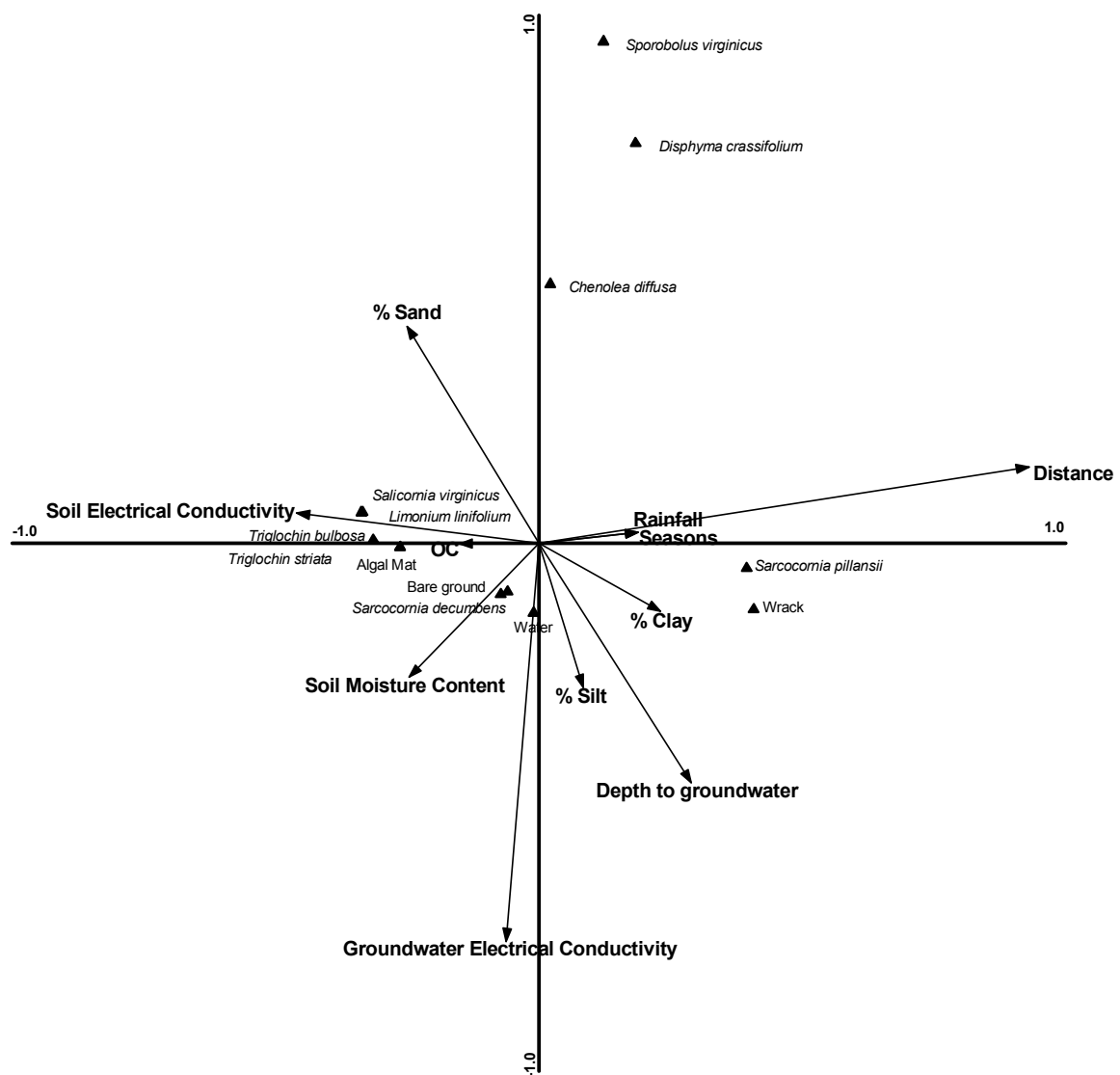


Figure F-17 Ordination diagram based on a CCA of seasonal species and environmental data for the Geelhoutboom tributary.

Table F-1 Summary of CCA of seasonal species and environmental data for the Geelhoutboom tributary ($p = 0.001$).

	Axis 1	Axis 2	Axis 3	Axis 4	Total Inertia
Eigenvalues	0.779	0.400	0.294	0.045	2.139
Species-environment correlation	0.945	0.920	0.762	0.679	
Cumulative percentage variance: of species data	36.4	55.1	68.8	70.9	
of species-environment relation	49.6	75.1	93.9	96.8	
Sum of all unconstrained eigenvalues					2.139
Sum of all canonical values					1.568

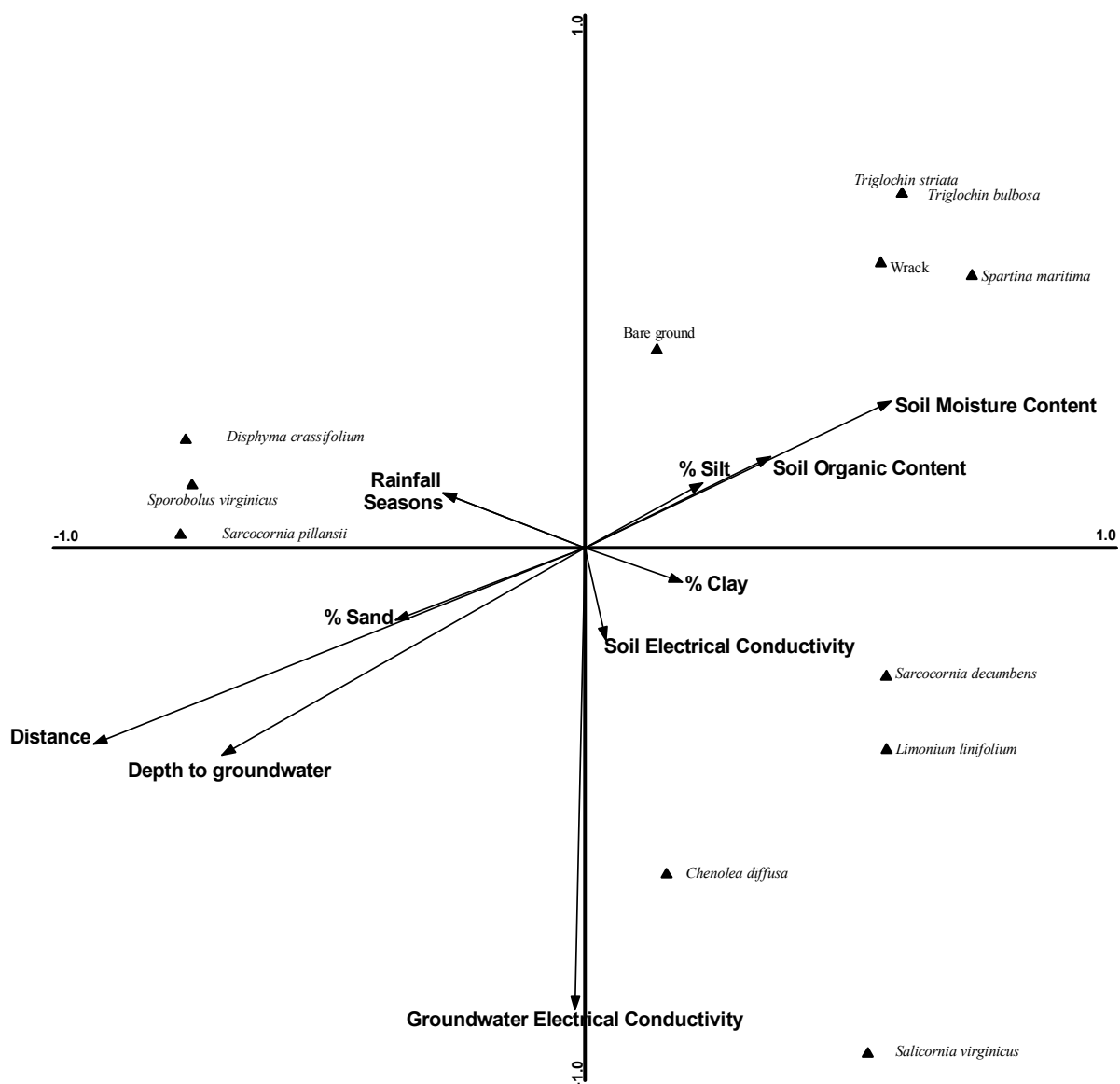


Figure F-18 Ordination diagram based on a CCA of seasonal species and environmental data for the Kromme Estuary.

Table F-2 Summary of CCA of seasonal species and environmental data for the Kromme Estuary ($p = 0.001$).

	Axis 1	Axis 2	Axis 3	Axis 4	Total Inertia
Eigenvalues	0.818	0.414	0.145	0.069	1.897
Species-environment correlation	0.983	0.972	0.888	0.679	
Cumulative percentage variance: of species data	43.1	65.0	72.6	76.3	
of species-environment relation	53.9	81.2	90.7	95.3	
Sum of all unconstrained eigenvalues					1.897
Sum of all canonical values					1.519

2.2.4 Correlation analysis (Table F-3 to F-4)

The correlation analysis made it possible to analyse the system as a whole and not as individual transects or single sampling periods that are difficult to compare. Only a few of the correlations were significant ($p < 0.05$) and due to the large sample size, the correlations were not very strong.

In the Geelhoutboom tributary (Table F-3), depth below the soil surface was negatively correlated with percentage soil organic content and the percentage sand fraction in the soil, and positively correlated with the percentage clay fraction in the soil. This indicates a decrease in percentage soil organic content and the percentage sand fraction in the soil, and an increase in the percentage clay fraction in the soil with an increase in depth below the soil surface. With an increase in distance inland from the estuary channel, the percentage clay fraction in the soil and the depth to groundwater increased, whereas soil electrical conductivity decreased.

Rainfall and season were the variables that showed the strongest correlations with other variables. Soil electrical conductivity, groundwater electrical conductivity and depth to groundwater all decreased with an increase in rainfall and a change of season (winter). Water column electrical conductivity ($42 - 57 \text{ mS.cm}^{-1}$) was generally lower than that of the soil ($31.7 - 114.83 \text{ mS.cm}^{-1}$) and the groundwater ($47.73 - 108.1 \text{ mS.cm}^{-1}$). Thus both rainfall and the salinity of the estuary water were found to influence soil electrical conductivity. Groundwater electrical conductivity was positively correlated with depth to groundwater, indicating an increase in groundwater electrical conductivity with an increase in depth to groundwater. Groundwater electrical conductivity also increased with an increase in soil electrical conductivity. The percentage silt fraction in the soil was negatively correlated to percentage sand and clay fraction in the soil, indicating that the percentage silt fraction decreased with an increase in percentage clay and sand fraction. Soil with a high clay fraction was associated with low electrical conductivity. These sites occurred furthest from the estuary channel and were associated with supratidal salt marsh.

In the Kromme Estuary (Table F-4), depth below the soil surface was negatively correlated with percentage soil organic content and the percentage sand and clay fraction in the soil, and positively correlated with the percentage silt fraction in the soil. This indicates a decrease in percentage soil organic content and the percentage sand and clay fraction in the soil, and an increase in the percentage silt fraction in the soil with an increase in depth below the soil surface. With an increase in distance inland from the estuary channel, the depth to groundwater increased, whereas soil moisture content decreased. Percentage silt fraction in the soil was the variable that showed the strongest correlations with other variables. Soil organic content and percentage clay and sand fraction all decreased with an increase in percentage silt fraction in the soil. Groundwater electrical conductivity and depth to groundwater both decreased with an increase in rainfall and a change of season (winter). Groundwater electrical conductivity was positively correlated with depth to groundwater, indicating an increase in groundwater electrical conductivity with an increase in depth to groundwater. Groundwater electrical conductivity also increased with an increase in soil electrical conductivity. Percentage clay fraction in the soil increased with a decrease in soil electrical conductivity. Similar relationships were thus found in the Geelhoutboom and Kromme salt marshes. However, the relationships between season, rainfall and soil- and groundwater electrical conductivity were stronger in the Geelhoutboom tributary. The reason for this is that the Geelhoutboom salt marsh was drier than the Kromme salt marsh, since the Kromme salt marsh had a larger submerged/lower intertidal area. Therefore rainfall has a greater effect on the Geelhoutboom salt marsh. An increase in rainfall will therefore reduce soil- and groundwater electrical conductivity by a greater percentage in the Geelhoutboom tributary.

Table F-3 Correlations among physico-chemical variables for the Geelhoutboom tributary over both sampling periods. (Percentage soil moisture content (% Moist), percentage soil organic content (% OC), soil electrical conductivity (EC), percentage clay fraction of the soil (% Clay), percentage sand fraction of the soil (% Sand), percentage silt fraction of the soil (% Silt), groundwater electrical conductivity (GWEC), depth to groundwater (GW Depth), rainfall (Rain), seasons (Season), distance from estuary channel (Distance) and depth below soil surface (Depth). Significant correlations, spearman r, are those for $p < 0.05$; $n = 348$).

	% Moist	% OC	EC	% Clay	% Sand	% Silt	GWEC	GW Depth	Rain	Season	Distance	Depth
% Moist	-											
% OC	N/S	-										
EC	N/S	N/S	-									
% Clay	N/S	N/S	-0.38	-								
% Sand	N/S	N/S	N/S	N/S	-							
% Silt	N/S	N/S	N/S	-0.4	-0.8	-						
GWEC	N/S	N/S	0.67	N/S	N/S	N/S	-					
GW Depth	N/S	N/S	N/S	N/S	N/S	N/S	0.51	-				
Rain	N/S	N/S	-0.85	N/S	N/S	N/S	-0.86	-0.44	-			
Season	N/S	N/S	-0.85	N/S	N/S	N/S	-0.86	-0.44	N/S	-		
Distance	N/S	N/S	-0.46	0.40	N/S	N/S	N/S	0.51	N/S	N/S	-	
Depth	N/S	-0.80	N/S	0.45	-0.39	N/S	N/S	N/S	N/S	N/S	N/S	-

Table F-4 Correlations among physico-chemical variables for the Kromme Estuary over both sampling periods. (Percentage soil moisture content (% Moist), percentage soil organic content (% OC), soil electrical conductivity (EC), percentage clay fraction of the soil (% Clay), percentage sand fraction of the soil (% Sand), percentage silt fraction of the soil (% Silt), groundwater electrical conductivity (GWEC), depth to groundwater (GW Depth), rainfall (Rain), seasons (Season), distance from estuary channel (Distance) and depth below soil surface (Depth). Significant correlations, spearman r, are those for $p < 0.05$; $n = 336$).

	% Moist	% OC	EC	% Clay	% Sand	% Silt	GWEC	GW Depth	Rain	Season	Distance	Depth
% Moist	-											
% OC	0.69	-										
EC	N/S	N/S	-									
% Clay	0.55	0.81	N/S	-								
% Sand	N/S	0.46	N/S	0.77	-							
% Silt	N/S	-0.48	N/S	-0.78	-0.99	-						
GWEC	N/S	N/S	N/S	N/S	N/S	N/S	-					
GW Depth	-0.54	N/S	N/S	N/S	N/S	N/S	0.67	-				
Rain	N/S	N/S	N/S	N/S	N/S	N/S	-0.45	-0.40	-			
Season	N/S	N/S	N/S	N/S	N/S	N/S	-0.45	-0.40	N/S	-		
Distance	-0.64	N/S	N/S	N/S	N/S	N/S	N/S	0.71	N/S	N/S	-	
Depth	N/S	-0.81	N/S	-0.75	-0.57	0.59	N/S	N/S	N/S	N/S	N/S	-

2.3 Discussion

The salt marsh vegetation of the Kromme Estuary was distributed in three distinct zones i.e. submerged vegetation, intertidal salt marsh and supratidal salt marsh. Submerged vegetation refers to plants growing entirely under water or exposed at low tide e.g. eelgrass *Zostera capensis*. Intertidal salt marsh occurs between the high and low water marks, whereas supratidal salt occurs above the high water mark. In other words, this area does not receive daily tidal inundation, but is normally flooded during spring tide and other associated high water levels (Bornman, 2002). *Zostera capensis* was the dominant species in the submerged zone. This species occupies the mudflats of the intertidal and shallow subtidal zone in permanently open South African estuaries (Adams, 1991).

Sarcocornia decumbens was the dominant species in the intertidal zone. This species generally occupies the mid and upper levels of estuarine salt marshes (O' Callaghan, 1992). *Sarcocornia pillansii* was the dominant species in the supratidal zone. This species is dominant in most of the supratidal areas in South African estuaries (Adams *et al.*, 1999). *Sarcocornia* species are good indicators of the salt concentration within the soil, i.e. these plants would indicate that surface soils have low enough salt concentrations for germination of certain terrestrial plants, but that it was at a concentration high enough to stunt their growth (Bornman, 2002). Thus the environmental variables would have less of an effect on the distribution of these species as they are adapted to tolerate such a wide range of variables (Muir, 2000).

Salt marsh zonation is determined by the spatial and temporal variation in physico-chemical soil properties (Van Diggelen, 1991, Bornman, 2002). Therefore to obtain a better understanding of the freshwater requirements of salt marsh in the Kromme Estuary, changes in vegetation cover and edaphic conditions were studied over time and space. From the results obtained in this survey, it is clear that certain environmental variables influence the distribution of salt marsh vegetation. These variables were distance from the estuary channel, groundwater electrical conductivity, depth to groundwater, rainfall, percentage clay fraction in the soil and season.

The supratidal macrophytes *Sarcocornia pillansii*, *Disphyma crassifolium* and *Sporobolus virginicus* were influenced by high rainfall. According to Adams *et al.* (1992) these species are usually associated with low moisture content due to limited tidal flushing occurring in this area, thus rainfall and evaporation are more important in influencing the distribution of these species. This implies that the supratidal communities are independent of the adjacent estuarine water body. Freshwater inputs into the system are therefore expected to have little influence on supratidal communities, except during floods when water levels are raised. Periodic floods are probably important in flushing out salts from this habitat.

Only two intertidal salt marsh species showed a response to rainfall, i.e. *Sarcocornia decumbens* and *Limonium linifolium*. These species are mostly confined to the mid to upper levels of estuarine salt marshes. Statements about the marsh elevation at which weather conditions start to influence soil salinity have been made by Beetrink (1977). Based on visual interpretation of long-term soil salinity data sets collected along intertidal gradients, they concluded that soil salinity becomes increasingly influenced by the weather conditions from the mean high watermark upward. De Leeuw *et al.* (1991) analysed the marsh elevation dependence of the relationship of soil salinity with the salinity of the flooding waters and with the weather conditions. They found that weather conditions do not influence the production of salt marsh plant communities below mean high water, but their influence becomes significant moving upward from mean high water. Adams (1991) found that sediment salinities of the intertidal macrophyte communities were determined by the salinity of the adjacent water body. Fluctuations in water column salinity would therefore raise and lower sediment salinities. This would influence macrophyte germination and growth.

The supratidal macrophytes were associated with low soil and groundwater electrical conductivity, increased distance from the estuary channel and an increase in depth to groundwater, whereas the opposite was true for the intertidal species. Various authors have shown that salinity decreases with increasing elevation and decreased tidal flushing (Bertness and Ellison, 1987; Adam, 1981;

Adams, 1991). Adams (1991) found that in the Gamtoos Estuary, supratidal salt marsh communities were characterised by low salinities and low sediment water contents as these communities were found in higher less well flooded areas. Bornman (2002) found that depth to the water table had the greatest influence on vegetation distribution in the Olifants Estuary. Elevation and distance from the estuary channel influenced the distribution of *Sarcocornia pillansii* through their influence on the depth to groundwater. The depth to groundwater increases with an increase in distance from the estuary channel and a higher elevation. Therefore depth to the water table was a factor of elevation and distance. Bornman (2002) showed that the cover abundance of *Sarcocornia pillansii* was visibly reduced where the water table was deeper than 1.5m and/or where the electrical conductivity of the groundwater was accessible and had a high ion concentration ($> 80 \text{ mS.cm}^{-1}$). Sanchez *et al.* (1998) and Rogel *et al.* (2001) found that groundwater salinity had a greater influence on the zonation of vegetation than water table depth in the intertidal area. This may be due to the fact that the depth to groundwater table in the intertidal zone is an insignificant variable to consider as moisture availability is not a problem due to daily tidal inundation.

The Kromme Estuary has relatively high surface sediment electrical conductivity when compared to other estuaries (Table F-5). Muir (2000) found that electrical conductivity in the Knysna Estuary only reached approximately 55 mS.cm^{-1} during the study period, whereas the surface sediment of the Kromme Estuary reached more than double that value (115 mS.cm^{-1}). The surface electrical conductivity of the Kromme Estuary compares better with west coast estuaries such as the Olifants and Orange estuaries. The low rainfall of the west coast results in higher surface electrical conductivity in this area. The consistent high salinities in the Kromme Estuary have resulted in the accumulation of salts in the intertidal region. This was characterised by numerous bare sandy patches (Figure F-19) in the salt marsh. At salinities greater than 20 ppt, germination of macrophytes is restricted (Chapman, 1976) and productivity (Barbour and Davis, 1969; Phleger, 1971; Price *et al.*, 1988), growth, density and species diversity are reduced (Ungar, 1974). The germination requirements of common high marsh plants was investigated by Shumway and Bertness (1992). They found that except for one notably patch-dependent fugitive species – *Salicornia*, the germination of high marsh plants is strongly inhibited by the high soil salinities routinely encountered in natural bare patches. Sediment salinities were higher in the Kromme Estuary in February 2004 (summer) than July (winter). Adams (1991) found similar responses. This may indicate increased evaporation and accumulation of salt during the summer months. In 1990 Adams *et al.* (1992) found that no salt marsh plants grew in areas with high sediment salinity (> 45 ppt).

Table F-5 A comparison of surface sediment electrical conductivity between four estuaries.

Estuary	Sediment Electrical Conductivity (mS.cm^{-1})
Kromme	17.76-114.83
Knysna	0-55
Olifants	17.6-98.6
Orange	10.42-103.97



Figure F-19 An example of bare patches in an intertidal salt marsh in the Kromme Estuary.

Seasonal vegetation changes in the Kromme Estuary were limited to the die-back of the annual *Salicornia virginicus* and the decrease in abundance of *Triglochin* species in winter. Both these species often colonise open areas and dried out pools of water where evaporation would result in high salinity (Muir, 2000). Therefore sampling during the summer months would be more representative of the species that occur in the salt marsh.

In summary, rainfall and tidal inundation are both important in regulating salt marsh salinities in the Kromme Estuary. In the past more frequent flooding by freshwater may have reduced sediment and groundwater salinity. However, because of a lack of historical data it is difficult to say whether salinity has increased over time.

3. B. SPECIES RICHNESS, PRESENT AND PAST DISTRIBUTION AND AREA COVERED BY THE DIFFERENT PLANT COMMUNITY TYPES

3.1 Methods and materials

From the available literature and the field surveys in 2004 the species richness and present distribution of macrophytes in the Kromme Estuary were described. Aerial photographs and field observations were used to create one past (1942) and one present (2004) vegetation map to depict any changes that have occurred over time. The maps were digitised in Arcview GIS. The smallest possible unit that could be accurately mapped was 25 m² in the 2004 vegetation map and 50 - 100 m² in the 1942 map. Small reed beds and other fringing vegetation could therefore not be mapped accurately.

3.2 Results and discussion

3.2.1 Species richness

Seven of the nine possible exclusive plant community types occur in the Kromme Estuary with only the subtropical swamp forest and mangrove communities being absent. The large intertidal salt marsh areas are important as only 18% of South African estuaries are permanently open and these marshes are considered to be rare.

Adams (1991) calculated Shannon-Weaver diversity indices (H') for the macrophytes in the Kromme and adjacent estuaries (Table F-6). Species diversity in the larger permanently open estuaries (Kromme and Gamtoos) was higher than the small temporarily open closed estuaries (Seekoei and Kabeljous). The Kromme Estuary had a higher species diversity than the Gamtoos because of the larger intertidal areas and well established salt marshes. Diversity was higher in summer than winter. This is mainly due to evaporation and an increase in salinity that reduces the salt marsh area in summer.

Salt marsh in general has a low species diversity compared to terrestrial habitats. It seems that this is because highly saline areas have few competitors (Macke and Ungar, 1971). The species that were recorded by Day (1981), Bickerton and Pierce (1988) and Adams *et al.* (1992) were similar to what was found in this study.

Table F-6 Shannon-Weaver diversity indices (H') for the Kromme, Gamtoos, Seekoei and Kabeljous estuaries (Adams 1991).

	March 1990	August 1990
Kromme	1.017	1.007
Gamtoos	0.995	0.988
Seekoei	0.708	0.715
Kabeljous	0.792	0.806

3.2.2 Submerged macrophytes

Zostera capensis (eelgrass) is the dominant species occurring from the lower reaches of the estuary and extending into the upper reaches. These beds range from sparse stands on the sand banks in the mouth region to dense stands in the protected creeks of the salt marshes and in the middle and upper reaches of the estuary. Adams and Talbot (1992) reported an increase in biomass from the mouth to the upper reaches (155 – 303 g m⁻²) in 1990.

There has been a steady increase in the area covered by *Zostera* since 1942 (10.8 ha), 1980 (13.7 ha), 1989 (21.7 ha) to 30.98 ha recorded in this study from aerial photographs in 2000. During the period 1980 to 1989 there was a four-fold increase in the biomass of eelgrass (Adams and Talbot 1992). This was related to reduced freshwater inflow, lack of scouring and sedimentary

disturbances, stable salinity values and reduced turbidities (Adams and Talbot 1992). The attenuation of floods has reduced the dynamic nature of the estuary and the associated increase in stability has favoured encroachment by *Zostera*. Prior to the construction of the Impofu dam, Hanekom and Baird (1988) found that fluctuations in biomass were related to flood events.

Zostera capensis is highly susceptible to destruction by bait collectors and boats. Boating activity may stir up bottom sediments that could impact the submerged macrophytes (*Zostera capensis*) reducing both cover and biomass. Hanekom (1982) attributed the lower biomass of *Z. capensis* in the Kromme Estuary after the December-January summer holiday season to increased human disturbance rather than water temperature differences. Boat activity can also cause the erosion of salt marshes. There is some evidence of this in the middle reaches of the estuary. Bickerton and Pierce (1988) reported that the recreational carrying capacity in the mouth area of the Kromme Estuary was already exceeded. Since then development and the number of people using the estuary has increased exponentially.

3.2.3 Macroalgae

Numerous marine macroalgae are found in the estuary, particularly in quiet sheltered areas. The lack of flushing and stable high salinity conditions has increased colonisation by these algae, particularly *Codium tenue* and *Gracilaria verrucosa*. Most of the algae are free floating except for the green alga *Caulerpa filiformis*, which grows rooted in the sandy bottom of the estuary in the lower-middle reaches. In 1989 it covered an area of 2.3 ha. The change in area over time for macroalgae has not been reported on, as it is difficult to distinguish this community type on aerial photographs. In many cases the macroalgal and *Zostera capensis* habitat overlap.

Adams and Talbot (1992) found large mats of *Ectocarpus* spp. and clumps of *Gracilaria verrucosa*, *Enteromorpha* sp. *Codium tenue* and *Hypnea viridis* in the middle- upper reaches of the estuary. In some cases there was a 50:50 ratio of macroalgal species to *Zostera capensis*. Field observations in 2004 indicate a similar situation. At some sites the macroalgae appear to be outcompeting *Zostera*. Filamentous green algae such as *Ulva* spp. form dense mats of entangled filaments over the *Zostera* beds, smothering them and decreasing available light. *Gracilaria verrucosa* was abundant and had an average biomass of $11.8 \pm 6.3 \text{ g m}^{-2}$ in the middle reaches of the estuary at the new communal jetty site. A dominant invertebrate was the sea hare, *Bursatella leachi africana*, (3 individuals m^{-2}) (Figure F-20).



Figure F-20 *Zostera capensis* interspersed with *Codium tenue* and filamentous green algae. Many sea hares (*Bursatella leachi africana*) were found grazing on these plants in August 2004.

3.2.4 Salt marsh

Salt marsh covers 81.237 ha in the Kromme Estuary. The largest salt marsh occurs on the seaward side of the road bridge on the eastern bank approximately 2 km from the mouth. Dominant plants here include the intertidal plants, *Spartina maritima*, *Chenolea diffusa*, *Sarcocornia decumbens*, *S. perennis*, *Limonium linifolium* and the supratidal species *Sarcocornia pillansii*. Small isolated salt marshes also occur further upstream on the west bank (4 km from the mouth) and on the east bank about 2 km from the head of the estuary. Salt marshes extend into the middle-upper reaches of the Geelhoutboom tributary. Small patches of reeds and other brackish species such as *Cotula coronopifolia* occur here as well.

The area covered by salt marsh has decreased by 17%, in spite of an overall increase in the lower reaches. The construction of the road bridge and numerous resort developments in the floodplain has resulted in the loss of 17 ha of salt marsh. There is some evidence of salt marsh erosion in the middle reaches of the estuary due to boat activity. Despite all these changes the large intertidal salt marshes areas have remained relatively intact, as they are dependent on an open mouth and daily tidal exchange.

High water column salinity and lack of flushing by floods may have resulted in salt accumulation in the salt marshes. Bare patches were evident in the salt marshes in the middle / upper reaches of the estuary.

3.2.5 Reeds and sedges

Reed beds occur upstream of the road bridge on the south bank, and in small streams and tributaries feeding the estuary in the middle-upper reaches. Reeds can survive tidal inundation with saline water as their roots and rhizomes are located in brackish water (Adams and Bate, 1999). The upper reaches of the Kromme Estuary are rocky and therefore extensive reed beds would not occur there naturally. However, reeds were probably more extensive in the Geelhoutboom tributary when salinity was lower.

The total area covered by reeds and sedges has decreased by 0.07% over the last 62 years (Table F-7). This is due to the loss of a large area (7.2 ha) of *Phragmites* near the village of St. Francis (Figure F-21 and Figure F-22). Ignoring the loss of this inland reedbed, one finds that there was actually an increase of over 6 ha in the estuary itself.

Table F-7 Differences in community type cover between 1945 and 2004.

Community Types	1942 (ha)	2004 (ha)
Reeds and sedges	13.920	12.952
Salt marsh	98.245	81.237
<i>Zostera capensis</i>	10.774	30.984
Sandbanks	145.667	89.644

3.2.6 Sand and mudbanks

Sand and mudbanks have decreased by over 56 ha since 1942 (Table F-7). These losses could be due to the following:

- Decreased flushing of the estuary (due to dam construction) aids the establishment of salt marsh and *Zostera* on the sand banks. This also explains the increase in *Zostera* in the system and the spread of the salt marsh in the lower reaches.
- Reduced sand input into the estuary from the Sand River system.
- Reduced sand input into the estuary through the mouth due to decreased sand supply along the beaches of St Francis Bay (a result of the stabilisation of the Oyster Bay St Francis Headland Bypass Dunefield).

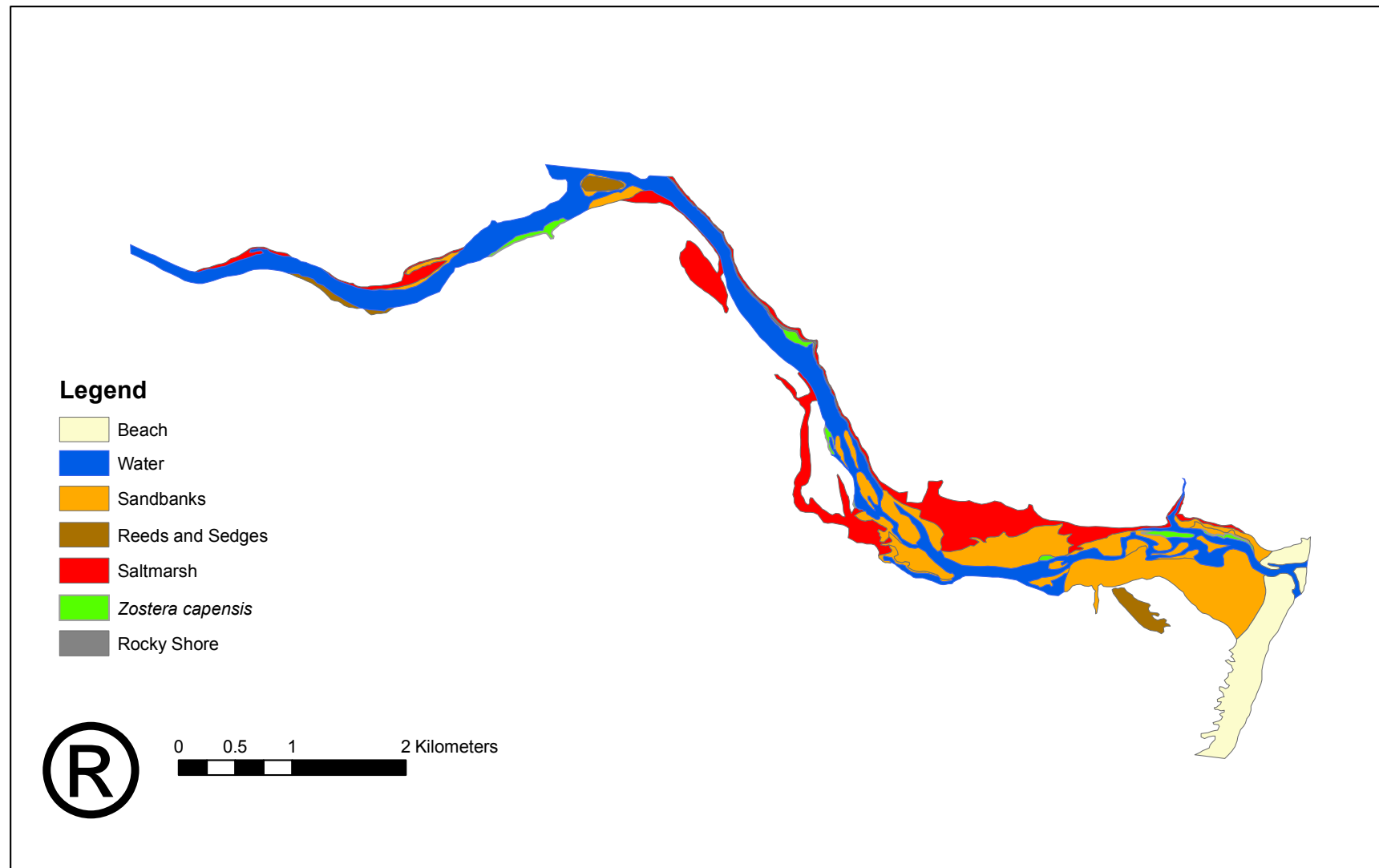


Figure F-21 Distribution of vegetation in the Kromme Estuary in 1942

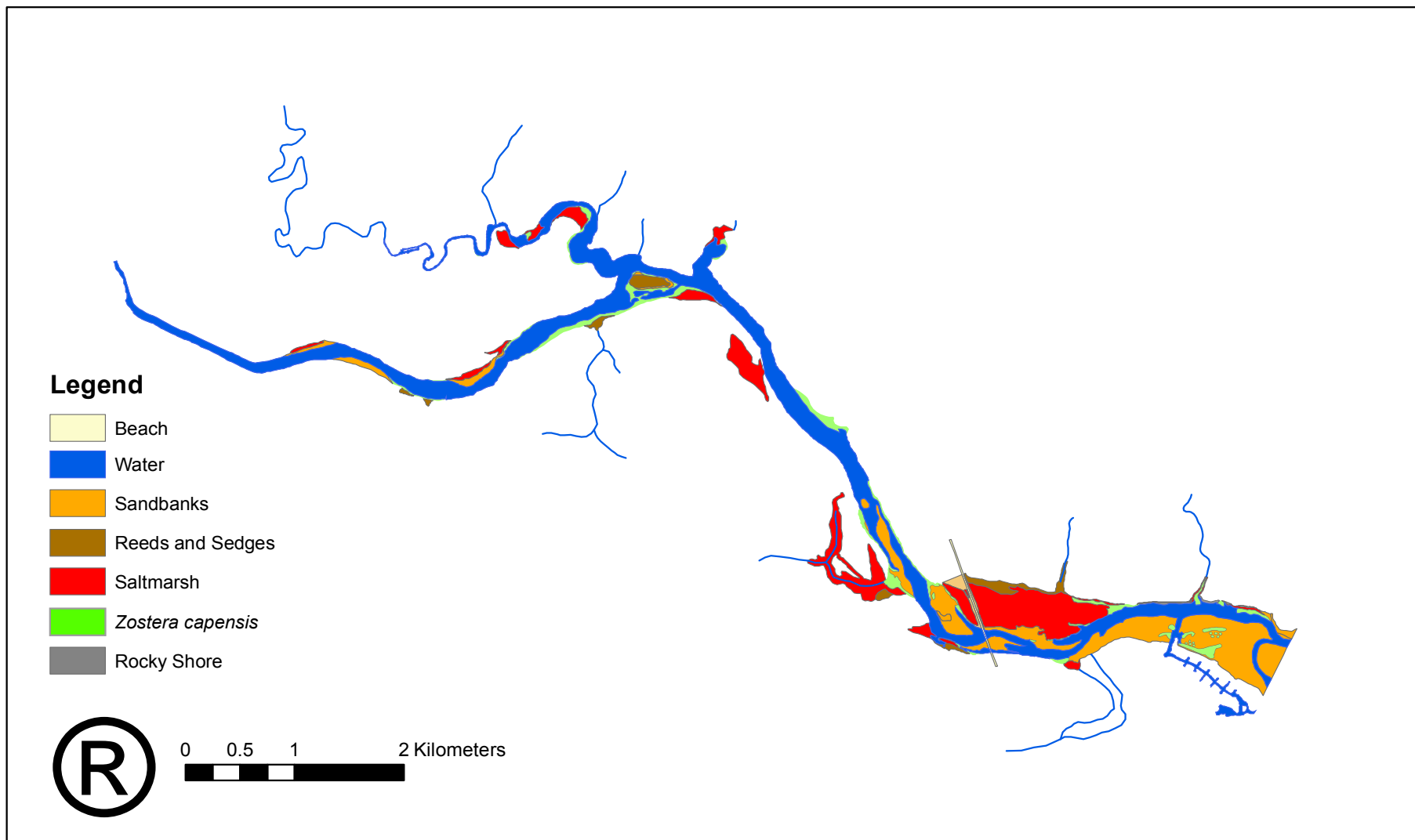


Figure F-22 Distribution of vegetation in the Kromme Estuary and Geelhoutboom Tributary in 2004

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ATTACHMENT A^F

Species List

Table 1 List of species, authorities, families and abbreviations as used in the text.

Genus	Species	Authority	Family	Abbreviation
<i>Chenolea</i>	<i>diffusa</i>	Thunb.	Chenopodiaceae	Chendif
<i>Disphyma</i>	<i>crassifolium</i>	(L.) L. Bol.	Mesembryanthemaceae	Dispcra
<i>Gracilaria</i>	sp.	-	-	Gracsp
<i>Limonium</i>	<i>linifolium</i>	(Thunb.) Kuntze	Plumbaginaceae	Limolin
<i>Linum</i>	<i>species</i>	-	-	Linusp
<i>Salicornia</i>	<i>meyeriana</i>	-	-	Salivir
<i>Sarcocornia</i>	<i>decumbens</i>	(Toelken) A.J. Scott	Chenopodiaceae	Sarcdec
<i>Sarcocornia</i>	<i>pillansii</i>	(Moss) A.J. Scott	Chenopodiaceae	Sarcpil
<i>Spartina</i>	<i>maritima</i>	(Curtis) Fernald	Poaceae	Sparmar
<i>Sporobolus</i>	<i>virginicus</i>	(L.) Kunth.	Poaceae	Sporvir
<i>Triglochin</i>	<i>bulbosa</i>	L.	Juncaginaceae	Trigbul
<i>Triglochin</i>	<i>striata</i>	Ruiz & Pav.	Juncaginaceae	Trigstr
<i>Zostera</i>	<i>capensis</i>	Setchell	Zosteraceae	Zostcap

ATTACHMENT B^F

Sediment Characteristics

Table 1 Sediment characteristics for both transects sampled in the Geelhoutboom tributary during summer (Zones = distance from estuary channel; Zone 1 = 30 m; Zone 2 = 80 m; Zone 3 = 120m.).

	GEELHOUTBOOM TRANSECT 1									GEELHOUTBOOM TRANSECT 2								
	Zone 1			Zone 2			Zone 3			Zone 1			Zone 2			Zone 3		
Depth below surface (m)	0-0.05	0.05-0.15	1-1.2	0-0.05	0.05-0.15	1-1.2	0-0.05	0.05-0.15	1-1.2	0-0.05	0.05-0.15	1-1.2	0-0.05	0.05-0.15	1-1.2	0-0.05	0.05-0.15	1-1.2
Sediment moisture content (%)	27.95	-	-	20.35	16.78	16.12	15.68	11.36	8.66	30.15	-	-	23.40	15.45	19.14	14.18	9.60	-
Sediment organic content (%)	3.50	-	-	4.70	4.16	2.47	4.84	2.78	1.64	3.72	-	-	5.44	2.89	3.35	3.72	2.29	-
Sediment electrical conductivity (mS.cm ⁻¹)	37.13	-	-	25.47	22.05	20.02	22.34	17.76	22.47	36.40	-	-	34.67	35.30	43.50	31.03	31.67	-
% Sand fraction of sediment	89.55	-	-	31.84	47.65	56.74	31.90	50.34	49.14	40.07	-	-	52.83	38.54	39.66	57.98	62.07	-
% Silt fraction of sediment	0.00	-	-	47.34	24.33	0.00	49.93	19.03	22.85	31.09	-	-	19.77	20.20	27.74	16.64	5.97	-
% Clay fraction of sediment	10.45	-	-	20.81	28.02	43.26	18.17	30.63	28.02	28.83	-	-	27.40	41.27	32.60	25.39	31.96	-
Groundwater electrical conductivity (mS)	-	-	54.30	-	-	52.77	-	-	58.60	-	-	47.30	-	-	56.50	-	-	-
Depth to water table (m)	-	-	0.04	-	-	0.25	-	-	0.58	-	-	0.09	-	-	0.23	-	-	-

Table 2 Sediment characteristics for both transects sampled in the Geelhoutboom tributary during winter (Zones = distance from estuary channel; Zone 1 = 30 m; Zone 2 = 80 m; Zone 3 = 120m.).

	GEELHOUTBOOM TRANSECT 1									GEELHOUTBOOM TRANSECT 2								
	Zone 1			Zone 2			Zone 3			Zone 1			Zone 2			Zone 3		
Depth below surface (m)	0-0.05	0.05-0.15	1-1.2	0-0.05	0.05-0.15	1-1.2	0-0.05	0.05-0.15	1-1.2	0-0.05	0.05-0.15	1-1.2	0-0.05	0.05-0.15	1-1.2	0-0.05	0.05-0.15	1-1.2
Sediment moisture content (%)	6.33	8.02	10.76	11.12	13.04	18.13	15.58	20.54	18.65	20.4	20.28	13.1	26.58	19.59	10.36	9.57	-	-
Sediment organic content (%)	2.95	3.24	2.00	5.18	2.32	1.71	4.18	2.01	1.26	3.48	2.95	2.23	6.46	4.30	1.37	4.26	-	-
Sediment electrical conductivity (mS.cm ⁻¹)	114.83	72.83	57.30	79.77	59.67	42.60	60.90	48.60	47.87	74.87	63.10	97.73	87.37	65.90	47.00	57.93	-	-
% Sand fraction of sediment	32.71	28.20	17.05	42.58	10.76	16.39	23.68	24.10	23.79	50.97	37.61	58.17	60.32	46.83	29.89	34.14	-	-
% Silt fraction of sediment	51.20	54.45	76.61	38.58	70.46	72.61	66.07	58.60	44.32	31.67	46.94	38.17	21.56	26.44	49.85	53.60	-	-
% Clay fraction of sediment	16.1	17.35	6.34	18.83	18.78	10.99	10.24	17.3	31.88	17.36	15.45	3.66	18.12	26.73	20.26	12.27	-	-
Groundwater electrical conductivity (mS)	-	-	87.03	-	-	85.33	-	-	108.10	-	-	73.37	-	-	82.60	-	-	-
Depth to water table (m)	-	-	0.23	-	-	0.50	-	-	1.00	-	-	0.50	-	-	0.93	-	-	-

Table 3 Sediment characteristics for both transects sampled in the Kromme Estuary during summer (Zones = distance from estuary channel; Zone 1 = 10 m; Zone 2 = 50 m; Zone 3 = 90m.).

	KROMME TRANSECT 1									KROMME TRANSECT 2								
	Zone 1			Zone 2			Zone 3			Zone 1			Zone 2			Zone 3		
Depth below surface (m)	0-0.05	0.05-0.15	1-1.2	0-0.05	0.05-0.15	1-1.2	0-0.05	0.05-0.15	1-1.2	0-0.05	0.05-0.15	1-1.2	0-0.05	0.05-0.15	1-1.2	0-0.05	0.05-0.15	1-1.2
Sediment moisture content (%)	17.46	8.57	7.87	11.77	12.19	10.43	7.36	7.04	8.28	24.18	10.97	10.72	14.27	11.30	9.15	8.33	8.20	8.20
Sediment organic content (%)	2.97	0.92	0.53	1.59	1.94	1.13	1.69	0.84	0.80	4.60	1.57	0.77	2.74	1.68	1.02	2.05	1.44	0.62
Sediment electrical conductivity (mS.cm ⁻¹)	46.60	42.30	43.90	49.10	51.50	46.60	69.90	62.50	34.50	49.67	34.67	31.70	48.73	43.93	44.57	35.60	35.50	42.97
% Sand fraction of sediment	39.40	24.55	8.23	12.33	13.59	20.24	19.81	9.77	6.97	33.15	7.60	6.97	20.93	26.49	12.96	33.92	28.20	7.60
% Silt fraction of sediment	40.56	64.55	87.48	79.36	74.19	67.61	76.40	85.80	88.70	51.45	83.48	88.70	67.59	59.39	80.76	58.43	61.09	88.74
% Clay fraction of sediment	20.04	10.89	4.29	8.31	12.22	12.15	3.80	4.43	4.34	15.39	8.92	4.34	11.48	14.12	6.28	7.66	10.71	3.66
Groundwater electrical conductivity (mS)	-	-	59.9	-	-	93.87	-	-	78.37	-	-	47.73	-	-	95.00	-	-	82.47
Depth to water table (m)	-	-	0.30	-	-	0.55	-	-	0.68	-	-	0.35	-	-	0.60	-	-	0.85

Table 4 Sediment characteristics for both transects sampled in the Kromme Estuary during winter (Zones = distance from estuary channel; Zone 1 = 10 m; Zone 2 = 50 m; Zone 3 = 90m.).

	KROMME TRANSECT 1									KROMME TRANSECT 2								
	Zone 1			Zone 2			Zone 3			Zone 1			Zone 2			Zone 3		
Depth below surface (m)	0-0.05	0.05-0.15	1-1.2	0-0.05	0.05-0.15	1-1.2	0-0.05	0.05-0.15	1-1.2	0-0.05	0.05-0.15	1-1.2	0-0.05	0.05-0.15	1-1.2	0-0.05	0.05-0.15	1-1.2
Sediment moisture content (%)	18.03	-	-	9.50	-	-	9.61	8.48	10.26	17.79	-	-	12.45	-	-	7.56	10.29	8.75
Sediment organic content (%)	2.66	-	-	1.51	-	-	2.29	1.21	1.32	2.84	-	-	2.12	-	-	1.21	1.73	0.45
Sediment electrical conductivity (mS.cm ⁻¹))	44.17	-	-	47.03	-	-	29.60	46.87	57.20	36.60	-	-	41.33	-	-	31.80	28.80	37.40
% Sand fraction of sediment	38.74	-	-	37.37	-	-	28.76	60.22	31.15	41.98	-	-	65.92	-	-	74.16	77.83	49.05
% Silt fraction of sediment	36.46	-	-	47.18	-	-	56.28	21.66	55.37	34.07	-	-	6.79	-	-	0.00	0.00	36.83
% Clay fraction of sediment	24.80	-	-	15.45	-	-	14.96	18.12	13.47	23.95	-	-	27.29	-	-	25.84	22.17	14.12
Groundwater electrical conductivity (mS)	-	-	50.40	-	-	57.80	-	-	55.17	-	-	55.10	-	-	66.10	-	-	62.17
Depth to water table (m)	-	-	0.30	-	-	0.25	-	-	0.51	-	-	0.27	-	-	0.22	-	-	0.56

APPENDIX G

INVERTEBRATES

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1. INTRODUCTION

An important characteristic distinguishing estuaries from adjacent sea and river habitats is the presence of salinity gradients. Along the estuary, this gradient may range from freshwater at the tidal head (near-zero salt content) to seawater at the mouth (salt concentration around 35 parts per thousand or 35 ppt). Vertical differences in salinity are also common, ranging from near zero at the surface to full seawater at the bottom in extreme cases. These gradients are dynamic, responding to changes in freshwater inflow, the degree of tidal mixing and bottom topography over different time scales; for example:

- the ebb and flow of the tides operate over time scales of a few hours,
- seasonal changes in evaporation and rainfall operate over time scales of months, and
- shifts between wet and dry cycles operate over time scales of years.

Tide-generated currents have a major influence on sediment characteristics and the type of organisms found along the estuary. Where strong currents prevail, the substrate will be coarse (sand or gravel). Finer particles (e.g. silt) settle where waters are calm and the currents weak. The state of the tidal inlet also exerts an influence on the salinity gradient. In South Africa, many estuaries close off periodically (about 72%) as a result of the accumulation of sediment in the lower estuary.

The variable nature of estuarine habitats, especially defined by fluctuating salinity and substrate type, make estuaries a stressful and rigorous environment in which to live. Estuarine organisms must cope with problems unlike those of plants and animals living in purely marine or fresh waters. In general, estuaries are inhabited by far fewer species compared to adjacent ecosystems, but they rank among the most productive environments on earth. This is only possible if estuaries maintain functional links with both rivers and the sea. Very few organisms are able to tolerate the full salinity range found in estuaries and are broadly separated into three groups:

- A marine associated component is the largest in terms of the number of species and are unable to tolerate, or barely able to tolerate salinity changes. This component is restricted to the tidal inlet region where salinity remains close to that of seawater.
- Typical estuarine organisms that are able to tolerate varying degrees of salinity reduction below 30 ppt and can penetrate some distance up-estuary. This category includes species restricted to estuaries. Many can tolerate salinity values down to about 15 ppt, with a few hardy species tolerating levels down to 3 ppt.
- Those organisms tolerant of low salinity values found at the top of the estuary where salinity does not exceed about 5 ppt.

Although naturally variable, salinity gradients in southern African estuaries are becoming increasingly modified because of freshwater attenuation. This is mainly due to the construction of large storage reservoirs. Together with many small dams in catchment areas, regulation of river systems is leading to a reduction in quantity, and a change in temporal availability of freshwater to many estuaries.

This study aims to provide the required background and data series so that the vertebrate component of the Comprehensive Reserve Determination of the Kromme Estuary can be undertaken. In particular, the available data and studies undertaken as part of this reserve determination are discussed in order to more fully understand the context (Present) State and what the system would have been like in the Reference Condition.

1.1 Characteristics of the Kromme River and catchment

The Kromme River rises some 95 kilometres from the sea in the Langkloof valley between the coastal Tsitsikamma Mountains and the Kouga range. Quartzite forms the largest part of the geological substrate in the catchment basin; the total area varying between 936 km² and 1125 km², depending on the source reference (Bickerton and Pierce, 1988).

Rainfall in the Kromme catchment is distributed throughout the year with spring and autumn peaks. Mean annual precipitation varies from 700 to 1200 mm. Flow patterns in the Kromme are erratic and floods have occurred in almost every month of the year (Bickerton and Pierce, 1988).

Two major reservoirs are located in the main catchment. The larger Impofu Dam (construction completed in 1983 with a capacity 100 x 106 m³) is 18 km from the coast and 4 km above the tidal head of the estuary. A second reservoir is located higher up in the catchment. The combined storage capacity of the two reservoirs is 133 x 106 m³, exceeding the MAR of 106 x 106 m³ from the catchment basin (DWAF, 1986). In addition, there are numerous farm dams situated on tributaries.

1.2 Characteristics of the Kromme Estuary

The 13.7 km long estuary has an approximate surface area of 300 ha. The estuary has one major tributary, the Geelhoutboom (Figures G-1 and G-3). Although constricted, the tidal inlet remains permanently open to the sea. Tides are semi-diurnal with a small diurnal inequality. Mean spring tide range outside the inlet is about 1.75 m, while neap tides average 0.57 m. A flood tidal delta extends 5 km from the mouth, but additional sand is derived from an adjacent dunefield. In the upper reaches the estuary is narrow and incised into bedrock. The lower estuary is shallow (<2 m depth); upstream water depth averages 3-4 m in the channel areas. Other physical characteristics of the estuary are given in Table G-1.

Table G-1 Physical characteristics of the Kromme Estuary. Data from Baird and Ulanowicz, 1993 and Bickerton and Pierce, 1988.

Length (km)	Width (m)	Depth (m)	Tidal prism
13.7	Maximum 175	Maximum 5	1.87 x 106 m ³
	Average 80	Average 2.5	

The Geelhoutboom tributary rises in the Humansdorp area where the underlying geological formation is Bokkeveld slate that is readily eroded (Reddering and Esterhuysen, 1983). Consequently, the Geelhoutboom River carries a relatively high sediment load when it enters the estuary about 8 km from the mouth. On occasions, fine sediment loading of the Geelhout tributary is exacerbated by runoff from farmlands adjacent to the river and estuary (Figure G-1).

The Kromme is an example of an estuary where freshwater inflow is significantly attenuated. Freshwater impoundments in the catchment have seriously reduced freshwater supply to the estuary and this has led to persistent marine dominance with little variation in water salinity along the estuary over prolonged periods of time (years). During dry periods, salinity in the upper estuary exceeds that of seawater. Attenuation of floods (frequency and intensity) by storage reservoirs has also resulted in excessive accumulation of marine derived sediment in the lower estuary. Sediment is therefore removed less frequently and only by large floods. Although occasional floods of sufficient magnitude scour estuarine channels, reservoirs in the Kromme catchment dampen or filter out all floods smaller than the 1-in-30 year event (Bickerton and Pierce, 1988).



Figure G-1 The confluence of the Geelhoutboom tributary and the main channel of the Kromme Estuary. The consequence of runoff from adjacent farmlands after heavy rains in the Geelhoutboom catchment is clearly visible. This tributary is possibly the main source of fine material into the estuary.

Sediments in the Kromme Estuary become progressively finer-grained in an upstream direction, mainly because of the decreasing velocity of tidal currents (Reddering and Esterhuysen, 1983). The fine muddy sediments in the middle and upper estuary have a fluvial origin, although the two large storage reservoirs probably stop most fluvial sediment input via the main tributary. Sediment input via the Geelhoutboom tributary will not be influenced by the reservoirs and fine material continues to be deposited into the estuary. According to Reddering and Esterhuysen (1983), the mixing of marine sand and mud results in a compact mass that is not easily removed by floods.

The lower reach of the estuary (ca 5 km) is relatively shallow and sandy with well-developed intertidal flats (Figure G-2). This section of the estuary is very dynamic and channels continually change their position. Most of this sand is of marine origin. A further source of sand influx is via the Sand River that enters the estuary approximately 2 km from the mouth (Figure G-2). The Sand River drains an extensive dune field to the southwest and carries sand into the lower estuary during occasional floods.



Figure G-2 Aerial view of the lower reaches of the Kromme Estuary. The building of two large reservoirs in the catchment has led to less frequent floods that are capable of removing sediment from the estuary. Sand is mostly of marine origin through the mouth, although some is deposited in the estuary via the Sand River flowing at times from the extensive dunefield seen on the left of the picture. This dunefield used to deposit sand where the marina is currently situated. Erosion along the dune complex separating the marina from the sea is also clearly visible.

2. PHYSICO-CHEMICAL CHARACTERISTICS

2.1 Salinity and temperature

Numerous studies since the 1970s have shown increased marine influence in summer with hypersaline conditions developing in the upper reaches of the estuary (Hecht, 1973; Baird *et al.*, 1981; Marais, 1983; Bickerton and Pierce, 1988; Wooldridge, 1999). Hanekom (1982), recorded salinity values during a three-year study of close to 35 ppt during each summer, with four floods (July-August 1979 and March and June 1981) flushing the estuary on each occasion. In 1979, surface salinity values in the upper reaches were still below 10 ppt two months after the August flood (Hanekom, 1982).

In summary, available data indicates that hypersaline conditions were recorded between 1972 and 1983 in the upper reaches of the Kromme Estuary and prior to completion of the Impofu Dam (the Elandsjacht Reservoir was already present). However, marine dominance has probably become more persistent because of the construction of the second reservoir only 4 km above the estuary.

Beginning 1988, a series of research programmes at the University of Port Elizabeth sampled invertebrates and collected physico-chemical data at ten sites in the main Kromme Estuary and Geelhoutboom tributary (Figure G-3). Data collected over 36 consecutive months (April 1988 – March 1991) again indicated marine dominance throughout the estuary, with hypersaline conditions present during the three of the four summers in the upper estuary (Figure G-4). The water column was generally well mixed, although stratification developed temporarily at times.

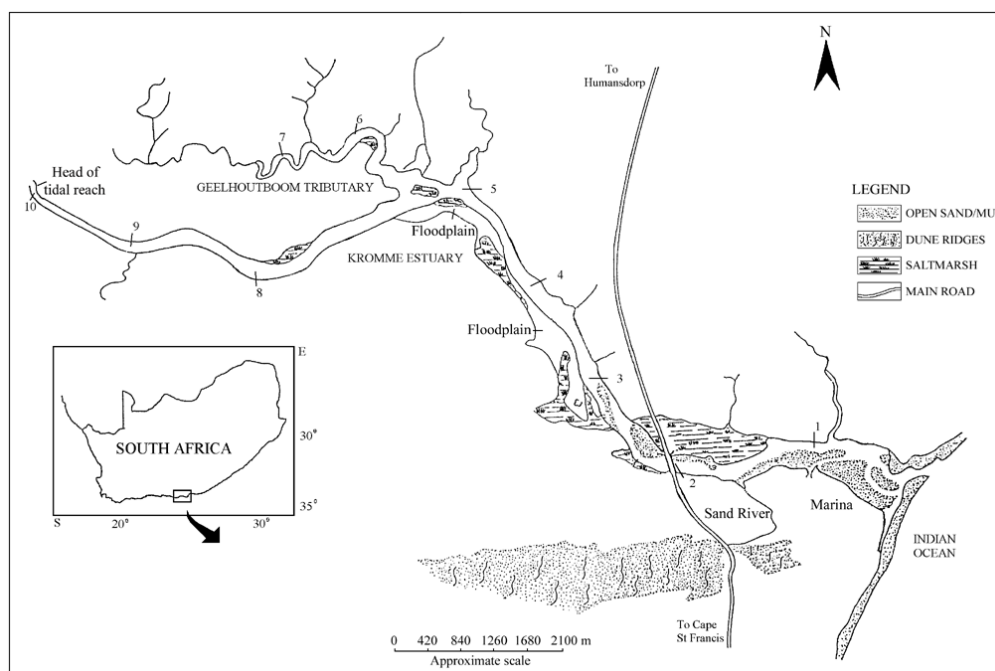


Figure G-3 Invertebrate sampling sites in the Kromme Estuary. In the earlier study (1988 – 1991), physico-chemical and zooplankton data were not collected at Sites 1-3.

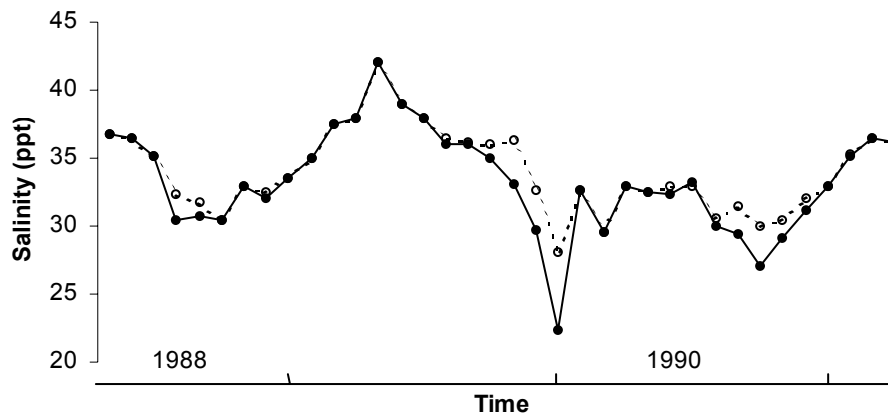


Figure G-4 Surface (solid line) and bottom (broken line) salinity at Station 10 (see Figure G-3) in the Kromme Estuary. Data were recorded monthly, starting April 1988 and terminating March 1991.

Salinity values at Station 4 (water depth 2 m) showed less variability compared to Station 10, (water depth 5 m) remaining close to 35 ppt most of the time. On occasions, hypersalinity developed (Figure G-4).

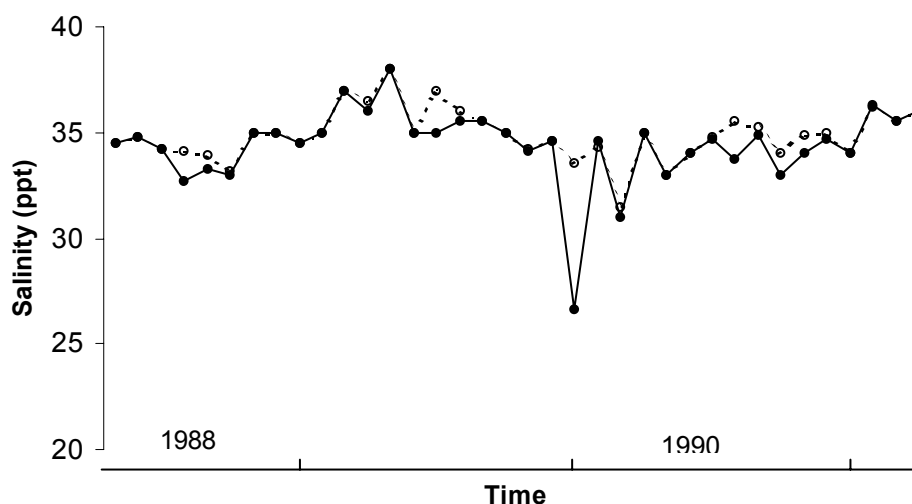


Figure G-5 Surface (solid line) and bottom (broken line) salinity at Station 4 (see Figure G-3) in the Kromme Estuary. Data were recorded monthly, starting April 1988 and terminating March 1991.

Salinity values in the Geelhoutboom tributary (Stations 6 and 7, Figure G-3) also showed no significant difference in comparison to salinity values recorded in the main tributary. Figure G-6 shows salinity values (integrated for the water column) recorded at the uppermost station in the Geelhoutboom (Station 7) compared to the uppermost station (Station 10) in the main tributary of the Kromme Estuary. Note that salinity values were sometimes higher in the Geelhoutboom.

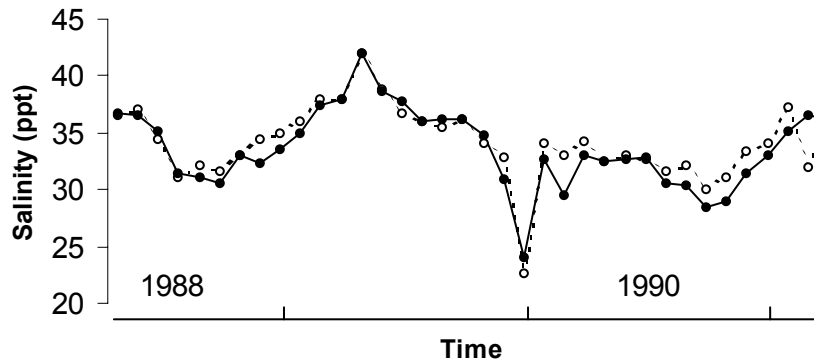


Figure G-6 A comparison of integrated water column salinity values recorded at the uppermost station in the Geelhoutboom (Station 7, dashed line and open circles) and Station 10 in the main Kromme tributary (solid line and closed circles). Data were recorded monthly, starting April 1988 and terminating March 1991.

Between May 1996 and July 1997 (15 months), a research programme again sampled on a monthly basis the same stations (Stations 4-10, Figure G-3). Two floods were experienced (November 1996 and April 1997), reducing surface salinity to below 5 ppt throughout much of the main estuary and Geelhout. Strong vertical stratification developed temporarily (particularly at Station 10 where water depth was 5 m), but was less marked in shallower parts of the estuary (Figures G-7 and G-8).

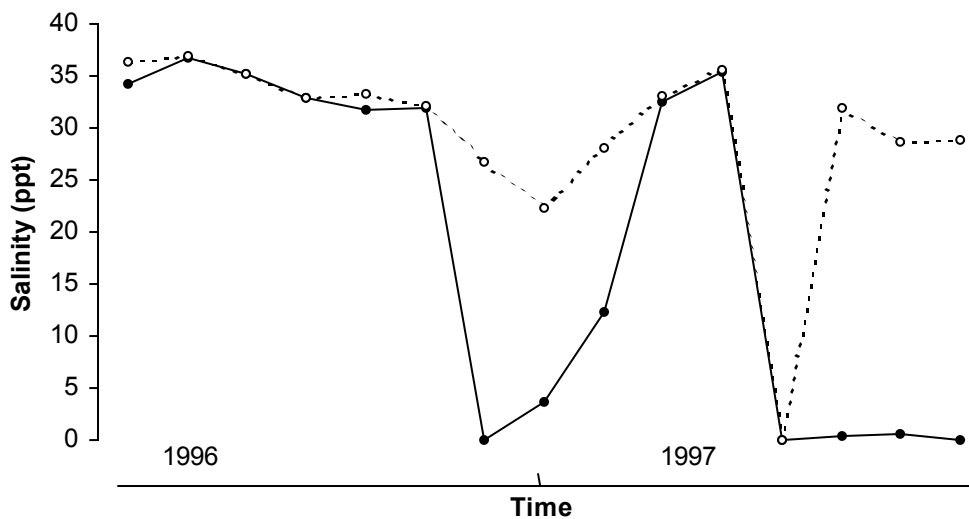


Figure G-7 Surface (solid line) and bottom (broken line) salinity at Station 10 (see Figure G-3) in the Kromme Estuary. Data were recorded monthly, starting May 1996 and terminating July 1998.

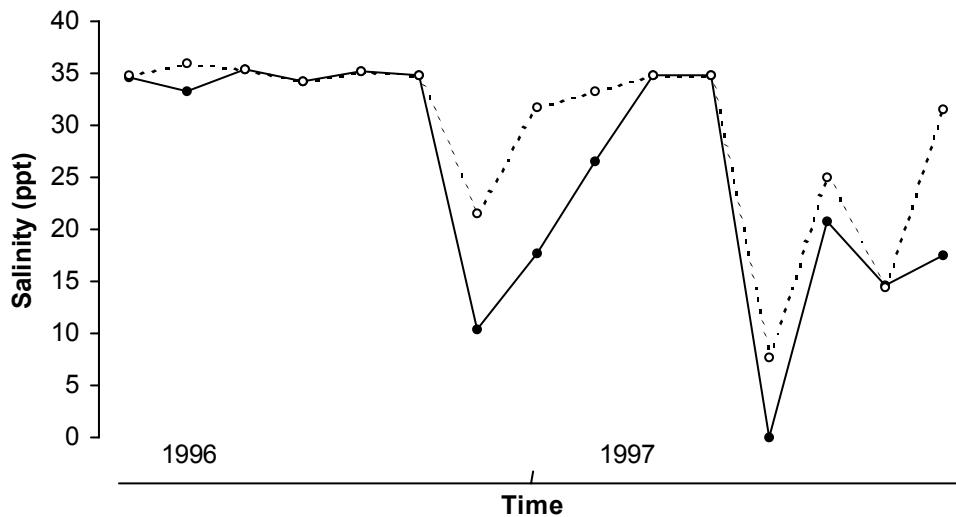


Figure G-8 Surface (solid line) and bottom (broken line) salinity at Station 4 (see Figure G-3) in the Kromme Estuary. Data were recorded monthly, starting May 1996 and terminating July 1998.

Water temperature in the Kromme Estuary ranges between 11 and 26°C (Figure G-9), although Hanekom (1982) reported water temperatures up to 28°C in summer. Figure G-9 shows that during the 1988 – 1991 study, Station 10 recorded a slightly higher range compared to the lower estuary (Station 4). Hecht (1973) reported only minor differences between the mean annual surface and bottom water temperatures (ca 0.5°C).

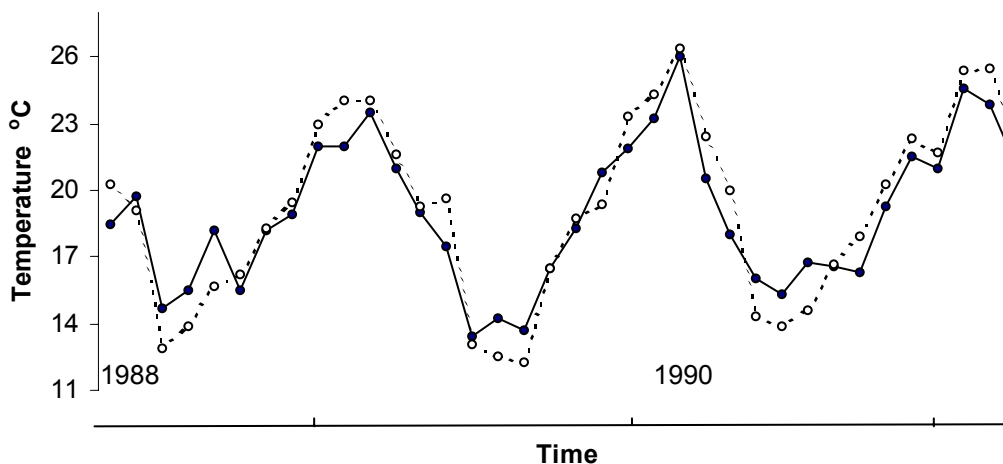


Figure G-9 A comparison of integrated water column temperature recorded at the uppermost station (Station 10, solid line and closed circles) and Station 4 in the lower Kromme Estuary (hatched line and open circles). Data were recorded monthly, starting April 1988 and terminating March 1991.

2.2 Nutrients

The nutrient status of the Kromme Estuary is low by comparison to other Eastern Cape estuaries (Emmerson *et al.* 1982). Similar conclusions were drawn by other authors (e.g. Bickerton and Pierce, 1988; Baird *et al.*, 1992). However, studies conducted in the marina canals indicate elevated levels of nitrates and phosphates during the summer holiday season when occupation of houses increases significantly (Baird *et al.*, 1992). These authors state that the nutrients are not toxic in the concentrations measured and no indication of anoxia was present during the period of study (1989-1990). However, there is some concern that effluent perceived to come from septic tanks might become problematical (Bickerton and Pierce, 1988), particularly if water exchange between canals and the main estuary decreases. In the early 1990's, canals were efficiently flushed (Schumann and de Meillon, 1993), although water temperatures were 1- 2°C warmer in the inner canals compared to the main estuary at the time of sampling. Current rate of flushing in the canals leads to marine dominance, although hypersaline conditions have not been recorded to-date.

3. PRESENT FRESHWATER SUPPLY TO THE ESTUARY

Present management policy provides for a total annual freshwater allocation of $2 \times 10^6 \text{ m}^3$ for the estuary, unless natural overtopping of the dam occurs. However, overtopping is infrequent, and years may pass between overspill events. The annual allocation for the estuary is therefore <2% of the Mean Annual Runoff (MAR). Severe drought at the end of the 1980s and early 1990s resulted in the reservoir levels falling below 30% of capacity (Jury and Levey, 1993). Freshwater was then released on a monthly basis in order to prevent hypersalinity developing in the upper estuary.

During the latter part of the drought (early 1990s) and up to the present time, no regular freshwater releases are made for environmental purposes. Consequently, river flow below the Impofu Dam is erratic and the estuary received little or no freshwater, except for local runoff after very heavy rains. Because the Impofu Dam reduces natural runoff from the catchment, marine conditions in the estuary now persist for extended periods (years). Although high salinity values (e.g. Figures. G-4 to G-6) were recorded throughout the estuary prior to dam construction (1982), present-day reductions in salinity are probably more occasional than before.

4. INVERTEBRATES OF THE KROMME ESTUARY

4.1 Zooplankton

Baird *et al.* (1981) listed 22 zooplankton species (Attachment A^G, Table 1) collected during two surveys in 1978 (June and November) from the Kromme Estuary. Near the mouth, typical marine copepods dominated the zooplankton and included *Corycaeus* sp (mean 12 m³), *Euterpina acutifrons* (mean 15 m³), *Microsetella norvegica* (mean 23 m³), *Oithona* spp. (mean 509 m³) and *Paracalanus crassirostris* (mean 23 m³). Further upstream, typical estuarine species such as *Acartia longipatella* (mean 18221 m³) and *Pseudodiaptomus hessei* (mean 13208 m³) occurred. Maximum population density of these two species was present in middle estuarine reaches and the lower Geelhoutboom (Stations 5 - 6, Figure G-3). *Acartia natalensis* was only recorded in low numbers at the head of the main estuary and at the top of the Geelhoutboom tributary (mean 1245 m³).

Three species of mysid shrimps were recorded during the 1978 surveys. *Gastrosaccus brevifissura* shows a strong association with sandy substrata (lower estuary) where mean abundance peaked at 346 m³. *Mesopodopsis wooldridgei* was abundant in middle estuarine reaches (mean 606 m³), while *Rhopalophthalmus terranatalis* occurred in lower numbers (mean 55 m³) in the same region of the estuary.

Two other zooplankton data sets are available for the Kromme Estuary. Both surveys concentrated on the euryhaline zooplankton community and excluded lower estuary (Stations 1 –3, Figure G-3). Two copepod species (*Pseudodiaptomus hessei* and *Acartia longipatella*) again dominated the estuarine zooplankton (refer to Attachment A^G, Table 2 for information from the 1996/1997 survey. Note that nauplii are copepod larval stages), while *Acartia natalensis*, occurred in low numbers only. The relationship of these three copepod species to salinity gradients is discussed in more detail below.

In estuaries having a full salinity gradient, *Acartia longipatella* and *A. natalensis* are spatially separated along the gradient. This is shown for the Gamtoos Estuary (Figure G-10) where *A. longipatella* occurs in water of higher salinity compared to *A. natalensis* (Wooldridge, 1999). In warm temperate estuaries, *A. longipatella* also occurs in the plankton during the cooler months while *A. natalensis* appears in summer (Wooldridge and Melville-Smith, 1979).

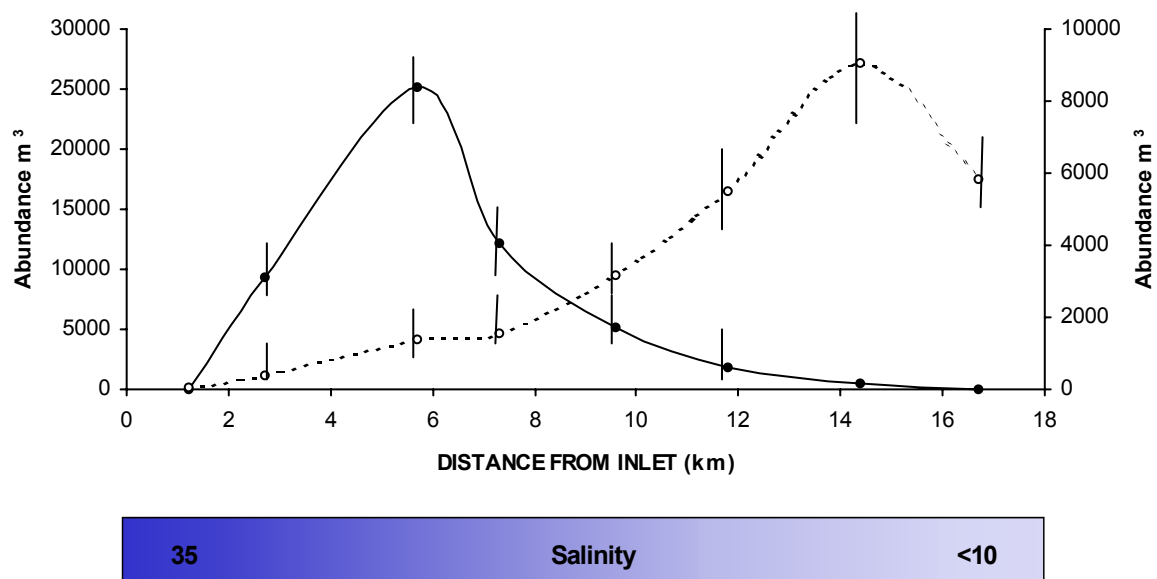
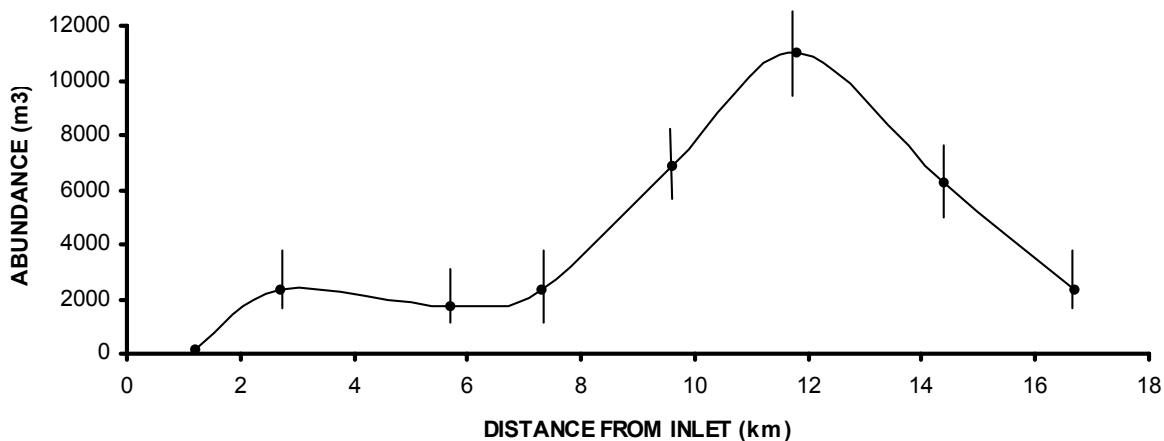


Figure G-10 Spatial succession of *Acartia longipatella* (solid line and Y1 axis) and *A. natalensis* (dashed line and Y2 axis) along the estuarine salinity gradient. *A. longipatella* prefers euryhaline salinities while *A. natalensis* occurs where salinity values are relatively low. Data are mean values ($\pm$ 1SD) recorded from the Gamtoos Estuary sampled over 26 consecutive months.

In the Kromme, a salinity gradient along the estuary is usually absent and this negatively influences distribution of the two acartiids. *A. natalensis* requires water of low salinity in order for eggs to hatch (ca 20 ppt). When salinity values exceed ca 20 ppt, eggs remain dormant in bottom sediments until favourable conditions return. Hatching of dormant eggs is also coupled to warm water temperature, and eggs will therefore only hatch in summer under suitable salinity conditions. *A. longipatella* on the other hand, prefers colder water (winter) and water salinity above 20 ppt. In the Kromme salinity is favourable along the entire length of the estuary for *A. longipatella* and this allows the species to colonise the upper reaches.

Pseudodiaptomus hessei also has a preference for mesohaline conditions (Wooldridge, 1999). This is shown for the Gamtoos Estuary (Figure G-11) where peak population densities occur in the middle and upper reaches. The same pattern is described for the Sundays Estuary (Wooldridge and Bailey, 1982) that also has a well established salinity gradient along the estuary.



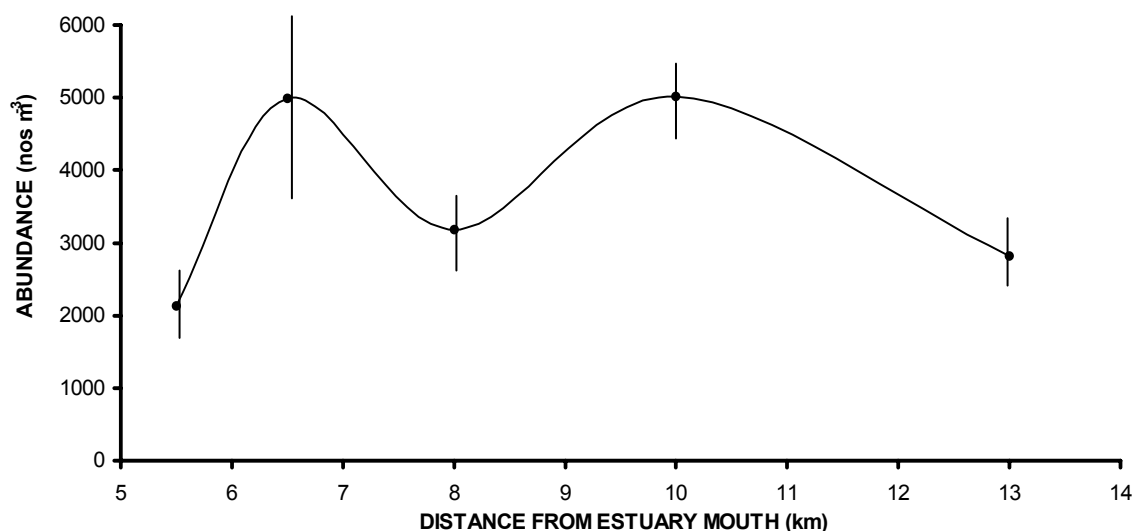
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Salinity

<10

Figure G-11 Typical spatial distribution of *Pseudodiaptomus hessei* along an estuarine salinity gradient. The species has a preference for upper estuarine reaches where mesohaline conditions prevail. Data are mean values ($\pm$ 1SD) recorded from the Gamtoos Estuary sampled over 26 consecutive months.

In the Kromme, the absence of a salinity gradient leads to a more ubiquitous distribution of *P. hessei*. (Figure G-12). Should a salinity gradient develop (e.g. after a flood), the distribution of *P. hessei* temporarily follows the pattern shown in Figure G-11.



35

Salinity

35

Figure G-12 Spatial distribution of *Pseudodiaptomus hessei* along the Kromme Estuary (excluding the Geelhout tributary). In the absence of a salinity gradient, distribution is ubiquitous in comparison to the Gamtoos Estuary (see Figure G-11). Data are mean values ($\pm$ 1SD) recorded for the Kromme Estuary sampled over 36 consecutive months. Sites refer to Stations 4-5 and 8-10 (see Figures G-3 and G-4 for detail).

An analysis of *P. hessei* temporal distribution indicates that peaks in population abundance levels do not follow a seasonal pattern, but are primarily linked in some way to freshwater pulsing that may occur during any season (Wooldridge, 1999). *P. hessei* has a high turnover rate (the P/B ratio varies between 70 and 100) and abundance levels increase rapidly following freshwater pulsing. During periods of no freshwater inflow to the Kromme Estuary (Figure G-4) population abundance levels decrease to relatively low levels. The link between riverine inflow and *P. hessei* abundance is probably due to a rapid increase in food availability (e.g. phytoplankton and microzooplankton) following freshwater pulsing. The positive population response in December 1989 (Figure G-13) to the late November flood (Figure G-4) in the Kromme reflects such response patterns. Note the relatively low numbers particularly during periods of hypersalinity.

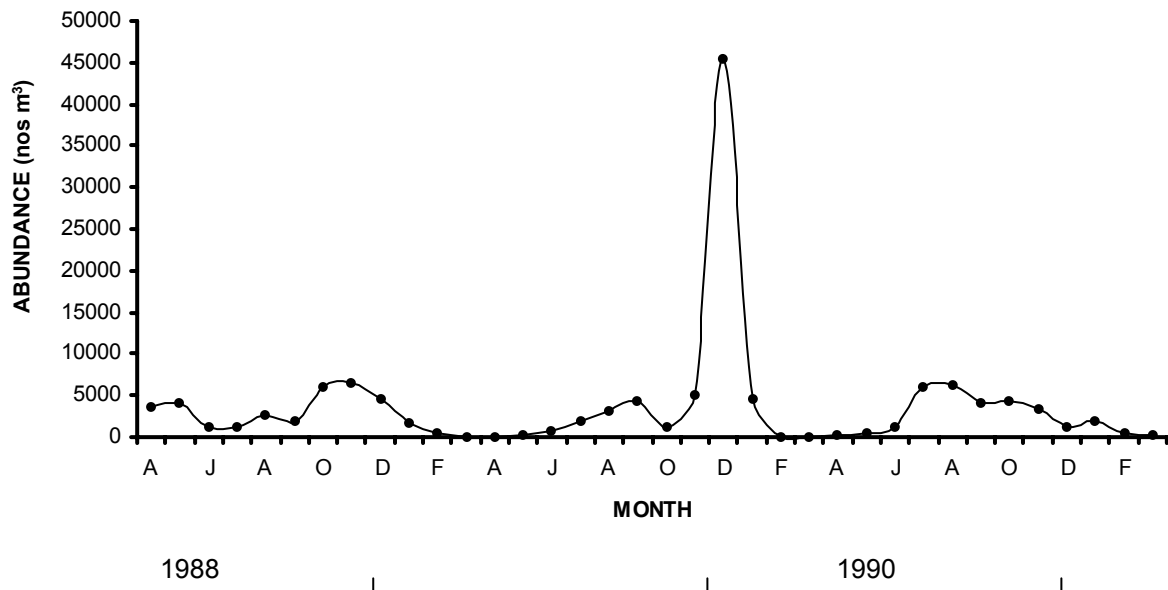


Figure G-13 *Pseudodiaptomus hessei* numbers increased significantly following the flood in late November 1989 (Figures G-4 and G-5). Data are mean values for all stations in the Kromme Estuary sampled over 36 consecutive months.

Abundance of *P. hessei* also increased significantly following a flood in November 1996 (Figure G-14), but no response was apparent following a flood a few months later (April 1997, Figure G-7). After the flood, surface salinity values remained close to zero for the remainder of the sampling programme.

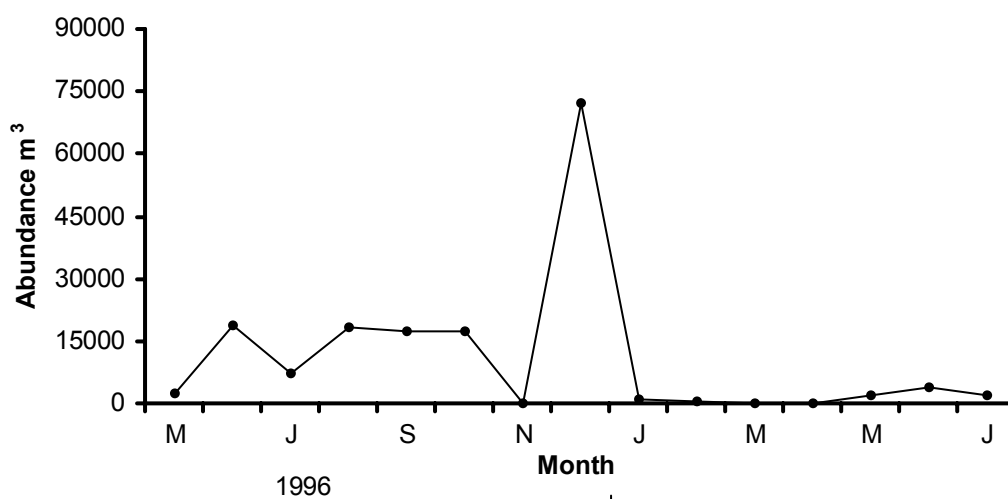


Figure G-14 *Pseudodiaptomus hessei* numbers also increased significantly after a flood in late November 1996 (Figure G-7). Data are from Station 10 in the Kromme Estuary sampled over 15 consecutive months.

In comparison to other estuaries in the region, biomass and diversity of the euryhaline zooplankton in the Kromme is low (Wooldridge, 1999). The Kromme has the lowest average copepod biomass (mg dry mass m⁻³) of six tidal estuaries for which extensive data sets are available (Figure G-15). This is linked to the low average longitudinal salinity gradient. Although a host of abiotic and biotic factors control primary productivity in estuaries, a positive correlation between phytoplankton biomass and the magnitude of freshwater inflow is a recurring one in many systems (e.g. Malone *et al.*, 1988; Mallin *et al.*, 1993). These patterns are also evident in South African estuaries, with freshwater pulses transporting significant amounts of inorganic nutrients to estuarine waters (e.g. Allanson and Read, 1995), thereby enhancing phytoplankton growth (Table 5.2, Adams and Bate, 1999). In estuaries along the south-eastern Cape coast, phytoplankton biomass is positively related to the mean axial salinity gradient regulated through river flow entering a particular system (Figure 4, Schlacher and Wooldridge, 1996). The same pattern holds for pelagic consumers that include copepods (Figure 7.12) endemic to estuaries (refer also to Allanson and Read, 1995) and fish (Figure 4, Schlacher and Wooldridge, 1996). Phytoplankton, endemic copepods and fish attained significantly higher biomass in estuaries having pronounced axial salinity gradients compared to estuaries having weak axial salinity gradients.

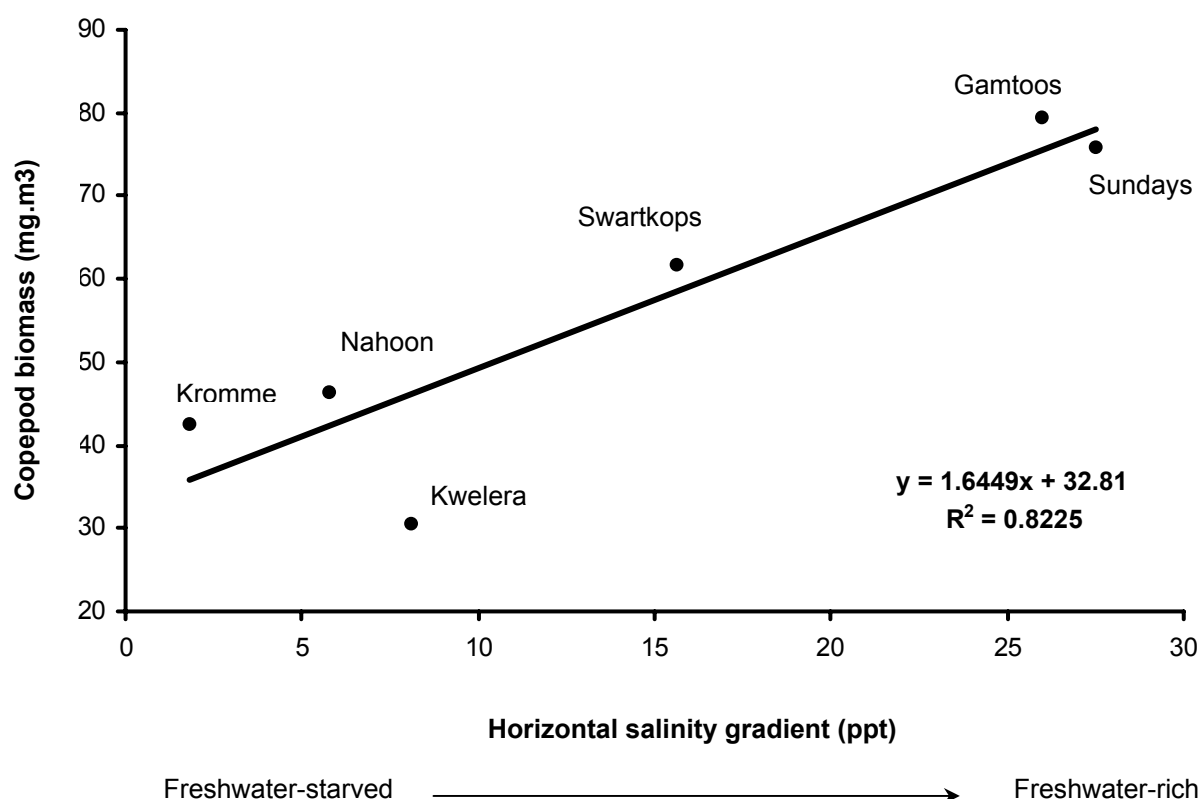


Figure G-15 Average copepod biomass in relation to average horizontal salinity gradient for six estuaries having extensive data sets (minimum 27 measurements collected monthly) in the warm temperate region.

4.2 Macrobenthos

4.2.1 General review of the macrobenthos from previous work

Although the number of macrobenthic species (animals living in or on the substrate and retained by a sieve mesh size of 0,5 mm) of local estuaries can exceed 300 (de Villiers *et al.*, 1999), the macrobenthos is typified and dominated by few species only. In the Kromme, Bickerton and Pierce (1988) list 56 species based on earlier research by numerous researchers. The sandprawn *Callianassa kraussi* is one of the most widespread species, attaining densities of over 100 individuals per m² of substrate above the road bridge (Day, 1981). This species is relatively scarce in the sands at the mouth where it is replaced by a high density (136 per m²) of *Loripes clausus* (Hecht, 1973; quoted in Emmerson *et al.*, 1982). *C. kraussi* and *L. clausus* are the only two macrofauna species that are relatively abundant in the sandbanks near the mouth (see Figure 22 in Bickerton and Pierce). However, previous work on the flood tidal delta of the Nahoon Estuary near East London (Bursey, 1998) has indicated that these habitats are not 'aquatic deserts' as generally perceived, but harbour a rich fauna with respect to the number of species present. In the Nahoon, 106 species were recorded, exceeding the 36 species recorded on the adjacent beach. Major taxa included small Crustacea, Molluscs and Polychaete worms. A feature of many of the organisms inhabiting flood tidal deltas is their mobility, an adaptation to the dynamic environment in which they live.

The mudprawn *Upogebia africana*, occurs upstream of the bridge where a muddy substratum is present. In places, density exceeds 100 individuals per m² (Day, 1981). The crab *Sesarma*

catenata is common in areas where saltmarsh occurs. Submerged *Zostera* beds (eelgrass) along the main estuary also harbour a rich and abundant fauna (Emmerson *et al.*, 1982; Hanekom, 1982). Emmerson *et al.* (1982) listed dominant species present in eelgrass beds that include the molluscs *Lamya capensis* (max. 469 individuals per m²), *Macoma litoralis* (max. 181 individuals per m²) and *Nassarius kraussianus* (max. 241 individuals per m²), as well as crustaceans such as *Cleistostoma edwardsii* and *C. algoensis* (max. 296 and 156 individuals per m² respectively).

Hanekom (1982) recorded 29 macrobenthic species using a 1 mm mesh sieve in intertidal *Zostera* beds. Thirteen of the species were crustaceans and 12 were molluscs (Table G-2). In addition, Hanekom (1982) sampled non-vegetated areas adjacent to *Zostera* beds. Most species occurred in both habitats, but the isopod *Exosphaeroma hylocoetes*, the molluscs *Lamya capensis*, *Haminea alfredensis* and *Natica genuana* were found only at sites covered with *Zostera*. Other species such as the polychaete worm *Cerathereis erythraeensis*, the crabs *Cleistostoma edwardsii* and *Hymenosoma orbiculare* were also more abundant in vegetated areas. The mudprawn *Upogebia africana* on the other hand, was more common in open areas.

The general distribution of the 29 species recorded by Hanekom (1982) along the length of the Kromme Estuary was similar to that recorded by Hecht (1973) who sampled in *Zostera* and non-*Zostera* areas. No one species was present at all sites, although the crown-crab *Hymenosoma orbiculare*, the bivalve *Macoma littoralis* and the crab *Cleistostoma edwardsii* occurred at most sites. Species such as *Alpheus crassimanus*, *Betaeus jucundus*, *Coryphoterus multifasciatus*, *Loripes clausus*, *Polybranchiorhynchus dayi* and *Solen capensis* were relatively rare (<10% of sites sampled).

Decapod crustaceans *Cleistostoma edwardsii* and *Upogebia africana* tended to dominate lower and lower-middle reaches, but upper reaches were dominated by a mollusc community (*Lamya capensis*, *Macoma litoralis*, *Solen corneus* and *Nassarius kraussiana*). The crown crab *Hymenosoma orbiculare* was more or less evenly distributed along the estuary. Bivalves such as *Loripes clausus* and *Solen capensis* were limited to the mouth region.

Bivalves such as *Dosinia hepatica*, *Eumarcia paupercula*, *Solen capensis*, *Solen corneus* and *Macoma litoralis* are suspension or deposit feeders (McLachlan, 1972) while the crustaceans *Cleistostoma algoense*, *C. edwardsii* and *Hymenosoma orbiculare* are deposit feeders (MacNae, 1957; Day, 1981). The mudprawn *Upogebia africana* is a suspension feeder (De Villiers *et al.*, 1999) and it is thought that only one species (*Nassarius kraussianus*) is herbivorous (Hanekom, 1982).

Table G-2 Mean abundance (summer and winter) of all macrobenthic species (numbers m²) at 10 sites sampled in intertidal *Zostera* beds (using a 1 mm mesh sieve) along the Kromme Estuary sampled by Hanekom (1982). Sites 1-3 were below the road bridge that spans the lower estuary, Sites 4-7 were positioned between the bridge and the Geelhoutboom tributary and sites 8-10 were positioned within 1.5 km above the confluence of the two tributaries. Each site was sampled at the upper and lower reaches of the intertidal. Mean abundance at Sites 1-3 was therefore calculated as the Sum of any species divided by 6. The calculation therefore does not take into account zonation patterns that may exist. Two gobiid species are excluded.

	Sites 1 – 3	Sites 4 – 7	Sites 8 - 10
Nemertea			
<i>Polybranchiorhynchus dayi</i>	1	-	-
Echiuroida			
<i>Ochaetostoma capense</i>	1	-	-
Polychaeta			
<i>Ceratonereis erythraeensis</i>	-	3	7
<i>Glycera tridactyla</i>	4	1	-
<i>Marphysa sanguinea</i>	1	-	1
Isopoda			
<i>Cyathura carinata</i>	-	1	7
<i>Exosphaeroma hylocoetes</i>	-	1	1
Macrura			
<i>Alpheus crassimanus</i>	-	1	1
<i>Betaeus jucundus</i>	1	-	-
Anomura			
<i>Diogenes beviristris</i>	19	1	-
<i>Upogebia africana</i>	26	29	1
Brachyura			
<i>Cleistostoma algoense</i>	2	4	38
<i>C. edwardsii</i>	135	134	2
<i>Hymenosoma orbiculare</i>	16	7	9
<i>Rhynchoplax bovis</i>	-	-	1
<i>Thaumastoplax spiralis</i>	2	1	1
Mollusca			
<i>Dosinia hepatica</i>	1	10	2
<i>Eumarcia paupercula</i>	-	1	1
<i>Lamya capensis</i>	-	68	172
<i>Loripes clausen</i>	16	-	-
<i>Macoma litoralis</i>	5	72	135
<i>Psammotolina capensis</i>	22	1	-

	Sites 1 – 3	Sites 4 – 7	Sites 8 - 10
<i>Solen capensis</i>	3	-	-
<i>Solen cylindraceus</i>	1	9	31
<i>Haminea alfredensis</i>	27	1	-
<i>Nassarius kraussianus</i>	5	32	49
<i>Natica genuana</i>	6	-	-

Winter and Baird (1988) have underlined the importance of anomuran, brachyuran and macruran crustaceans in controlling energy flow in many Eastern Cape estuaries, including the Kromme. The most important of these species from an energy flow perspective is the shrimp *Palaemon perengueyi* (Table G-3). *Palaemon perengueyi* (formerly *P. capensis*) occurs primarily in subtidal eelgrass habitat (Emmerson, 1986) and attains extremely high densities (max. 1016 individuals per m²) (Emmerson *et al.*, 1982). This species breeds in nearshore oceanic waters and postlarvae then migrate into estuaries or pools along the intertidal rocky shore where they utilise available resources. Table G-3 below ranks the five most important species with respect to energy flow in the Kromme Estuary:

Table G-3 Annual production rates of the five most important invertebrates present in the Kromme Estuary (extracted from Winter and Baird, 1988).

Species	Somatic production (gm-2y-1)	Annual production (tons dry mass)
<i>Palaemon peringueyi</i>	8.48	25.44
<i>Sesarma catenata</i>	5.84	17.52
<i>Upogebia africana</i>	3.46	10.30
<i>Macoma litoralis</i>	2.60	7.80
<i>Callianassa kraussi</i>	2.19	6.57

The three major producers contribute 67% to total production, indicating the importance of key species in the estuary. In terms of habitat, benthic macroinvertebrate production is greatest in *Zostera capensis* beds (35.2%), followed by salt marsh and mud habitats (each 25.2%). Thus, 85% of macroinvertebrate production in the Kromme Estuary is associated with non-sandy habitats upstream of the mouth area.

In terms of freshwater reduction to estuaries, changes in the biota do not lead to changes in the trophic levels, but rather to major shifts in the primary producers and trophic pathways (Grange *et al.*, 2000). In the Kromme Estuary, Baird and Heymans (1996) report that there was a major decline in the zooplankton standing stock as a consequence of reduced phytoplankton stock after the dam was built. Phytoplankton biomass declined from 3.7 g C m⁻² to 0.4 g C m⁻² (Baird, 1999). Submerged macrophyte biomass on the other hand increased from 60 to 125 g C m⁻², leading to changes in the balance between primary producers. This is supported by Adams and Talbot (1992) who recorded a four-fold increase in standing biomass of *Zostera capensis* in the nine-year period after construction of the Impofu dam. This included a 2.4 fold increase in density and a 1.6 fold increase in aerial coverage.

Increase in *Z. capensis* density and coverage after dam construction would also have led to changes in zoobenthic community structure. Predicted shifts in population abundance levels for some of the important benthic species are listed in Table G-4, supporting earlier conclusions that a reduction in freshwater supply led to changes in energy pathways (Baird and Heymans, 1996, Grange *et al.*, 2000). *Palaemon perengueyi* for example, occurs primarily in eelgrass beds (Emmerson, 1986). The increase in *Z. capensis* density and coverage would therefore favour an increase in *P. perengueyi* biomass, a species now responsible for about 25% of invertebrate annual production (Table G-3) in the Kromme Estuary.

Table G-4 Predicted change in the standing stock of important macrobenthic species after the construction of the Impofu Dam. The predicted change is based on habitat preference of the species (see text) and the four-fold increase in *Zostera capensis* standing stock in the estuary. (+) indicates an increase in standing stock, (-) indicates a decrease in standing stock.

Species	Predicted change	Reference
<i>Upogebia africana</i>	-	Hanekom (1982)
<i>Exosphaeroma hylocoetes</i>	+	Hanekom (1982)
<i>Palaemon perengueyi</i>	+	Emmerson <i>et al.</i> (1982)
<i>Cleistostoma edwardsii</i>	+	Hanekom (1982)
<i>Hymenosoma orbiculare</i>	+	Hanekom (1982)
<i>Lamya capensis</i>	+	Hanekom (1982)
<i>Haminea alfredensis</i>	+	Hanekom (1982)
<i>Natica genuana</i>	+	Hanekom (1982)

Emmerson *et al.* (1982) listed dominant species present in eelgrass beds that include the molluscs *Lamya capensis* (max. 469 individuals per m²), *Macoma litoralis* (max. 181 individuals per m²) and *Nassarius kraussianus* (max. 241 individuals per m²), as well as crustaceans such as *Cleitosoma edwardsii* and *C. algoensis* (max. 296 and 156 individuals per m² respectively).

Hanekom (1982) recorded 29 macrobenthic species using a 1 mm mesh sieve in intertidal *Zostera* beds. Thirteen of the species were crustaceans and 12 were molluscs (Table G-2). In addition, Hanekom (1982) also sampled non-vegetated areas adjacent to *Zostera* beds. Most species occurred in both habitats, but the isopod *Exosphaeroma hylocoetes* and the molluscs *Haminea alfredensis*, *Lamya capensis* and *Natica genuana* were found only at sites covered with *Zostera*. Other species such as the polychaete worm *Ceratonereis erythraeensis* and the crab *Hymenosoma orbiculare* were also more abundant in vegetated areas. The mudprawn *Upogebia africana* on the other hand, was more common in open areas.

High salinity values in the Kromme Estuary have also enabled sessile marine organisms typical of rocky shores on the open coast to colonise suitable estuarine habitat. These rocky shore species include the gastropod *Notilittorina scabra*, the barnacle *Balanus elizabethae* and red-bait, *Pyura stolonifera*. These species were described as dominant (>200 m⁻²) on hard substrata in the upper estuary (quoted in Jerling and Wooldridge, 1994).

4.2.2 Subtidal macrobenthic monitoring programme: 2004

Previous surveys on the subtidal macrozoobenthos of the Kromme Estuary utilised sieves having relatively coarse mesh (1 mm aperture). A 1mm sieve does not effectively retain many species such as polychaete worms, tanaids, isopods and amphipods and more recent studies have tended towards 0.5 mm mesh sizes. Although relatively small, many of these species attain very high abundance levels. In 2004, a monitoring programme was therefore initiated to investigate the subtidal macrozoobenthos using a 0.5 mm mesh sieve.

The estuary was visited on four occasions: 16-20 February, 19-21 May, 28-30 June and 16-18 November. Collection of samples was done from the deck of a 4.5 m twin-hull fibreglass boat equipped with a 40 hp outboard motor at 10 sites (Figure G-3). Subtidal benthic invertebrates were collected using a Van Veen type grab and the contents sieved through a 500 µm mesh screen bag. The grab has a 200 cm² bite that penetrated the sediment down to about 10 cm depth. Six replicates were taken at each site during daylight hours. Replicates were collected over an area of about 10 m² in the channel area at each site. Animals retained by the sieve were stored in 500 ml plastic bottles and preserved with 10% formaldehyde solution. Final abundance was expressed as the average number of each species per m² of substratum at each site, obtained from the six replicates.

Analysis of samples was completed in the laboratory. Invertebrates were identified to species level wherever possible and the data analysed using multivariate statistics from the statistical package, PRIMER V.5 (Plymouth Routines in Multivariate Ecological Research). If multivariate techniques were not appropriate, other packages using MS Excel or Statistica for Windows were used.

A YSI 6600 multi-parameter zone was deployed at all 10 stations (Figure G-3) during a continuous run up the estuary each trip. Variables were measured near the surface, at 0.5 m depth, at 1 m and thereafter at 1 m depth intervals. The following parameters were recorded at every level: Dissolved oxygen (percent saturation and in mg per litre), salinity (ppt), temperature (°C), and pH. During the February visit, turbidity was also measured.

A sediment sample collected at each station provided information on particle size distribution and percent organic content. Dry samples (dried at 60°C for a minimum of 48 h and then weighed) were incinerated at 550°C for 12 h to burn off the organic matter. The difference in weight of the sample after incineration provided information on organic content, expressed as a percentage. Three replicates from each sediment sample were used to obtain a final value. Samples were then soaked in distilled water for 24 h to remove salts. Excess water was carefully siphoned off and the sample again dried at 60°C for 72 h. Dried sediment was then vibrated through a series of metal test sieves (2 mm, 1 mm, 500 µm, 355 µm, 250 µm, 180 µm, 125 µm, 90 µm, 63 µm and <63 µm).

Percent organic content was obtained after incinerating pre-weighed dry sediment samples (dried at 60°C) for 24 hrs at 660°C.

4.2.3 Results of the 2004 subtidal macrobenthic monitoring programme

Abiotic measurements recorded during each of the four trips are given in Tables G-5 to G-8. The estuary remained hypersaline throughout the study, ranging between 35 and 36.4 ppt at the mouth (February, May and July) to over 40 ppt between the mouth and Station 8 in November. In November, salinity at the uppermost station (Station 10) was slightly lower than the middle and lower estuary (ca 1.5 ppt), probably due to local runoff at that time. On all other occasions, salinity values were marginally higher in the upper estuary compared to nearer the mouth. Salinity values in the Geelhoutboom were similar to salinity values recorded in the main tributary, following the pattern recorded in 1988-1991 (Figure G-6). The water column was well mixed during all sampling trips, although bottom salinity was up to 1.5 ppt higher on occasions.

Table G-5 Abiotic measurements recorded in February 2004 for the 10 stations (see Figure G-3) in the Kromme Estuary. Integrated readings refer to mean values for all readings in the water column at each station (see text). Surface readings refer to the top 15 cm of the water column; bottom readings reflect conditions just above the substratum. Stations 6 and 7 are located in the Geelhoutboom tributary.

Station number	1	2	3	4	5	6	7	8	9	10
Salinity (integrated)	36.0	36.2	36.4	36.8	37.4	36.6	37.2	38.1	38.5	38.6
Salinity (surface)	36.0	36.3	36.4	36.7	35.8	36.2	37.1	38.1	38.5	38.6
Salinity (bottom)	36.0	36.1	36.4	36.9	37.5	37.0	37.3	38.1	38.5	38.6
Temperature (integrated °C)	17.3	17.5	17.6	17.6	17.3	17.7	17.3	17.6	17.9	18.0
Temperature (surface °C)	17.3	17.5	17.6	17.6	17.4	17.7	17.4	17.6	18.0	18.0
Temperature (bottom °C)	17.3	17.5	17.6	17.5	17.3	17.7	17.3	17.5	17.8	17.9
Oxygen (integrated mg/l)	6.0	4.7	5.3	5.1	4.8	4.6	4.4	4.8	4.9	5.0
Oxygen (surface mg/l)	9.2	6.2	7.4	6.6	5.0	4.6	4.4	5.0	5.0	5.1
Oxygen (bottom mg/l)	4.9	4.4	5.3	5.3	5.2	4.6	4.3	5.1	5.0	5.0
Oxygen (% saturation integrated)	78.0	61.2	69.6	68.2	65.2	62.6	59.0	65.4	66.5	67.5
Oxygen (% saturation surface)	118.0	80.0	91.8	82.6	67.4	62.4	59.0	67.6	68.1	68.1
Oxygen (% saturation bottom)	64.0	57.0	70.6	71.3	70.6	62.7	59.0	68.1	68.0	69.0
NTU (integrated)	35.3	35.5	35.7	36.0	36.5	35.8	36.3	37.1	37.5	37.6
NTU (surface)	35.3	35.6	35.7	36.0	35.2	35.5	36.3	37.1	37.5	37.6
NTU (bottom)	35.3	35.4	35.7	36.1	36.7	36.2	36.4	37.1	37.5	37.6
Depth (m)	2.0	2.0	3.0	4.0	3.5	0.5	0.5	3.5	4.0	4.0
pH (integrated)	8.2	8.2	8.2	8.2	8.2	8.1	7.9	8.2	8.1	8.0
Chlorophyll a (mg/l integrated)	3.0	0.7	0.4	1.0	1.5	1.8	1.0	1.2	1.2	1.0
Chlorophyll a (mg/l maximum)	0.8	1.0	0.9	1.1	4.6	2.1	1.0	1.7	1.3	1.2
Sediment - % mud (<0.065 mm)	1.9	1.5	1.1	9.0	33.2	88.8	79.9	45.1	16.0	15.7
Sediment - % sand (0.125 - 0.250 mm)	83.4	84.9	88.5	73.0	37.1	2.5	5.1	41.0	20.8	14.8
Sediment - % sand (0.355 - 0.500 mm)	9.7	9.0	5.9	8.0	13.1	0.8	5.0	11.9	21.3	23.0
Sediment organic matter (%)	1.2	1.8	0.7	5.7	4.6	6.3	14.8	2.1	5.7	5.9

Table G-6 Abiotic measurements recorded in May 2004 for the 10 stations (see Figure G-3) in the Kromme Estuary. Integrated readings refer to mean values for all readings in the water column at each station (see text). Surface readings refer to the top 15 cm of the water column; bottom readings reflect conditions just above the substratum. Stations 6 and 7 are located in the Geelhoutbos tributary.

Station number	1	2	3	4	5	6	7	8	9	10
Salinity (integrated)	36.0	36.3	36.4	36.8	37.3	36.6	37.2	38.1	38.5	38.6
Salinity (surface)	36.0	36.3	36.4	36.7	35.8	36.2	37.2	38.1	38.5	38.6
Salinity (bottom)	36.0	36.3	36.4	36.9	37.3	37.0	37.3	38.1	38.5	38.6
Temperature (integrated °C)	17.3	17.5	17.7	17.6	17.3	17.7	17.3	17.6	18.1	17.8
Temperature (surface °C)	17.3	17.5	17.6	17.6	17.4	17.7	17.4	17.6	18.0	17.8
Temperature (bottom °C)	17.3	17.5	17.7	17.6	17.3	17.7	17.3	17.5	17.9	17.8
Oxygen (integrated mg/l)	6.7	4.8	5.6	5.1	4.8	4.6	4.4	4.8	4.9	4.9
Oxygen (surface mg/l)	9.2	6.2	7.4	6.2	5.0	4.6	4.4	5.0	4.9	4.9
Oxygen (bottom mg/l)	5.5	4.4	5.6	5.3	4.9	4.6	4.3	4.6	4.9	4.9
Oxygen (% saturation integrated)	86.7	62.2	72.2	69.3	64.7	62.6	59.0	65.2	66.3	66.8
Oxygen (% saturation surface)	118.0	80.0	91.8	82.6	67.4	62.4	59.0	67.6	67.3	66.8
Oxygen (% saturation bottom)	72.0	57.2	72.2	71.3	65.7	62.7	59.0	61.5	65.7	66.8
Depth (m)	1.0	2.0	2.0	3.0	3.0	0.5	1.0	3.0	4.0	4.0
pH (integrated)	8.2	8.2	8.2	8.2	8.2	8.1	7.9	8.2	8.1	8.0
Sediment - % mud (<0.065 mm)	2.4	1.2	2.0	71.2	38.1	74.9	48.3	17.9	3.3	7.5
Sediment - % sand (0.125 - 0.250 mm)	49.2	84.8	90.8	8.0	20.4	10.1	12.2	8.9	19.5	8.3
Sediment - % sand (0.355 - 0.500 mm)	42.1	6.6	2.5	4.9	19.9	2.1	19.1	24.4	59.7	17.5
Sediment organic matter (%)	1.4	0.7	0.8	7.4	10.1	7.7	14.7	12.4	0.9	6.3

Table G-7 Abiotic measurements recorded in July 2004 for the 10 stations (see Figure G-3) in the Kromme Estuary. Integrated readings refer to mean values for all readings in the water column at each station (see text). Surface readings refer to the top 15 cm of the water column; bottom readings reflect conditions just above the substratum. Stations 6 and 7 are located in the Geelhoutboom tributary.

Station number	1	2	3	4	5	6	7	8	9	10
Salinity (integrated)	36.4	36.4	36.4	36.5	36.5	35.9	35.0	36.6	36.6	36.5
Salinity (surface)	36.4	36.4	36.4	36.5	36.5	35.9	35.0	36.6	36.6	36.5
Salinity (bottom)	36.4	36.4	36.4	36.5	36.5	35.9	35.0	36.6	36.0	36.5
Temperature (integrated °C)	14.5	14.4	14.1	13.4	13.4	13.4	13.2	13.3	13.4	13.6
Temperature (surface °C)	14.5	14.4	14.1	13.4	13.4	13.4	13.2	13.3	13.4	13.4
Temperature (bottom °C)	14.5	14.4	14.2	13.4	13.4	13.4	13.2	13.3	13.4	14.5
Oxygen (integrated mg/l)	8.7	10.3	12.9	10.6	11.1	11.5	11.8	10.2	9.1	9.9
Oxygen (surface mg/l)	8.3	10.3	13.1	10.6	11.0	11.4	11.2	9.8	8.8	10.0
Oxygen (bottom mg/l)	9.7	10.3	12.8	10.6	11.4	11.6	12.4	10.8	9.8	9.9
Oxygen (% saturation integrated)	104.2	126.2	157.5	127.4	133.6	138.4	139.6	122.6	109.6	119.2
Oxygen (% saturation surface)	101.7	126.5	158.6	127.9	132.2	138.1	132.3	117.2	106.3	120.0
Oxygen (% saturation bottom)	110.5	126.5	156.5	127.6	136.5	138.7	146.8	130.7	118.4	119.6
Depth (m)	2.0	2.0	2.0	1.0	2.0	0.5	0.5	2.0	4.0	3.0
pH (integrated)	8.3	8.3	8.3	8.3	8.3	8.3	8.2	8.3	8.3	8.2
Sediment - % mud (<0.065 mm)	1.8	1.7	4.8	52.0	53.5	40.6	37.9	42.1	9.3	66.5
Sediment - % sand (0.125 - 0.250 mm)	86.4	79.7	27.3	33.0	18.4	9.2	9.3	7.0	7.8	7.5
Sediment - % sand (0.355 - 0.500 mm)	10.7	10.6	58.4	3.3	8.3	14.1	21.0	19.4	17.2	4.0
Sediment organic matter (%)	1.0	0.7	0.7	8.3	8.7	9.0	11.5	10.9	1.3	8.3

Table G-8 Abiotic measurements recorded in November 2004 for the 10 stations (see Figure G-3) in the Kromme Estuary. Integrated readings refer to mean values for all readings in the water column at each station (see text). Surface readings refer to the top 15 cm of the water column; bottom readings reflect conditions just above the substratum. Stations 6 and 7 are located in the Geelhoutboom tributary.

Station number	1	2	3	4	5	6	7	8	9	10
Salinity (integrated)	40.5	40.6	40.6	40.7	40.7	40.7	40.0	40.3	39.1	38.7
Salinity (surface)	40.5	40.6	40.6	40.7	40.7	40.7	40.0	40.1	38.9	38.7
Salinity (bottom)	40.5	40.6	40.6	40.7	40.7	40.7	40.0	40.6	39.3	38.8
Temperature (integrated °C)	23.8	24.1	24.1	25.4	26.2	26.5	26.7	25.8	25.6	25.9
Temperature (surface °C)	23.8	24.2	24.2	25.7	26.2	26.5	27.0	26.1	25.8	25.9
Temperature (bottom °C)	23.8	24.2	24.1	24.9	26.1	26.5	26.3	25.5	25.0	25.8
Oxygen (integrated mg/l)	9.8	9.0	7.8	7.3	7.5	6.3	6.2	7.0	7.1	7.1
Oxygen (surface mg/l)	9.8	9.7	8.1	7.5	7.6	6.9	6.5	7.3	7.5	7.3
Oxygen (bottom mg/l)	9.8	8.3	7.6	7.1	7.2	5.2	5.9	6.2	6.4	7.0
Oxygen (% saturation integrated)	145.8	136.7	117.4	113.1	116.0	102.5	97.2	108.4	108.9	109.3
Oxygen (% saturation surface)	145.4	145.8	123.1	117.2	120.6	108.2	104.1	114.4	114.3	112.1
Oxygen (% saturation bottom)	145.8	125.3	114.4	109.1	111.7	92.5	91.9	97.5	98.1	107.1
Depth (m)	2.0	3.0	3.0	3.0	3.0	1.0	1.0	4.0	4.0	3.0
pH (integrated)	8.2	8.2	8.2	8.2	8.2	8.1	7.9	8.1	8.0	8.0
Sediment - % mud (<0.065 mm)	2.3	1.7	2.0	40.4	58.4	88.8	54.0	21.7	5.0	7.4
Sediment - % sand (0.125 - 0.250 mm)	64.1	76.4	89.5	52.9	25.6	7.2	30.3	37.0	22.5	5.4
Sediment - % sand (0.355 - 0.500 mm)	30.8	3.3	1.6	5.1	7.1	0.8	17.1	38.9	70.7	37.3
Sediment organic matter (%)	\	\	\	\	\	\	\	\	\	\

Water temperature values followed normal seasonal patterns, ranging between 13.2°C in July (Station 7 in the Geelhout) and 27 °C in November at the same station. In February, May and July, water temperatures at the mouth were little different (<1 °C) from those recorded in the upper estuary. In November, differences were ca 2 °C.

No consistent pattern was evident in recorded oxygen values in the estuary. Unexpectedly high values were recorded in July and November, and are likely due to a faulty instrument. Generally, saturation levels remained above 55%, with lowest values recorded at the uppermost site (Station 7) in the Geelhoutboom on three of the four sampling trips.

Sand (0.125 – 0.500 mm particle size) dominated at Stations 1- 4 on all sampling occasions. The sand content of bottom sediments was also relatively high in the middle and upper estuary, mostly exceeding 20%. Sediment samples were collected in channel areas and are likely to be different compared to shallower areas. Sediment in the Geelhoutboom tributary had a relatively high mud content (<0.065 mm) compared to the main estuary, sometimes exceeding 80%.

Organic content of the sediment was relatively high in muddy substrata, with maxima exceeding 10% in the upper Geelhoutboom (Station 7) and at Station 8 in the main estuary.

Abundance and distribution of macrozoobenthic organisms recorded during the four surveys are listed in Attachment A^G Tables 3 to 6. The number of species varied between 38 and 44 for the four sampling trips, with polychaete worms dominating on each occasion. The number of species and the percentage contribution of the three most abundant taxa are shown in Figure G-16 and Table G-9.

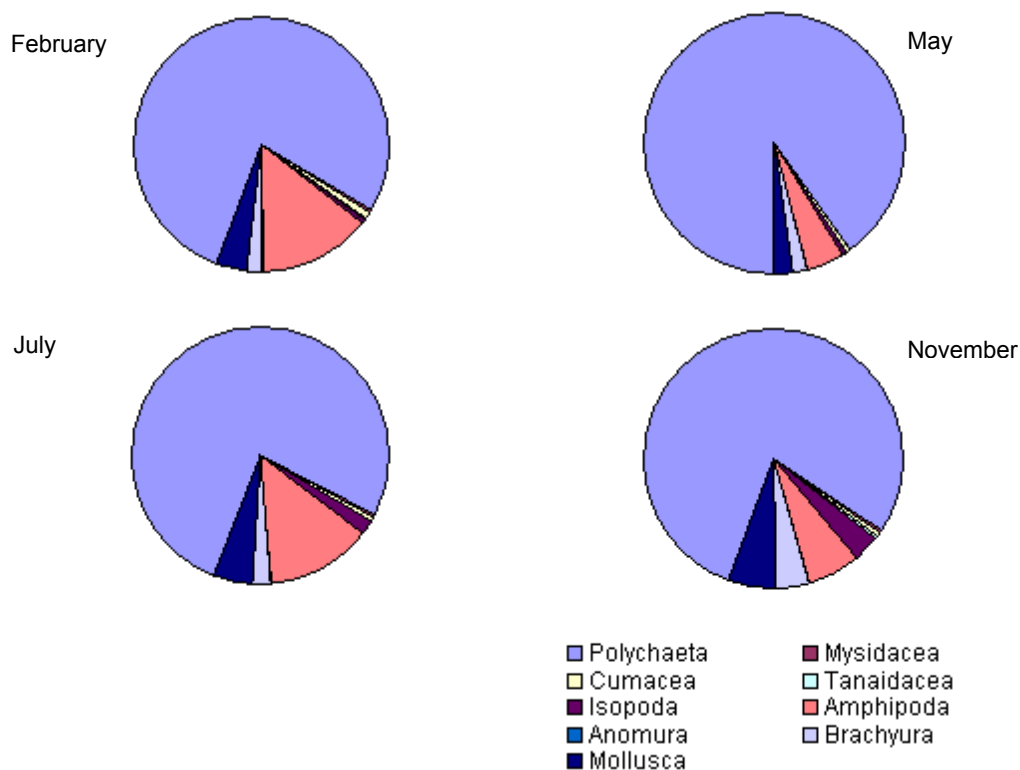


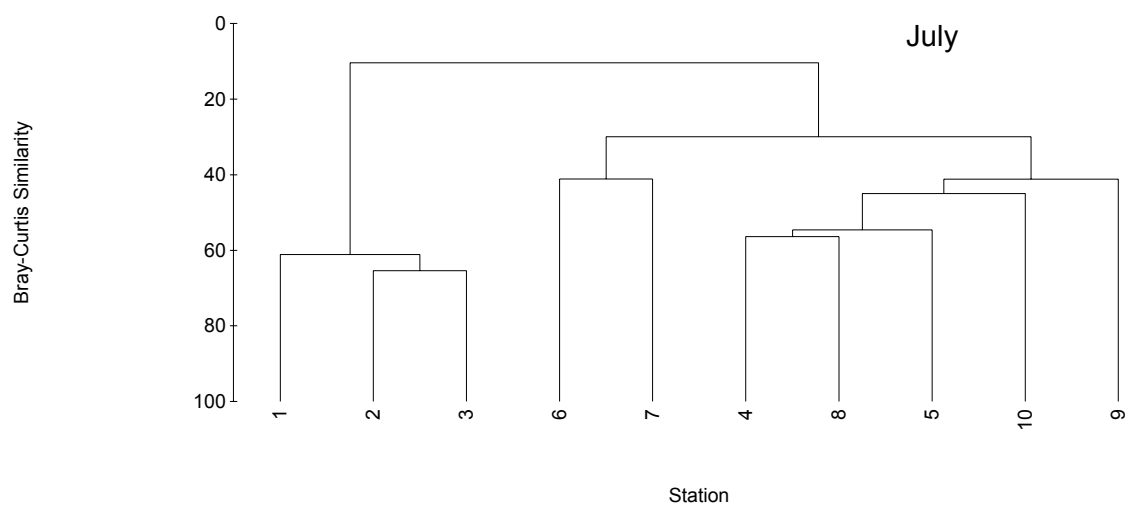
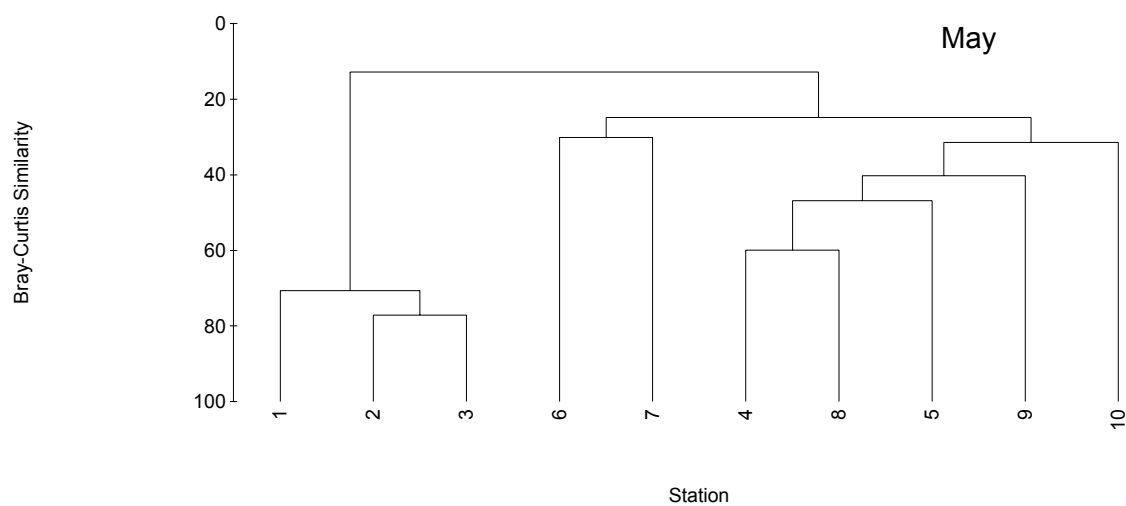
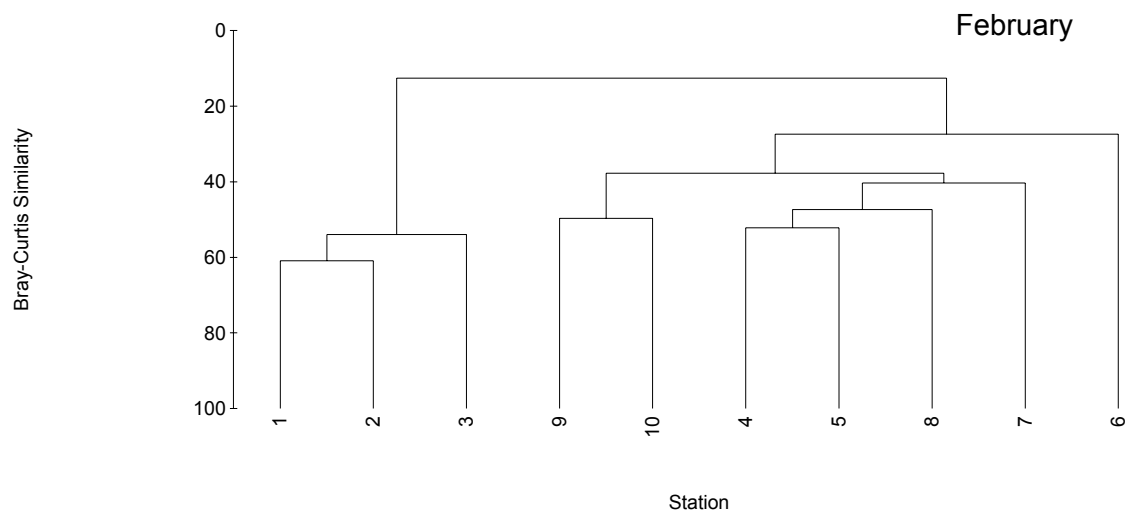
Figure G-16 Percentage abundance of all taxa in the subtidal macrozoobenthos of the Kromme Estuary. Data are for four sampling trips in 2004.

There was relatively little variation between sampling trips, both in the number of taxa and percentage contribution of the three most important groups. The relative contribution (%) of the three groups (based on numerical abundance) is shown in Table G-9.

Table G-9 The number of species and percentage contribution of the three most abundant macrobenthic taxa on each of the four sampling trips to the Kromme Estuary, 2004.

	February	May	July	November
Number of taxa	38	44	39	39
Polychaete worms (%)	78	89	77	78
Amphipods (%)	14	5	13	7
Molluscs (%)	4	3	5	6

Bray-Curtis similarity analysis using group average mode on square-root transformed data (from Attachment A^G, Tables 3-6) showed two main clusters for all sampling trips (Figure G-17). Stations 1-3 were always distinct from remaining stations, separating at <20% similarity level. Remaining sites were usually <60% similar to each other, although Geelhoutboom sites (Stations 6 and 7) grouped together on two occasions (May and July).



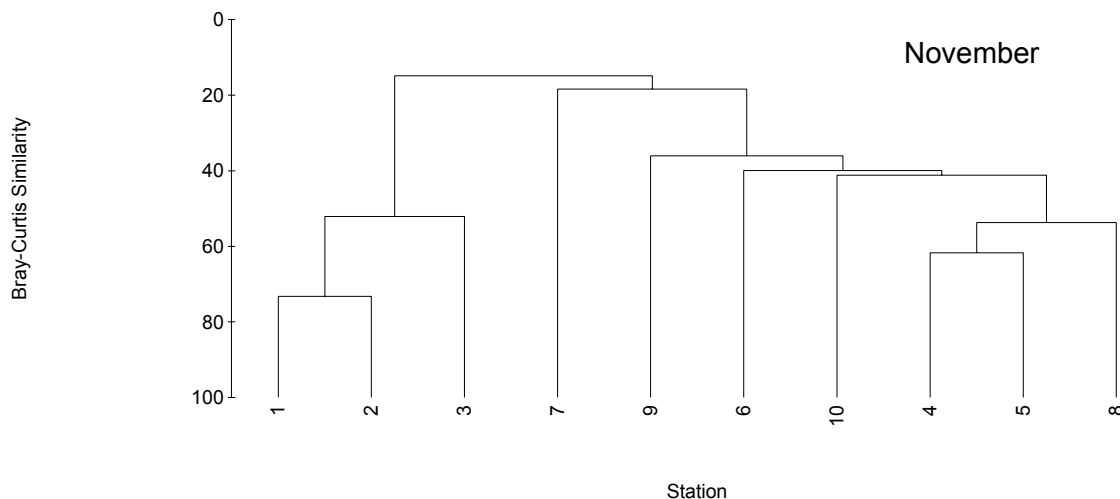


Figure G-17 Dendrogram for Bray-Curtis similarity clustering of sites based on composition and abundance of the subtidal macrobenthos of the Kromme River estuary. Data for February, May, July and November 2004.

Group linkages shown by the Bray-Curtis similarity matrix are also reflected by the non-metric multi-dimensional scaling (MDS) plot (Figure G-18). Because of the relative similarity between the four surveys, data were pooled in order to explore the possibility that a common pattern exists. Three major groups are evident. The lower sites (Stations 1-3) are again distinct for all sampling trips (see caption for explanation of the symbols). The uppermost site in the Geelhoutboom (Station 7) grouped separately for three of the sampling trips (B-D), while all remaining sites formed the third group. This suggests that the structure and composition of the macrozoobenthic community is broadly grouped in to three clusters that remained relatively stable during 2004. The stress level of 0.15 is moderately high, indicating a medium degree of confidence in the accuracy of sample relationships (Clarke and Warwick 1994). Analysis of similarity (ANOSIM) using the Primer package indicated a Global R value of 0.925; and the null hypothesis of no difference between selected groups shown in Figure G-18 (1-3, 7, and a group comprising the remaining stations) are rejected at the 0.1% level.

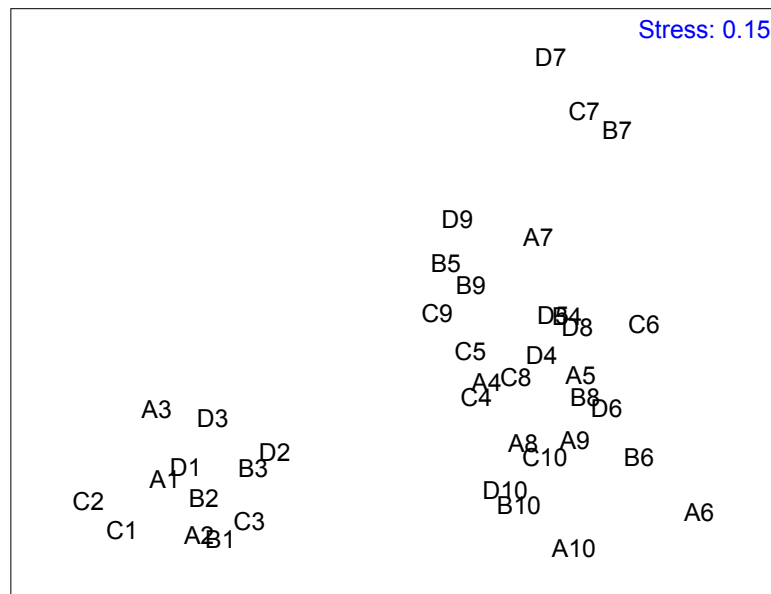


Figure G-18 2-dimensional MDS configuration of the subtidal benthic community in the Kromme Estuary, 2004. Relative distances between points is a reflection of the degree of similarity between them with respect to community composition and composition. Data from all four trips are combined for Stations 1-10: February = A, May = B, July = C, November = D.

Environmental variables (Tables G-5 to G-8) were then linked to the appropriate biotic assemblage data (Attachment A^G, Tables 3-6) using the PRIMER package BIO-ENV in order to establish which of the physico-chemical parameters best explain linkages. A Draftsman Plot was first performed in order to exclude closely correlated variables. Consequently, surface and bottom salinity, surface and bottom temperature, surface and bottom turbidity, and all O₂ data except integrated saturation (%) were excluded from further analysis for each of the four sampling trips. Results are summarised in Table G-10.

Table G-10 Correlation between the benthic species assemblage and environmental variables for each of the four sampling trips to the Kromme Estuary, 2004.

Month	Variables	Correlation	Comments
February	NTU Integrated Mud (%) Fine-med sand (%)	71%	Sediment characteristics account for 67% of the correlation.
May	O ₂ saturation (%) Depth Mud (%) Fine-med sand (%) Organic matter (%)	75%	Mud and organic content account for 54% of the correlation
July	Salinity integrated Temp. integrated Mud (%) Fine-med sand (%) Organic matter (%)	85%	Fine to medium sand and organic content account for 71% of the correlation.
November	Sediment data not available		

SIMPER analysis on community structure in the three main clusters shown in Figure G-18 rank the species in order of numerical dominance up to a cut-off cumulative contribution of 90%. Groups were characterised by having a relatively high number of species per group (Stations 1-3, nine species; Station 7, eight species; and Stations 4-6, 8-10, 15 species). Except for Polychaete species 2, dominance was also relatively low, with most species contributing around 10% or less to total abundance (Table G-11).

Table G-11 SIMPER analysis of the numerically dominant species (ranked) in the three major cluster groups shown in Figure G-18. Columns represent average numerical abundance at each site in the cluster, average similarity between sites, Similarity Standard deviation, Contribution of each species to total numerical abundance and the cumulative contribution (at the 90% cut-off value).

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Stations 1 - 3					
Polychaete Species 2	2891	21.53	5.19	41.75	41.75
<i>Prionospio sexoculata</i>	33.3	6.09	1.99	11.8	53.55
<i>Iphinoe truncata</i>	44.44	5.01	1.38	9.70	63.26
<i>Sanguinolaria capensis</i>	15.28	4.48	1.34	8.69	71.95
<i>Orbinia angrapequensis</i>	20.83	2.88	0.84	5.58	77.53
<i>Nephtys sphaerocirrata</i>	61.81	1.77	0.52	3.43	80.96
<i>Cirratulid</i> sp. 1	8.33	1.71	0.67	3.32	84.28
<i>Capitella capitata</i>	9.72	1.70	0.67	3.29	87.57
<i>Gastrosaccus brevifissura</i>	12.50	1.50	0.53	2.92	90.49
Station 7					
<i>Apseudes digitalis</i>	4014.58	10.73	0.91	16.95	16.95
<i>Xenathura</i> sp.	266.67	10.58	5.80	16.72	33.67
<i>Prionospio bocki</i>	260.42	9.29	6.92	14.68	48.34
<i>Macoma litoralis</i>	145.83	8.46	3.99	13.37	61.71
Isopod sp.	64.58	6.77	6.73	10.70	72.41
<i>Cyathura estuaria</i>	81.25	5.41	9.51	8.55	80.96
<i>Grandidierella lignorum</i>	318.76	4.30	0.90	6.80	87.76
<i>Heteromastus</i> sp. 2	16.67	2.67	0.90	4.22	91.98
Stations 4-6, 8-10.					
<i>Heteromastus</i> species 2	94.79	5.86	2.01	12.80	12.80
<i>Prionospio bocki</i>	93.75	5.39	1.69	11.78	24.58
<i>Orbinia angrapequensis</i>	90.97	3.99	1.32	8.73	33.31
<i>Cirratulid</i> sp. 2	78.13	3.85	1.36	8.41	41.72
<i>Xenanthura</i> sp.	89.93	3.83	1.33	8.37	50.09
<i>Macoma litoralis</i>	37.15	3.78	1.17	8.27	58.36
<i>Eteone siphodonta</i>	47.22	3.38	1.06	7.39	65.75
<i>Desdemona ornate</i>	59.72	2.37	0.94	5.19	70.94
<i>Capitella capitata</i>	62.15	2.15	0.71	4.71	75.65
<i>Heteromastus</i> species 1	42.01	1.92	0.64	4.19	79.84
<i>Paratyloidiplax blephariskios</i>	44.79	1.74	0.62	3.81	83.65
<i>Modiolus capensis</i>	26.04	1.72	0.75	3.77	87.42

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Isopod sp.	6.60	0.52	0.33	1.13	88.55
<i>Thaumastoplax spiralis</i>	6.94	0.50	0.33	1.10	89.64
<i>Hymenosoma orbiculare</i>	5.21	0.41	0.33	0.90	90.54

4.3 Hyperbenthos

There is no historical hyperbenthos information available and therefore the estuary was visited in 2004 on the same four occasions indicated for the macrobenthos. Hyperbenthic animals were sampled at all 10 stations (Figure G-3) using a sled mounted on broad skids. Two replicates were collected at each site. The rectangular opening to the sled measured 75 x 70 cm, to which is attached a 500 µm mesh net. A calibrated Kahlsico flowmeter mounted in the entrance quantified water volume passing through the net. Animals collected were then stored in 500 ml plastic bottles and preserved in 10% formaldehyde solution. In the laboratory animals were identified to species level under a microscope and final abundance expressed as numbers per m³ of water calculated from the two samples collected at each site. Animals captured in sled samples are usually fairly large, measuring up to 1-2 centimetres. Most of the smaller organisms such as copepods escape through the mesh and were therefore not enumerated or identified in sled samples. Physico-chemical data are given in Tables G-5 to G-8.

Analysis of samples was completed in the laboratory. Invertebrates were identified to species level wherever possible and the data analysed using multivariate statistics from the statistical package, PRIMER V.5 (Plymouth Routines in Multivariate Ecological Research). If multivariate techniques were not appropriate, other packages using MS Excel or Statistica for Windows were used.

Abundance and distribution of the hyperbenthic animals recorded during the four surveys are listed in Attachment A^G Tables 7 to 10. The number of species varied between 14 and 18 (Figure G-19) for the four sampling trips, with brachyuran larva dominating in summer (February and November) and mysids dominating during the cooler months (May and July). The number of species and the percentage contribution of the three most abundant taxa are shown in Table G-12.

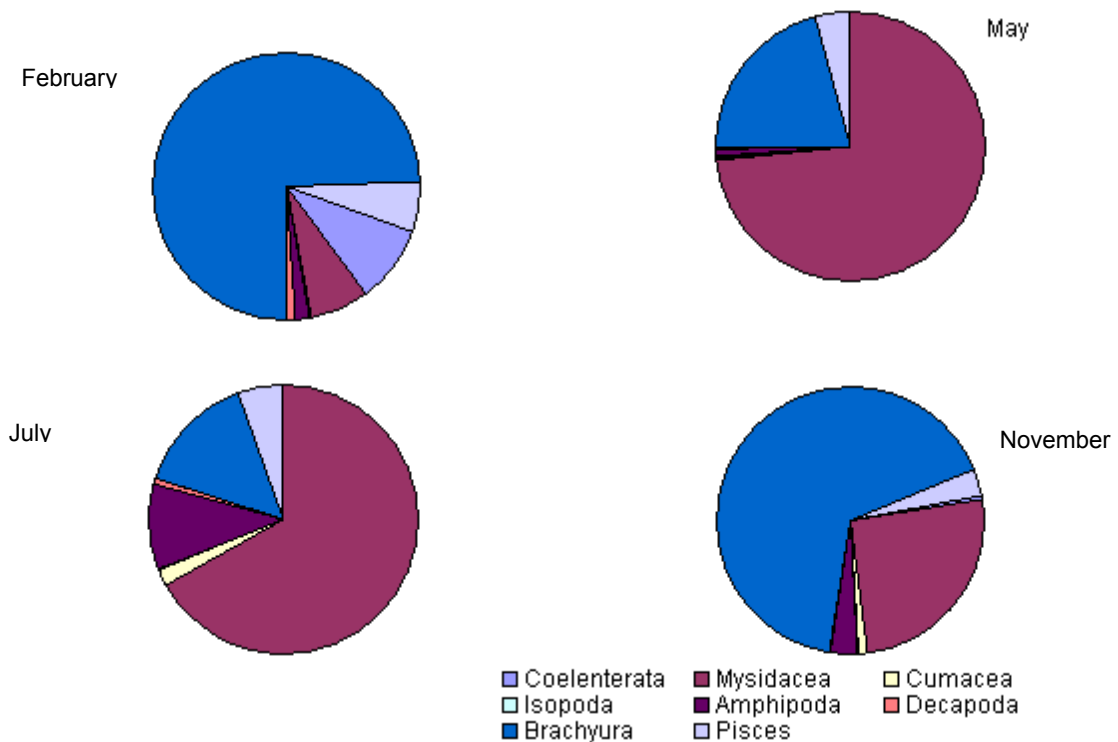
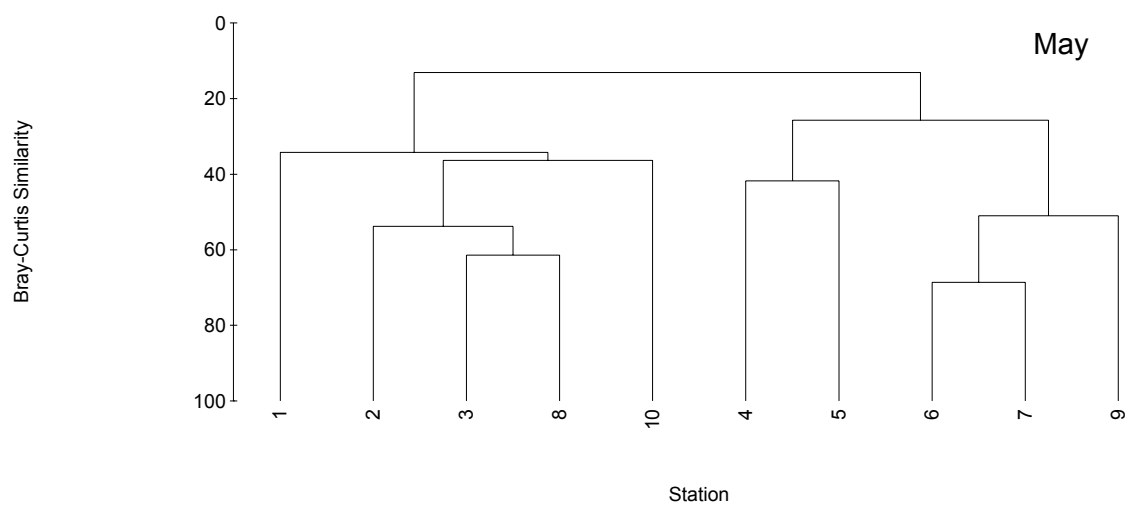
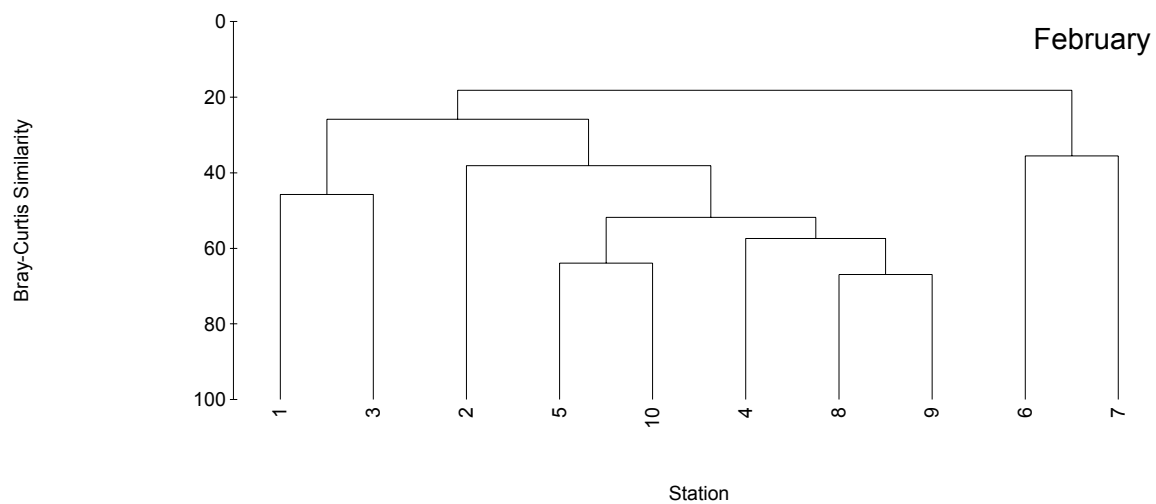


Figure G-19 Percentage abundance of the hyperbenthos in the Kromme Estuary. Data are for four sampling trips in 2004.

Table G-12 The number of species and percentage contribution of the three most abundant hyperbenthic taxa on each of the four sampling trips to the Kromme Estuary, 2004.

	February	May	July	November
Number of taxa	18	18	14	14
Brachyuran larvae	75	21	15	67
Mysids	7	74	67	26
Coelenterata	9	-	-	-
Amphipods	-	-	11	3
Pisces	-	4	-	3

Bray-Curtis similarity analysis using group average mode on square-root transformed data (Data from Attachment A^G, Tables 7-10) showed no regular pattern between sampling trips (Figure G-20) for the hyperbenthos. The relative mobility of hyperbenthic organisms and similar salinity values at all stations probably explains observed distribution patterns. MDS plots also showed an irregular pattern between sampling trips, with no trend emerging from the data.



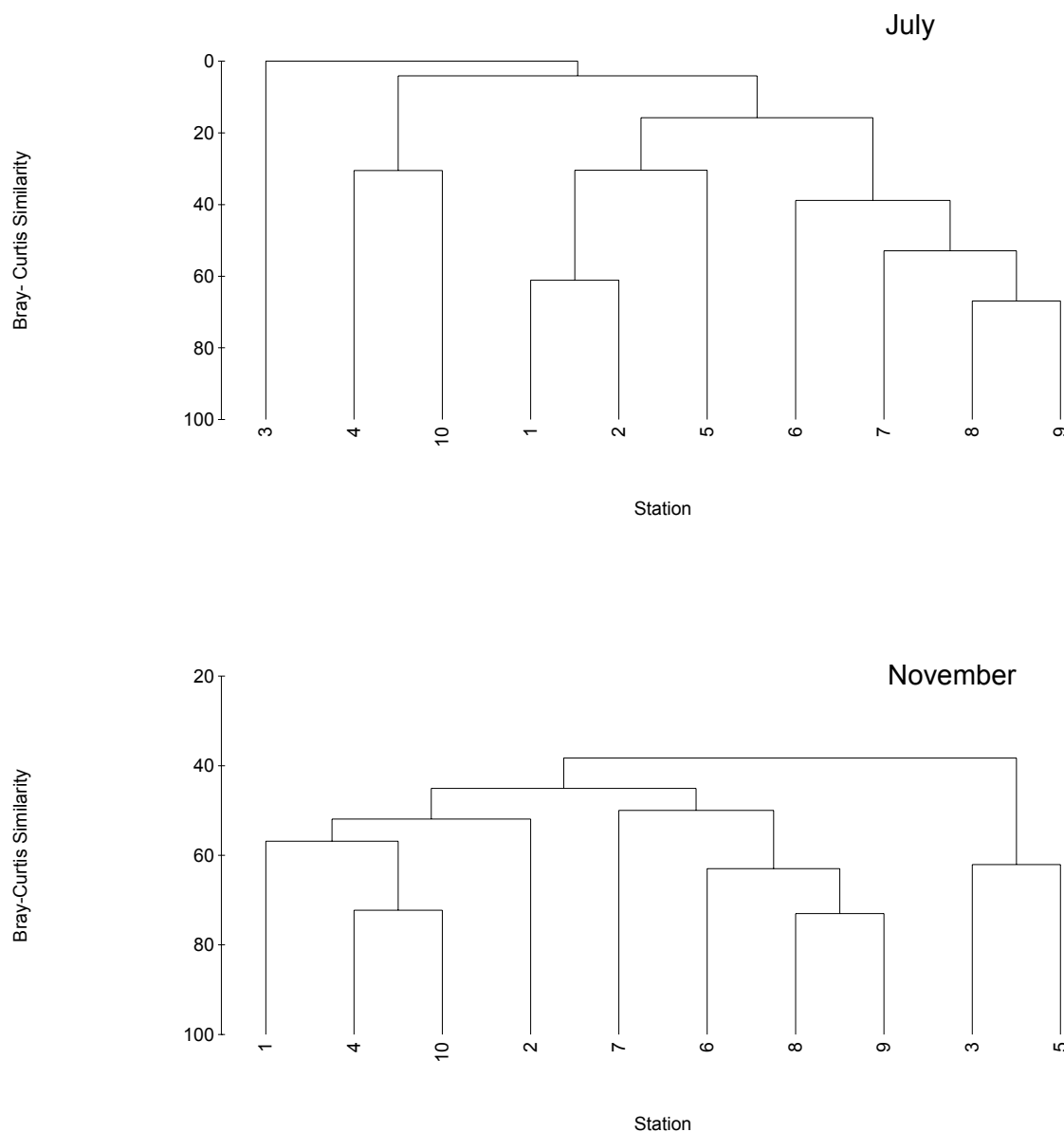


Figure G-20 Dendrogram for Bray-Curtis similarity clustering of sites based on composition and abundance of the hyperbenthos of the Kromme River estuary. Data for February, May, July and November 2004.

Environmental variables (Tables G-5 to G-8) were then linked to the appropriate biotic assemblage data (Attachment A^G, Tables 7-10) using the PRIMER package BIO-ENV in order to establish which of the physico-chemical parameters best explain linkages. A Draftsman Plot was first performed in order to exclude closely correlated variables. Consequently, surface and bottom salinity, surface and bottom temperature, surface and bottom turbidity, and all O₂ data except integrated saturation (%) were excluded from further analysis for each of the four sampling trips. Results are summarised in Table G-13.

Table G-13. Correlation between the hyperbenthic species assemblage and environmental variables for each of the four sampling trips to the Kromme Estuary, 2004.

Month	Variables	Correlation	Comments
February	Cha Integrated Mud (%) Fine-med sand (%) Organic matter (%)	69%	No factor dominating the suite of variables.
May	Salinity surface (ppt) O ₂ surface (%) pH Fine-med sand (%)	36%	No factor dominating the suite of variables.
July	Fine-med sand (%) Coarse sand (%)	63%	No factor dominating the suite of variables.
November	Sediment data not available		

Only three species were numerically important in the Kromme samples (Attachment A^G Tables 7 to 10); *Hymenosoma orbiculare* larvae and the mysids *Mesopodopsis wooldridgei* and *Rhopalophthalmus terranatalis*. Although dominating the hyperbenthos in the Kromme, abundance levels were low to medium in comparison to other estuaries in the region.

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Attachment A^G

Table 1 Zooplankton species composition and numbers m³ at 10 stations in the Kromme Estuary and Geelhoutboom tributary (see Figure G-3). Data are mean values for two surveys undertaken in June and November 1978. Stations 6 and 7 are in the Geelhoutboom tributary. (-) denotes absence of species.

Station	1	2	3	4	5	6	7	8	9	10
Annelida										
Polychaete larvae	92	-	-	-	-	-	-	-	-	-
Copepoda										
<i>Acartia longipatella</i>	-	2942	5375	8083	2702	8221	3098	7945	1782	1586
<i>A. natalensis</i>	-	-	-	20	-	-	1245	-	-	127
Copepod sp.	439	158	96	158	85	-	67	126	283	222
<i>Corycaeus</i> sp.	12	-	-	-	-	-	-	-	-	-
<i>Euterpina acutifrons</i>	23	15	-	-	-	-	-	-	-	-
<i>Microseppella norvegica</i>	23	-	-	-	-	-	-	-	-	-
Nauplii larvae	162	4938	4491	10472	3492	13208	5080	10036	2080	3405
<i>Oithona</i> sp.	509	-	-	-	-	-	-	-	-	-
<i>Oncaea</i> sp.	46	-	-	-	-	-	-	-	-	-
<i>Paracalanus crassirostris</i>	23	-	-	-	-	-	-	-	-	-
<i>Pseudodiaptomus hessei</i>	-	666	10906	11371	12592	12935	13652	7026	5094	4404
<i>Pseudodiaptomus nudus</i>	23	-	-	-	-	-	-	-	-	-
<i>Tortanus capensis</i>	-	-	-	-	-	-	-	167	-	-
Mysidacea										
<i>Gastrosaccus brevifissura</i>	17	346	22	12	17	13	-	4	8	2
<i>Mesopodopsis wooldridgei</i>	1	1	298	109	279	606	270	360	160	13
<i>Rhopalophthalmus terranatalis</i>	-	-	9	13	4	55	42	11	19	3
Cumacea										
<i>Iphinoe truncata</i>	15	1	-	-	-	-	-	1	-	-
Amphipoda										
<i>Melita zeylanica</i>	-	-	-	-	-	-	-	4	-	-
Brachyura										
Megalopa larvae	8	8	2	-	-	-	-	32	-	-
Zoea larvae	6	58	-	20	-	2	-	212	121	91
Chaetognatha										
<i>Sagita</i> sp.	23	-	-	-	-	-	-	-	-	-

Table 2 Zooplankton species composition and numbers m³ at 7 stations in the Kromme Estuary and Geelhoutboom tributary (see Figure G-3). Data are mean values for 15 surveys undertaken between May 1996 and July 1997. Stations 6 and 7 are in the Geelhoutboom tributary. (-) denotes absence of species.

Station	3	4	5	6	7	8	10
Polychaeta							
Polychaete larvae	3.3	0.3	-	0.5	-	-0	0.8
Copepoda							
<i>Acartia longipatella</i>	18.4	1037.9	2525.2	3697.5	13303.7	8563.8	4521.5
<i>A. natalensis</i>	-	2.4	4.2	5.1	193.1	43.4	128.8
Copepod spp.	903.5	187.5	76.3	505.5	232.7	98.7	56.8
<i>Oithona</i> spp.	50.7	25.8	5.1	-	-	1.7	1.4
<i>Oncaea</i> sp.	15.8	7.4	-	-	-	-	0.3
<i>Pseudodiaptomus hessei</i>	100.6	4908.7	7283.4	14168.2	3752.8	7530.4	10967.7
<i>Tortanus capensis</i>	-	-	-	0.1	-	0.6	1.4
Mysidacea							
<i>Gastrosaccus brevifissura</i>	121.5	128.0	42.1	24.7	1.3	14.9	10.3
<i>Mesopodopsis wooldridgei</i>	3.1	16.2	17.6	243.8	74.2	84.0	54.6
<i>Rhopalophthalmus terranatalis</i>	1.1	1.8	5.3	17.7	9.5	11.9	7.0
Cumacea							
Cumacean spp.	-	3.0	-	-	-	-	-
<i>Iphinoe truncata</i>	121.8	17.8	13.2	3.3	1.1	1.8	0.6
Tanaidacea							
<i>Apseudes digitalis</i>	-	-	1.5	1.8	-	0.3	0.2
Isopoda							
<i>Cirolana fluviatilis</i>	-	0.5	0.3	22.5	3.0	0.5	1.9
<i>Corallana africana</i>	-	-	-	0.2	0.5	1.4	0.3
Sphaeromid sp.	4.3	-	-	-	-	-	-
Amphipoda							
Amphipoda spp.	24.9	-	-	-	-	-	-
<i>Corophium triaenonyx</i>	0.4	0.4	0.3	0.5	-	0.3	0.4
<i>Grandidierella lignorum</i>	10.7	19.4	14.3	7.7	2.5	12.1	5.0
<i>Melita zeylanica</i>	-	-	-	-	0.3	-	-
<i>Urothoe serrulidactylus</i>	0.2	-	-	-	-	-	-
Caridea							
<i>Palaemon peringueyi</i> postlarvae	0.1	-	-	2.1	-	-	-
Anomura							
<i>Upogebia africana</i> stage 1	341.6	74.7	34.3	56.1	0.2	18.5	19.9
<i>Upogebia africana</i> postlarvae	0.2	-	-	-	-	-	-
Brachyura							
<i>Hymenosoma orbiculare</i>	0.1	1.0	-	-	-	0.1	0.4
<i>Paratyloidioplax edwardsii</i> larvae	1405.1	404.5	1269.8	1431.6	20.8	178.7	214.2
Zoea larvae	300.3	109.1	176.7	208.7	242.2	199.7	119.8
Chaetognatha							
<i>Sagitta</i> sp.	-	-	-	-	-	-	-
Pisces							
<i>Gilchristella aestuaria</i> eggs	1.9	1.1	6.1	0.9	9.5	6.7	8.5
<i>Gilchristella aestuaria</i> larvae	-	2.1	15.3	4.3	11.8	38.5	109.5
Gobiid larvae	-	-	0.3	1.5	0.7	-	1.5

Table 3 Composition and abundance (numbers m⁻²) of macrozoobenthos collected February 2004 at 10 stations in the Kromme Estuary. Stations 6 and 7 are located in the Geelhoutboom tributary (Figure G-3). (-) denotes absence of species.

Station	1	2	3	4	5	6	7	8	9	10
Polychaeta										
Species 1	-	-	-	-	-	-	-	-	-	-
Species 2	1900.0	1391.7	491.7	25.0	-	-	-	-	-	-
Species 3	-	-	-	-	-	-	-	-	-	-
Species 4	-	-	-	-	-	-	-	-	-	-
Species 5	-	-	-	-	-	-	-	-	-	-
<i>Boccardia</i> sp.	-	-	-	-	-	-	-	-	-	-
<i>Capitella capitata</i>	8.3	-	-	8.3	-	33.3	-	-	50.0	375.0
<i>Ceratonereis keiskama</i>	-	-	41.7	-	-	-	-	-	-	8.3
<i>Cirratulid</i> sp. 1	-	8.3	-	-	16.7	-	-	-	-	-
<i>Cirratulid</i> sp. 2	-	-	-	16.7	16.7	-	-	16.7	350.0	-
<i>Cossura</i> sp.	-	16.7	-	-	-	-	-	-	25.0	41.7
<i>Dendronereis arborifera</i>	-	-	-	-	16.7	-	-	-	-	-
<i>Desdemona ornata</i>	8.3	-	-	16.7	16.7	-	33.3	8.3	41.7	41.7
<i>Eteone siphodonta</i>	-	-	-	-	-	-	-	16.7	25.0	-
<i>Glycera alba</i>	-	-	-	-	-	-	-	-	-	-
<i>Glycera tridactyla</i>	-	-	-	-	-	-	-	8.3	-	-
<i>Glycera</i> sp.	-	-	-	-	-	-	-	-	-	-
<i>Heteromastus</i> sp 1	-	16.7	16.7	-	33.3	-	0.0	16.7	150.0	16.7
<i>Heteromastus</i> sp 2	-	8.3	-	250.0	75.0	100.0	8.3	75.0	25.0	141.7
<i>Heteromastus</i> sp 3	-	-	-	-	-	-	-	-	-	-
<i>Nephtys sphaerocirrata</i>	-	-	-	-	-	-	-	-	-	-
<i>Orbinia angrapequensis</i>	16.7	-	33.3	50.0	25.0	-	-	16.7	8.3	25.0
<i>Paraonis</i> sp.	-	50.0	-	8.3	-	-	-	66.7	-	16.7
<i>Prionospio bocki</i>	-	-	-	16.7	50.0	8.3	133.3	150.0	225.0	558.3
<i>Prionospio sexoculata</i>	16.7	33.3	50.0	8.3	-	-	58.3	125.0	-	-
<i>Sabella</i> sp.	16.7	-	-	25.0	-	-	-	-	-	-
Unidentified sp. 1 (Juvenile)	-	-	-	-	-	91.7	-	-	-	-
Unidentified sp. 2 (Juvenile)	-	-	-	-	-	25.0	-	-	-	-
Mysidacea										
<i>Gastrosaccus brevifissura</i>	16.7	-	16.7	-	-	-	-	-	-	-
Cumacea										
<i>Iphinoe truncata</i>	16.7	50.0	25.0	-	-	-	-	-	-	-
Tanadeceae										
<i>Apseudes digitalis</i>	-	-	-	-	-	-	-	-	-	8.3
Isopoda										
Isopod sp.	-	-	-	-	-	-	16.7	-	-	-
<i>Coralana africana</i>	-	-	-	-	-	-	16.7	-	-	-
<i>Cyathura estuaria</i>	-	-	-	-	16.7	-	8.3	-	-	-
Amphipoda										
<i>Grandidierella lignorum</i>	-	-	-	-	-	-	58.3	-	-	-
<i>Urothoe serrulidactylus</i>	100.0	-	1075.0	8.3	-	-	-	-	-	-
<i>Xenathura</i> sp.	-	-	-	91.7	16.7	-	83.3	-	16.7	-
Anomura										
<i>Upogepia africana</i>	-	-	-	8.3	-	-	-	-	-	-

Station	1	2	3	4	5	6	7	8	9	10
Brachyura										
<i>Hymenosoma orbiculare</i>	-	-	-	-	-	-	8.3	-	8.3	-
<i>Paratyloidiplax blephariskios</i>	-	-	-	41.7	33.3	8.3	-	-	25.0	-
<i>Paratyloidiplax algoense</i>	-	-	-	16.7	-	-	-	-	8.3	-
<i>Thaumastoplax spiralis</i>	-	-	-	25.0	-	-	8.3	-	16.7	-
Mollusca										
<i>Bullia laevissima</i>	-	-	-	-	-	-	-	-	-	-
<i>Macoma litoralis</i>	-	-	-	91.7	66.7	16.7	25.0	33.3	-	-
<i>Modiolus capensis</i>	-	-	-	16.7	-	-	-	25.0	-	-
<i>Nassa kraussiana</i>	-	-	-	-	-	-	-	-	-	-
<i>Sanguinolaria capensis</i>	25.0	8.3	16.7	-	-	-	-	-	-	-
<i>Solen capensis</i>	-	-	-	-	25.0	-	-	-	-	-
<i>Tapes sulcarius</i>	-	-	-	-	-	-	8.3	16.7	-	-
<i>Tivela</i> sp.	-	-	-	-	-	-	-	-	-	-

Table 4 Composition and abundance (numbers m⁻²) of macrozoobenthos collected May 2004 at 10 stations in the Kromme Estuary. Stations 6 and 7 are located in the Geelhoutboom tributary (Figure G-3). (-) denotes absence of species.

Station	1	2	3	4	5	6	7	8	9	10
Polychaeta										
Species 1	25.0	-	16.7	-	-	-	-	-	-	-
Species 2	9750.0	5141.7	4466.7	-	66.7	-	-	-	50.0	16.7
Species 3	-	-	-	-	-	8.3	-	-	-	-
Species 4	16.7	-	-	-	75.0	-	-	-	-	-
Species 5	-	-	8.3	-	-	-	-	-	-	-
<i>Boccardia</i> sp.	-	-	-	-	-	-	-	-	58.3	16.7
<i>Capitella capitata</i>	8.3	8.3	16.7	-	-	8.3	-	-	16.7	108.3
<i>Ceratonereis keiskama</i>	8.3	8.3	-	-	-	-	-	-	458.3	-
<i>Cirratulid</i> sp. 1	8.3	8.3	16.7	-	-	8.3	-	-	-	-
<i>Cirratulid</i> sp. 2	-	-	-	83.3	41.7	-	-	75.0	-	16.7
<i>Cossura</i> sp.	-	-	-	-	-	-	-	-	-	75.0
<i>Dendronereis arborifera</i>	-	-	16.7	-	-	-	-	-	8.3	-
<i>Desdemona ornata</i>	8.3	-	-	8.3	-	-	-	-	41.7	-
<i>Eteone siphodonta</i>	8.3	-	16.7	191.7	16.7	-	-	41.7	58.3	116.7
<i>Glycera alba</i>	-	-	-	-	-	-	8.3	-	-	-
<i>Glycera tridactyla</i>	8.3	-	-	-	-	-	-	-	-	-
<i>Glycera</i> sp.	-	-	-	-	-	-	-	-	-	-
<i>Heteromastus</i> sp 1	-	8.3	-	-	-	141.7	-	66.7	58.3	-
<i>Heteromastus</i> sp 2	-	-	8.3	333.3	25.0	25.0	8.3	100.0	16.7	8.3
<i>Heteromastus</i> sp 3	-	-	-	75.0	25.0	-	-	-	-	-
<i>Nephtys sphaerocirrata</i>	250.0	50.0	58.3	-	-	-	-	-	-	-
<i>Orbinia angrapequensis</i>	41.7	16.7	66.7	41.7	8.3	-	-	25.0	16.7	16.7
<i>Paraonis</i> sp.	16.7	-	-	8.3	-	-	-	-	-	-
<i>Prionospio bocki</i>	-	-	-	16.7	-	75.0	41.7	8.3	-	83.3
<i>Prionospio sexoculata</i>	100.0	16.7	50.0	-	-	-	-	-	-	-
<i>Sabella</i> sp.	-	8.3	-	-	8.3	-	-	-	-	-
Unidentified sp. 1 (Juvenile)	-	-	-	33.3	-	-	-	-	-	-
Unidentified sp. 2 (Juvenile)	-	-	-	33.3	-	-	-	83.3	66.7	-
Mysidacea										
<i>Gastrosaccus brevifissura</i>	-	8.3	-	-	-	-	-	-	-	-
Cumacea										
<i>Iphinoe truncata</i>	33.3	-	33.3	-	-	-	-	-	-	-
Tanadecea										
<i>Apseudes digitalis</i>	-	-	-	-	-	16.7	2141.7	-	-	-
Isopoda										
Isopod sp.	-	-	8.3	8.3	-	-	50.0	16.7	8.3	-
<i>Coralana africana</i>	-	-	-	-	-	-	-	-	41.7	-
<i>Cyathura estuaria</i>	-	-	-	-	8.3	-	8.3	-	-	-
Amphipoda										
<i>Grandidierella lignorum</i>	-	-	-	-	-	-	-	-	-	-
<i>Urothoe serrulidactylus</i>	-	-	-	-	-	-	-	-	-	-
<i>Xenathura</i> sp.	-	16.7	8.3	266.7	233.3	16.7	316.7	8.3	366.7	8.3
Anomura										
<i>Upogepia africana</i>	-	-	-	-	-	-	-	-	-	-
<i>Hymenosoma orbiculare</i>	-	-	-	8.3	16.7	-	-	-	41.7	-
<i>Paratyloplax blephariskios</i>	-	-	-	133.3	16.7	-	-	41.7	-	-

Station	1	2	3	4	5	6	7	8	9	10
<i>Paratyloidiplax algoense</i>	-	-	-	-	50.0	-	-	16.7	-	-
<i>Thaumastoplax spiralis</i>	-	-	-	25.0	8.3	-	-	16.7	16.7	-
Mollusca										
<i>Bullia laevissima</i>	-	-	-	-	-	-	-	-	-	-
<i>Macoma litoralis</i>	-	-	-	16.7	33.3	25.0	250.0	25.0	75.0	-
<i>Modiolus capensis</i>	-	-	-	-	-	-	-	-	83.3	8.3
<i>Nassa kraussiana</i>	-	-	-	-	-	-	-	-	-	-
<i>Sanguinolaria capensis</i>	16.7	16.7	8.3	-	-	-	-	-	-	-
<i>Solen capensis</i>	-	-	-	-	16.7	-	-	-	-	-
<i>Tapes sulcarius</i>	-	-	-	-	8.3	-	-	-	41.7	8.3
<i>Tivela</i> sp.	-	-	-	-	-	-	-	-	33.3	-

Table 5 Composition and abundance (numbers m⁻²) of macrozoobenthos collected July 2004 at 10 stations in the Kromme Estuary. Stations 6 and 7 are located in the Geelhoutboom tributary (Figure G-3). (-) denotes absence of species.

Station	1	2	3	4	5	6	7	8	9	10
Polychaeta										
Species 1	25.0	16.7	8.3	-	41.7	-	-	58.3	-	-
Species 2	1725.0	1333.3	1658.3	33.3	-	-	-	-	-	-
Species 3	-	-	-	-	-	-	-	-	-	-
Species 4	-	-	-	-	25.0	-	-	-	-	-
Species 5	-	-	-	-	-	-	-	-	-	-
<i>Boccardia</i> sp.	-	-	-	-	-	-	-	-	116.7	-
<i>Capitella capitata</i>	-	-	50.0	16.7	8.3	-	-	16.7	283.3	183.3
<i>Ceratonereis keiskama</i>	-	-	-	-	-	-	-	-	766.7	-
<i>Cirratulid</i> sp. 1	41.7	-	-	16.7	8.3	-	-	41.7	116.7	8.3
<i>Cirratulid</i> sp. 2	-	-	8.3	16.7	241.7	8.3	-	-	458.3	8.3
<i>Cossura</i> sp.	-	-	-	-	-	-	-	-	8.3	-
<i>Dendronereis arborifera</i>	-	-	-	-	-	-	-	-	-	-
<i>Desdemona ornata</i>	-	-	-	25.0	83.3	33.3	8.3	8.3	1033.3	16.7
<i>Eteone siphodonta</i>	-	-	-	108.3	16.7	16.7	0.0	108.3	58.3	58.3
<i>Glycera alba</i>	-	-	-	-	-	-	-	-	108.3	-
<i>Glycera tridactyla</i>	100.0	-	-	-	-	-	-	-	-	8.3
<i>Glycera</i> sp.	-	-	-	-	-	-	-	-	-	-
<i>Heteromastus</i> sp 1	-	-	-	41.7	8.3	-	-	8.3	175.0	250.0
<i>Heteromastus</i> sp 2	-	-	-	325.0	8.3	158.3	50.0	366.7	100.0	8.3
<i>Heteromastus</i> sp 3	-	-	-	-	-	-	-	-	-	-
<i>Nephtys sphaerocirrata</i>	333.3	-	16.7	8.3	16.7	-	-	-	-	-
<i>Orbinia angrapequensis</i>	-	-	33.3	66.7	8.3	-	-	208.3	216.7	325.0
<i>Paraonis</i> sp.	-	-	-	-	-	-	-	-	-	-
<i>Prionospio bocki</i>	-	-	8.3	33.3	16.7	383.3	400.0	300.0	8.3	91.7
<i>Prionospio sexoculata</i>	33.3	-	41.7	8.3	16.7	-	8.3	41.7	66.7	-
<i>Sabella</i> sp.	-	-	-	-	-	-	-	-	8.3	-
Unidentified sp. 1 (Juvenile)	-	-	-	-	-	-	-	-	-	-
Unidentified sp. 2 (Juvenile)	-	-	-	-	-	-	-	-	-	-
Mysidacea										
<i>Gastrosaccus brevifissura</i>	-	-	-	-	-	-	-	-	-	-
Cumacea										
<i>Iphinoe truncata</i>	16.7	-	8.3	-	8.3	-	-	-	16.7	-
Tanadecea										
<i>Apseudes digitalis</i>	-	-	-	-	-	75.0	5566.7	16.7	-	-
Isopoda										
Isopod sp.	-	-	-	-	-	16.7	158.3	25.0	-	-
<i>Coralana africana</i>	-	-	-	-	-	-	-	-	25.0	-
<i>Cyathura estuaria</i>	-	-	-	-	8.3	-	33.3	16.7	8.3	-
Amphipoda										
<i>Grandidierella lignorum</i>	-	-	-	-	8.3	41.7	983.3	-	41.7	8.3
<i>Urothoe serrulidactylus</i>	-	16.7	-	-	-	-	-	-	25.0	-
<i>Xenathura</i> sp.	-	-	-	308.3	250.0	-	425.0	8.3	166.7	8.3
Anomura										
<i>Upogepia africana</i>	-	8.3	-	8.3	8.3	-	-	-	8.3	-
<i>Hymenosoma orbiculare</i>	-	-	-	-	-	-	-	-	8.3	8.3
<i>Paratyloplax blephariskios</i>	-	-	-	241.7	41.7	-	-	25.0	-	-

Station	1	2	3	4	5	6	7	8	9	10
<i>Paratyloidiplax algoense</i>	-	-	-	33.3	8.3	-	-	8.3	-	-
<i>Thaumastoplax spiralis</i>	-	-	-	33.3	-	-	-	-	-	-
Mollusca										
<i>Bullia laevissima</i>	-	-	-	-	-	-	-	-	-	-
<i>Macoma litoralis</i>	-	-	-	-	16.7	33.3	108.3	50.0	100.0	8.3
<i>Modiolus capensis</i>	-	-	-	8.3	8.3	16.7	-	8.3	241.7	16.7
<i>Nassa kraussiana</i>	-	-	-	8.3	-	-	-	-	-	8.3
<i>Sanguinolaria capensis</i>	-	16.7	33.3	-	-	-	-	-	25.0	-
<i>Solen capensis</i>	-	-	-	8.3	-	-	-	-	41.7	8.3
<i>Tapes sulcarius</i>	-	-	-	-	8.3	-	8.3	25.0	-	-
<i>Tivela</i> sp.	-	-	-	-	-	-	-	-	-	-

Table 6 Composition and abundance (numbers m⁻²) of macrozoobenthos collected November 2004 at 10 stations in the Kromme Estuary. Stations 6 and 7 are located in the Geelhoutboom tributary (Figure G-3). (-) denotes absence of species.

Station	1	2	3	4	5	6	7	8	9	10
Polychaeta										
Species 1	-	-	-	-	-	-	-	-	-	-
Species 2	3491.7	2716.7	625.0	-	-	-	-	-	8.3	25.0
Species 3	-	-	-	-	-	-	-	-	-	-
Species 4	-	-	16.7	8.3	25.0	-	-	-	-	-
Species 5	-	-	-	-	-	-	-	-	-	-
<i>Boccardia</i> sp.	16.7	-	-	-	-	-	-	-	-	-
<i>Capitella capitata</i>	8.3	16.7	-	16.7	-	8.3	-	-	-	358.3
<i>Ceratonereis keiskama</i>	8.3	25.0	-	-	-	8.3	-	-	250.0	16.7
<i>Cirratulid</i> sp. 1	8.3	8.3	-	-	-	-	-	-	-	-
<i>Cirratulid</i> sp. 2	-	-	-	8.3	8.3	25.0	-	225.0	16.7	166.7
<i>Cossura</i> sp.	-	-	-	-	-	-	-	-	-	8.3
<i>Dendronereis arborifera</i>	-	-	-	-	-	-	-	-	-	-
<i>Desdemona ornata</i>	-	-	-	-	33.3	-	16.7	8.3	8.3	8.3
<i>Eteone siphodonta</i>	-	8.3	8.3	33.3	58.3	33.3	-	116.7	-	58.3
<i>Glycera alba</i>	-	-	-	-	-	-	-	8.3	-	-
<i>Glycera tridactyla</i>	-	-	-	-	-	-	-	-	-	-
<i>Glycera</i> sp.	-	-	-	-	-	-	-	-	-	-
<i>Heteromastus</i> sp 1	-	-	-	-	8.3	33.3	-	-	-	-
<i>Heteromastus</i> sp 2	-	-	-	8.3	16.7	83.3	-	16.7	8.3	-
<i>Heteromastus</i> sp 3	-	8.3	-	-	-	-	-	-	-	-
<i>Nephtys sphaerocirrata</i>	33.3	-	-	-	-	-	-	-	-	-
<i>Orbinia angrapequensis</i>	-	33.3	8.3	100.0	141.7	-	-	83.3	408.3	391.7
<i>Paraonis</i> sp.	8.3	-	8.3	16.7	-	-	-	-	-	83.3
<i>Prionospio bocki</i>	8.3	33.3	-	33.3	25.0	33.3	466.7	16.7	8.3	108.3
<i>Prionospio sexoculata</i>	25.0	8.3	25.0	-	-	-	-	-	-	-
<i>Sabella</i> sp.	8.3	-	-	-	-	-	-	-	-	-
Unidentified sp. 1 (Juvenile)	-	-	-	66.7	25.0	-	-	-	-	-
Unidentified sp. 2 (Juvenile)	-	-	-	-	-	-	-	66.7	-	75.0
Mysidacea										
<i>Gastrosaccus brevifissura</i>	25.0	58.3	25.0	-	-	-	-	-	-	-
Cumacea										
<i>Iphinoe truncata</i>	133.3	75.0	141.7	-	-	-	-	-	-	-
Tanadecea										
<i>Apseudes digitalis</i>	8.3	-	-	25.0	-	-	8350.0	8.3	-	-
Isopoda										
Isopod sp.	25.0	8.3	-	16.7	-	-	33.3	33.3	33.3	-
<i>Coralana africana</i>	-	-	-	-	-	-	16.7	-	50.0	-
<i>Cyathura estuaria</i>	-	-	-	-	-	-	275.0	-	-	-
Amphipoda										
<i>Grandidierella lignorum</i>	-	-	-	-	33.3	-	233.3	-	-	-
<i>Urothoe serrulidactylus</i>	-	-	-	-	-	-	-	-	-	-
<i>Xenathura</i> sp.	-	16.7	-	141.7	183.3	8.3	241.7	16.7	33.3	8.3
Anomura										
<i>Upogepia africana</i>	-	-	-	-	-	-	-	-	-	-
Brachyura										
<i>Hymenosoma orbiculare</i>	-	8.3	-	-	16.7	-	-	16.7	-	-

Station	1	2	3	4	5	6	7	8	9	10
<i>Paratyloidiplax blephariskios</i>	-	-	8.3	333.3	83.3	-	-	50.0	-	-
<i>Paratyloidiplax algoense</i>	-	-	-	-	-	-	-	-	-	-
<i>Thaumastoplax spiralis</i>	-	-	8.3	25.0	-	-	-	-	-	-
Mollusca										
<i>Bullia laevissima</i>	-	-	-	-	-	-	-	-	-	-
<i>Macoma litoralis</i>	-	-	8.3	-	33.3	116.7	200.0	116.7	8.3	25.0
<i>Modiolus capensis</i>	-	-	-	8.3	8.3	8.3	-	8.3	-	158.3
<i>Nassa kraussiana</i>	-	-	-	-	-	-	-	-	-	-
<i>Sanguinolaria capensis</i>	8.3	33.3	-	-	-	-	8.3	-	-	-
<i>Solen capensis</i>	-	-	-	-	-	8.3	-	-	-	-
<i>Tapes sulcarius</i>	-	-	-	-	-	-	-	-	33.3	-
<i>Tivela</i> sp.	-	-	-	-	16.7	-	-	8.3	33.3	-

Table 7 Composition and abundance (numbers m⁻²) of Hyperbenthos collected February 2004 at 10 stations in the Kromme Estuary. Stations 6 and 7 are located in the Geelhoutboom tributary (Figure G-3). (-) denotes absence of species.

Station	1	2	3	4	5	6	7	8	9	10
Coelenterata										
Hydra medusa	-	-	0.3	8.5	22.7	6.6	104.3	16.3	-	-
Mysidacea										
<i>Gastrosaccus brevifissura</i>	-	0.9	0.1	0.0	-	-	-	-	-	-
<i>Mesopodopsis wooldridgei</i>	-	-	-	23.1	-	19.9	25.4	-	4.0	-
<i>Rhopalophthalmus terranatalis</i>	-	-	-	-	-	-	50.1	-	-	-
Cumacea										
Cumacean spp	0.8	1.9	-	-	-	-	-	-	-	-
<i>Ipipinoe truncata</i>	-	-	0.4	-	-	-	-	-	-	-
Ipipinoe sp. 1	-	-	-	-	-	-	-	-	-	-
Tanaidacea										
<i>Apseudes digitalis</i>	-	-	-	-	-	-	-	-	-	-
Isopoda										
Anthurid sp.	-	-	-	-	-	-	-	-	-	-
<i>Cirolana fluviatilis</i>	-	-	-	-	-	-	-	-	-	-
<i>Horoloanthura capensis</i>	-	-	-	-	-	-	-	-	-	-
<i>Paridotea unguolata</i>	-	-	-	-	-	-	-	-	-	-
Amphipoda										
<i>Afrochiltonia capensis</i>	-	-	-	-	-	-	10.2	-	-	-
<i>Corophium triaenonyx</i>	-	0.9	-	-	-	-	-	-	-	-
<i>Grandidierella lignorum</i>	-	-	-	-	-	-	12.7	-	-	-
<i>Lysianasa ceritina</i>	-	-	-	-	-	4.4	-	-	4.0	-
Decapoda										
Decapod larvae	-	0.9	0.1	0.6	-	-	10.2	-	4.0	-
Caridea										
<i>Palaemon peringueyi</i>	-	-	-	-	-	-	-	-	-	-
Anomura										
<i>Upogebia africana</i> stage 1	-	-	0.7	-	-	-	-	-	-	-
Brachyura										
<i>Hymenosoma orbiculare</i> larvae	3.6	32.0	5.9	234.3	61.6	-	10.2	170.9	193.8	118.5
<i>Hymenosoma orbiculare</i>	-	-	-	-	-	2.2	-	-	4.0	-
Porcellinidea spp. 1 larvae	-	-	-	-	-	-	-	-	-	-
<i>Sesarma catenata</i> larvae	3.2	-	1.1	-	13.9	-	-	149.8	88.8	40.8
<i>Sesarma</i> sp. 1 larvae	-	30.1	3.4	9.7	-	-	-	70.8	40.4	-
Zoea larvae	-	-	-	-	-	-	-	-	-	-
Pisces										
Fish eggs	-	-	-	-	-	-	-	6.6	-	-
Fish larvae	-	-	0.1	9.1	6.8	4.4	10.2	66.4	-	-

Table 8 Composition and abundance (numbers m⁻²) of Hyperbenthos collected in May 2004 at 10 stations in the Kromme Estuary. Stations 6 and 7 are located in the Geelhoutboom tributary (Figure G-3). (-) denotes absence of species.

Station	1	2	3	4	5	6	7	8	9	10
Coelenterata										
Hydra medusa	-	-	-	-	-	-	1.7	-	-	-
Mysidacea										
<i>Gastrosaccus brevifissura</i>	-	-	-	-	-	-	-	-	1.5	-
<i>Mesopodopsis wooldridgei</i>	0.3	-	0.9	4.0	3.5	291.6	154.7	-	154.7	-
<i>Rhopalophthalmus terranatalis</i>	-	0.1	-	4.0	8.7	-	-	-	6.8	-
Cumacea										
Cumacean spp	-	-	-	-	-	-	-	-	-	-
<i>Iphinoe truncata</i>	0.2	0.3	0.9	-	-	-	-	-	-	-
<i>Iphinoe</i> sp. 1	0.9	-	-	-	-	-	-	-	-	-
Tanaidacea										
<i>Apseudes digitalis</i>	-	-	-	-	1.7	-	-	-	-	-
Isopoda										
Anthurid sp.	-	-	-	-	-	-	-	-	-	-
<i>Cirolana fluviatilis</i>	-	0.1	-	-	-	-	-	-	-	-
<i>Horoloanthura capensis</i>	-	-	-	1.0	-	-	-	-	-	-
<i>Paridotea unguolata</i>	-	-	-	-	-	-	-	-	0.8	-
Amphipoda										
<i>Afrochiltonia capensis</i>	-	-	-	-	1.7	2.1	-	-	-	-
<i>Corophium triaenonyx</i>	-	-	-	-	-	-	-	-	-	-
<i>Grandidierella lignorum</i>	-	-	-	-	-	-	-	-	-	-
<i>Lysianasa ceritina</i>	-	-	-	-	1.7	-	1.7	-	-	-
Decapoda										
Decapod larvae	0.2	0.1	0.9	-	-	-	-	-	-	-
Caridea										
<i>Palaemon peringueyi</i>	-	-	-	-	-	-	-	-	-	-
Anomura										
<i>Upogebia africana</i> stage 1	0.2	-	-	-	-	-	-	-	-	-
Brachyura										
<i>Hymenosoma orbiculare</i> larvae	0.8	4.4	16.3	2.0	-	2.1	-	13.0	141.2	1.1
<i>Hymenosoma orbiculare</i>	-	-	-	-	1.7	-	-	-	3.0	-
Porcellinidea spp. 1 larvae	-	-	-	-	-	-	-	-	-	-
<i>Sesarma catenata</i> larvae	0.3	-	-	-	-	-	-	-	-	-
<i>Sesarma</i> sp. 1 larvae	-	-	-	-	-	-	-	-	-	-
Zoea larvae	-	-	-	-	-	-	-	-	-	-
Pisces										
Fish eggs	-	-	-	-	-	-	-	-	-	-
Fish larvae	-	-	-	4.0	-	-	1.7	1.7	27.8	-

Table 9 Composition and abundance (numbers m⁻²) of Hyperbenthos collected July 2004 at 10 stations in the Kromme Estuary. Stations 6 and 7 are located in the Geelhoutboom tributary (Figure G-3). (-) denotes absence of species.

Station	1	2	3	4	5	6	7	8	9	10
Coelenterata										
Hydra medusa	-	-	-	-	-	-	-	-	-	-
Mysidacea										
<i>Gastrosaccus brevifissura</i>	-	-	-	-	-	-	-	-	-	-
<i>Mesopodopsis wooldridgei</i>	0.1	-	-	-	0.8	1.6	4.7	32.3	30.8	-
<i>Rhopalophthalmus terranatalis</i>	-	-	-	-	-	0.8	8.8	27.2	8.6	-
Cumacea										
Cumacean spp	-	-	-	-	-	-	-	-	-	-
<i>Iphinoe truncata</i>	-	-	-	-	-	-	-	-	3.4	-
<i>Iphinoe</i> sp. 1	-	-	-	-	-	-	-	-	-	-
Tanaidacea										
<i>Apseudes digitalis</i>	-	-	-	-	-	-	-	-	-	-
Isopoda										
Anthurid sp.	-	-	-	-	-	-	-	-	-	-
<i>Cirolana fluviatilis</i>	-	-	-	-	-	-	-	-	-	-
<i>Horoloanthura capensis</i>	-	-	-	-	-	-	-	-	-	-
<i>Paridotea unguolata</i>	-	-	-	0.1	-	-	-	-	-	-
Amphipoda										
<i>Afrochiltonia capensis</i>	-	-	-	-	-	-	9.3	-	-	-
<i>Corophium triaenonyx</i>	-	-	-	-	-	-	-	-	-	-
<i>Grandidierella lignorum</i>	-	-	-	-	-	-	-	-	-	-
<i>Lysianasa ceritina</i>	-	-	-	-	-	1.6	-	2.4	5.1	-
Decapoda										
Decapod larvae	-	-	-	-	-	-	-	0.8	-	-
Caridea										
<i>Palaemon peringueyi</i>	-	-	-	0.8	-	-	-	-	-	-
Anomura										
<i>Upogebia africana</i> stage 1	-	-	-	-	-	-	-	-	-	-
Brachyura										
<i>Hymenosoma orbiculare</i> larvae	0.3	0.6	-	-	8.4	-	7.2	0.8	6.9	-
<i>Hymenosoma orbiculare</i>	-	-	-	0.2	-	-	-	-	1.7	-
Porcellinidea spp. 1 larvae	-	0.1	-	-	-	-	-	-	-	-
<i>Sesarma catenata</i> larvae	-	-	-	-	-	-	-	-	-	-
<i>Sesarma</i> sp. 1 larvae	-	0.1	-	-	-	-	-	-	-	-
Zoea larvae	-	-	-	-	-	-	-	-	-	-
Pisces										
Fish eggs	0.4	0.2	-	-	-	-	-	-	-	-
Fish larvae	-	-	-	0.3	-	1.6	3.1	-	3.4	0.2

Table 10

Composition and abundance (numbers m⁻²) of Hyperbenthos collected November 2004 at 10 stations in the Kromme Estuary. Stations 6 and 7 are located in the Geelhoutboom tributary (Figure G-3). (-) denotes absence of species.

Station	1	2	3	4	5	6	7	8	9	10
Coelenterata										
Hydra medusa	-	-	-	-	-	-	-	1.7	-	-
Mysidacea										
<i>Gastrosaccus brevifissura</i>	-	-	-	-	-	-	-	-	-	-
<i>Mesopodopsis wooldridgei</i>	-	-	8.3	4.2	12.8	208.7	-	2.5	33.0	-
<i>Rhopalophthalmus terranatalis</i>	-	-	-	-	-	27.7	1.2	3.3	-	-
Cumacea										
Cumacean spp	-	-	-	-	-	-	-	-	-	-
<i>Iphinoe truncata</i>	-	15.2	-	-	-	-	-	-	-	-
Iphinoe sp. 1	-	-	-	-	-	-	-	-	-	-
Tanaidacea										
<i>Apseudes digitalis</i>	-	-	-	-	-	-	3.7	-	-	-
Isopoda										
Anthurid sp.	-	-	-	-	-	-	-	-	-	-
<i>Cirolana fluviatilis</i>	-	-	-	-	-	1.6	-	-	-	-
<i>Horoloanthura capensis</i>	-	-	-	-	-	-	-	-	-	-
<i>Paridotea unguolata</i>	-	-	-	-	-	-	-	-	-	-
Amphipoda										
<i>Afrochiltonia capensis</i>	-	-	-	-	-	-	7.5	5.0	3.9	-
<i>Corophium triaenonyx</i>	-	-	-	-	-	-	-	-	-	-
<i>Grandidierella lignorum</i>	-	-	-	-	-	-	1.2	-	-	-
<i>Lysianasa ceritina</i>	-	-	-	-	3.5	4.9	8.7	5.9	-	-
Decapoda										
Decapod larvae	-	-	-	-	-	-	-	-	-	-
Caridea										
<i>Palaemon peringueyi</i>	-	-	-	-	-	-	-	-	-	-
Anomura										
<i>Upogebia africana</i> stage 1	-	-	-	-	-	-	-	-	-	-
Brachyura										
<i>Hymenosoma orbiculare</i> larvae	25.4	147.1	3.3	57.9	9.3	140.2	39.7	102.8	124.1	62.0
<i>Hymenosoma orbiculare</i>	-	-	-	-	2.5	-	2.5	-	-	-
Porcellinidea spp. 1 larvae	-	-	-	-	-	-	-	-	-	-
<i>Sesarma catenata</i> larvae	12.5	40.6	3.3	7.1	3.5	-	-	-	-	-
<i>Sesarma</i> sp. 1 larvae	-	-	-	-	-	-	-	-	-	-
Zoea larvae	-	-	-	2.8	-	-	-	-	-	-
Pisces										
Fish eggs	-	-	-	-	-	-	-	-	-	-
Fish larvae	-	-	6.7	9.9	-	6.5	1.2	6.7	3.9	5.0

APPENDIX H

FISH

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EXECUTIVE SUMMARY

A total of 46 fish species from 25 families have been recorded from the Kromme Estuary but some of these species are likely to be absent from the system during normal river flow conditions. Eleven species are dependent on estuaries for breeding purposes and include resident taxa such as the estuarine round-herring *Gilchristella aestuaria* and estuarine goby *Glossogobius callidus*. A total of 15 marine species, including the Cape stumpnose *Rhabdosargus holubi* and groovy mullet *Liza dumerili*, are dependent on estuaries as nursery areas. A further 10 marine species (e.g. blacktail *Diplodus sargus* and southern mullet *Liza richardsoni*) are at least partially dependent on estuaries as nursery areas. Eight of the remaining taxa were stenohaline marine species (e.g. sand steenbras *Lithognathus mormyrus* and zebra *Diplodus cervinus*) occur in the lower reaches where full seawater salinities prevail.

A limited number of freshwater fish species (e.g. Cape kurper *Sandelia capensis*) have been recorded in the headwaters of the Kromme Estuary but reduced river flow in recent decades has eliminated this component from the estuary. Anguillid eels (e.g. longfin eel *Anguilla mossambica*) and the freshwater mullet (*Myxus capensis*) make extensive use of the estuary during migrations to and from the river catchment. However, with the construction of the Impofu Dam upstream of the estuary head, the ability of these eels to colonise the Kromme catchment has been compromised.

Based on their distributional ranges, 25 (54%) of the fish species recorded in the Kromme Estuary are southern African endemics. The high degree of endemism can be attributed to the locality of the Kromme Estuary within the warm temperate biogeographic region. There are no rare or endangered fish species within the Kromme Estuary.

This review has shown that

- (1) The Kromme Estuary supports a rich and diverse ichthyofauna. In comparison with other permanently open estuaries in the region, this system ranks highly as a suitable fish habitat.
- (2) Poor zooplankton resources as a result of reduced river inflow have contributed to a reduction in the abundance and biomass of planktivorous fish species in the estuary.
- (3) Expansion of eelgrass (*Zostera capensis*) beds up the estuary has increased the available nursery and foraging area for certain fish species but reduced available habitat for others.
- (4) The Kromme Estuary acts as a conduit for immigrating anguillid eel larvae and emigrating adult eels. However, the construction of major impoundments, especially the Impofu Dam, would have resulted in much of the catchment being unavailable for eel colonisation.

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1. INTRODUCTION

The state of knowledge of the Kromme Estuary before the building of catchment dams is negligible but considerable research on the system has been conducted in recent decades (e.g. Baird *et al.*, 1981; Fromme and Badenhorst, 1987; Emmerson and Erasmus, 1987; Hanekom and Baird, 1988; Hecht, 1973; Reddering and Esterhuysen, 1983). Indeed, the availability of food web information has permitted the modelling of the functioning of this particular estuary (Baird and Heymans, 1996; Baird *et al.*, 1991; Heymans and Baird, 1995).

The Kromme system, in its present condition, appears to function more as an 'arm of the sea' rather than a true estuary with a permanent salinity gradient from the head to the mouth. Although the mouth of the estuary has never closed, primarily due the tidal prism generating sufficient scouring forces to prevent closure, the incremental accumulation of sediments within the estuary may ultimately lead to such an occurrence.

The Kromme Estuary is a permanently open system in the western extremity of St Francis Bay and is fed by a catchment of approximately 1085 km² (Bickerton and Pierce, 1988). The estimated MAR from the catchment is estimated at 97 million m³. With a water surface area of approximately 240 ha, the Kromme Estuary represents one of the most important systems on the southern Cape coast. Therefore in the context of a nursery area for a wide range of juvenile marine fishes in the warm temperate region, especially the lack of suitable estuarine areas along the Tsitsikamma coastline, this system ranks highly from a conservation perspective.

1.1 Background information and aims

No additional fieldwork was proposed for this study due to the very good published and unpublished data available on the fishes of the Kromme Estuary. Past studies (e.g. Hanekom and Baird, 1984; Harrison *et al.*, 1996a; 1996b; Marais, 1983) have shown that the estuary is dominated by marine fish species throughout the system. With the exception of a few estuarine species, all the marine taxa utilise the estuary primarily as a nursery and foraging area.

The 'health' of the system, when analysed using the fish community as an indicator (Harrison *et al.*, 2000), was good when compared to similar estuaries in the warm-temperate region.

This report synthesises existing information on the fish component of the Kromme Estuary Reserve Study, including:

- Species composition and estuarine dependence categories for those species found in the estuary;
- A previous assessment of the relative importance of the estuary to different species or groups of species;
- A previous assessment of the likely effects of altered river inflows on the ichthyofauna;
- Providing recommendations for further work in order to enhance the reliability of predictions of fish responses to changes in Kromme River flow.

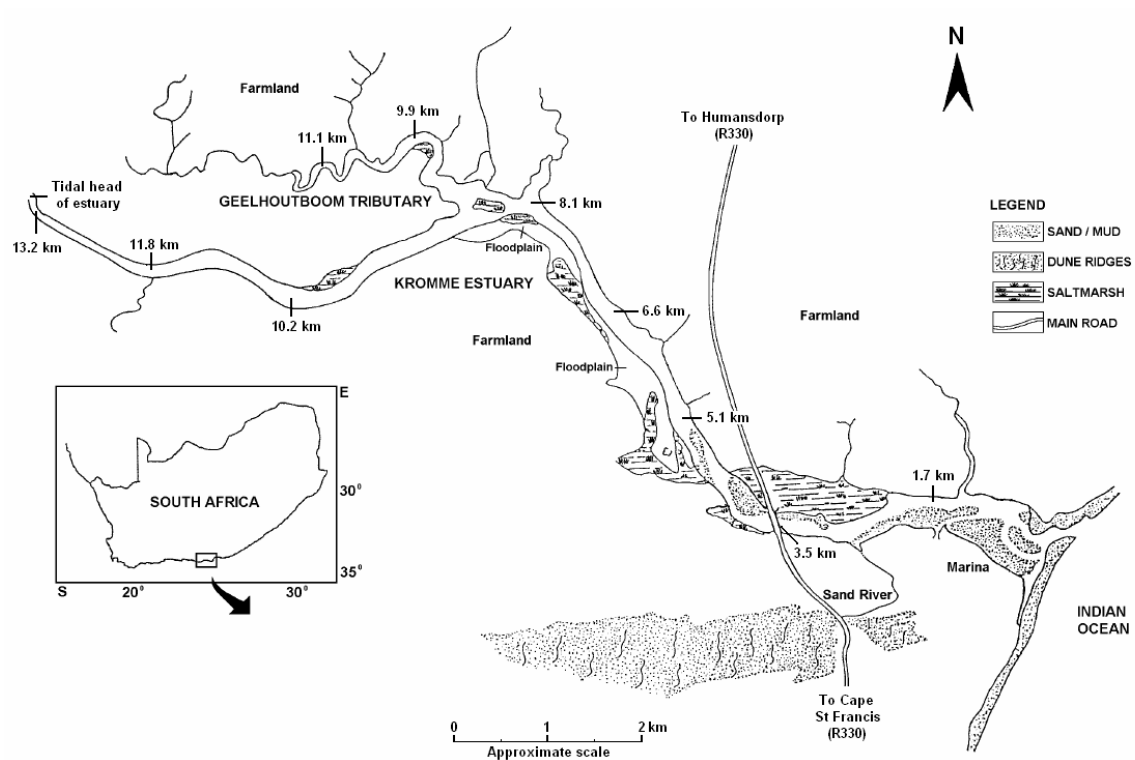


Figure H-1 Map of the Kromme Estuary showing localities mentioned in the text.

2. FISH COMMUNITY

2.1 The Kromme Estuary Ichthyofauna

A total of 46 fish species from 25 families, analysed using the categories outlined in Table H-1, have been recorded from the Kromme Estuary (Table H-2). Eleven of these species are dependent on estuaries for breeding purposes, and include resident taxa such as *Gilchristella aestuaria* and *Omobranchus woodi*. A total of 15 marine species, including the *Rhabdosargus holubi* and *Liza dumerili*, are dependent on estuaries as nursery areas. A further 10 marine species (e.g. *Diplodus sargus* and *Liza richardsoni*) are at least partially dependent on estuaries as nursery areas. Eight of the remaining taxa were stenohaline marine species (e.g. *Lithognathus mormyrus* and *Diplodus cervinus*) occur in the lower and/or middle reaches where full seawater salinities prevail.

An analysis of the fish species groupings in the Kromme Estuary according to life history traits of the various taxa is shown in Figure H-2. This figure indicates that marine immigrant species are dominant, followed by estuarine residents, marine stragglers and then catadromous taxa. Catadromous taxa are now primarily represented by the freshwater mullet, which is able to survive in the estuary if the river is unavailable for colonisation. However, the virtual absence of river flow for much of the year has meant that freshwater fish species are no longer found in the headwaters of the estuary. The relatively high proportion of marine stragglers (17%) is an indication that this system has become an 'arm of the sea'. However, even under natural run-off conditions, marine stragglers were likely to be well represented in the lower Kromme Estuary, especially when river flow was low.

Fish species groupings in the Kromme Estuary analysed according to relative abundance of the various taxa are shown in Figure H-3. Once again marine immigrant species are dominant followed by estuarine residents. However, marine stragglers and catadromous taxa contribute little to the overall fish abundance in the system. When these fish species groupings are analysed according to relative biomass of the various taxa, marine immigrants are shown to be overwhelmingly dominant (Figure H-4). This dominance is because all the estuarine residents are small species and therefore contribute considerably less to the overall catch when analysed on a biomass basis.

Anguillid eels (e.g. *Anguilla mossambica*) make extensive use of the estuary during migrations to and from the river catchment. The life history of these species is complex. It involves oceanic breeding, a pelagic planktonic larval stage, migration into estuaries and metamorphosis into a glass eel, at which stage it migrates into freshwater and becomes an elver. Further migration upstream follows and the mature eel finally returns to the sea to breed. Before entering the sea it undergoes a physiomorphological change to the sea-going form (silver eel). The entire life cycle takes several years depending on the species. Anguillid eels were probably the single most important fish species in the Kromme catchment due to their abundance and widespread distribution at different altitudes.

Based on their distributional ranges, 25 (54%) of the fish species recorded in the Kromme Estuary are southern African endemics. The high degree of endemism can be attributed to the locality of the Kromme Estuary within the warm temperate biogeographic region. According to the fish sampling that has been conducted in the estuary there are no rare or endangered fish species within the system.

Table H-1 The five major categories of fishes that utilise South African estuaries

I	Estuarine species that breed in South African estuaries. Further subdivided 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 South African estuaries. Further subdivided 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. These species are known as marine stragglers.	
IV	Euryhaline freshwater species, whose penetration into estuaries is determined primarily 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 and may also, occupy estuaries in certain regions. Further subdivided 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.

Table H-2 A list of indigenous fish species recorded in the Kromme Estuary. The species are classified into five major categories of estuarine-dependence as outlined in Table H-1 and southern African endemic taxa are indicated with an asterisk (*)

Family	Scientific name	Common name	Category
Anguillidae	<i>Anguilla mossambica</i>	Longfin eel	Va
Ariidae	<i>Galeichthys feliceps</i> *	White seacatfish	IIb
Atherinidae	<i>Atherina breviceps</i> *	Cape silverside	Ib
Blenniidae	<i>Omobranchus woodi</i> *	Kappie blenny	Ia
Carangidae	<i>Lichia amia</i>	Leervis	IIa
Clinidae	<i>Clinus superciliosus</i> *	Super klipfish	Ib
Clupeidae	<i>Gilchristella aestuaria</i> *	Estuarine roundherring	Ia
Dasyatidae	<i>Dasyatis brevicaudata</i>	Short-tail stingray	III
Elopidae	<i>Elops machnata</i>	Ladyfish	IIa
Engraulidae	<i>Stolephorus holodon</i>	Thorny anchovy	IIc
Engraulidae	<i>Etrumeus whiteheadi</i> *	Redeye roundherring	III
Gobiidae	<i>Caffrogobius gilchristi</i> *	Prison goby	Ib
Gobiidae	<i>Caffrogobius natalensis</i> *	Baldy	Ib
Gobiidae	<i>Caffrogobius nudiceps</i> *	Barehead goby	Ib
Gobiidae	<i>Glossogobius callidus</i> *	River goby	Ib
Gobiidae	<i>Psammogobius knysnaensis</i> *	Speckled sandgoby	Ib
Haemulidae	<i>Pomadasys commersonii</i>	Spotted grunter	IIa
Haemulidae	<i>Pomadasys olivaceum</i>	Piggy	III
Hemiramphidae	<i>Hemiramphus far</i> *	Spotted halfbeak	IIc
Hemiramphidae	<i>Hyporhamphus capensis</i> *	Cape halfbeak	Ia
Monodactylidae	<i>Monodactylus falciformis</i>	Oval moony	IIa
Mugilidae	<i>Liza dumerili</i>	Groovy mullet	IIb
Mugilidae	<i>Liza macrolepis</i>	Largescale mullet	IIb
Mugilidae	<i>Liza richardsoni</i> *	Southern mullet	IIc
Mugilidae	<i>Liza tricuspidens</i> *	Striped mullet	IIb
Mugilidae	<i>Mugil cephalus</i>	Flathead mullet	IIa
Mugilidae	<i>Myxus capensis</i> *	Freshwater mullet	Vb
Mugilidae	<i>Valamugil buchanani</i>	Bluetail mullet	IIc
Myliobatidae	<i>Myliobatis aquila</i>	Eagleray	III
Ophichthidae	<i>Ophisurus serpens</i>	Sand snake-eel	IIc
Platycephalidae	<i>Platycephalus indicus</i>	Bartail flathead	IIc
Pomatomidae	<i>Pomatomus saltatrix</i>	Elf	IIc
Rhinobatidae	<i>Rhinobatos annulatus</i> *	Lesser guitarfish	III
Sciaenidae	<i>Argyrosomus japonicus</i>	Dusky kob	IIa
Soleidae	<i>Heteromycteris capensis</i> *	Cape sole	IIb
Soleidae	<i>Solea bleekeri</i> *	Blackhand sole	IIb
Sparidae	<i>Acanthopagrus vagus</i>	Estuarine bream	IIa
Sparidae	<i>Diplodus cervinus hottentotus</i> *	Zebra	III
Sparidae	<i>Diplodus sagus capensis</i> *	Blacktail	IIc
Sparidae	<i>Lithognathus lithognathus</i> *	White steenbras	IIa
Sparidae	<i>Lithognathus mormyrus</i>	Sand steenbras	III
Sparidae	<i>Rhabdosargus globiceps</i> *	White stumpnose	IIc
Sparidae	<i>Rhabdosargus holubi</i> *	Cape stumpnose	IIa
Sparidae	<i>Sarpa salpa</i>	Streepie	IIc
Sparidae	<i>Spondylisoma emarginatum</i> *	Steentjie	III
Syngnathidae	<i>Syngnathus temmincki</i>	Longsnout pipefish	Ib

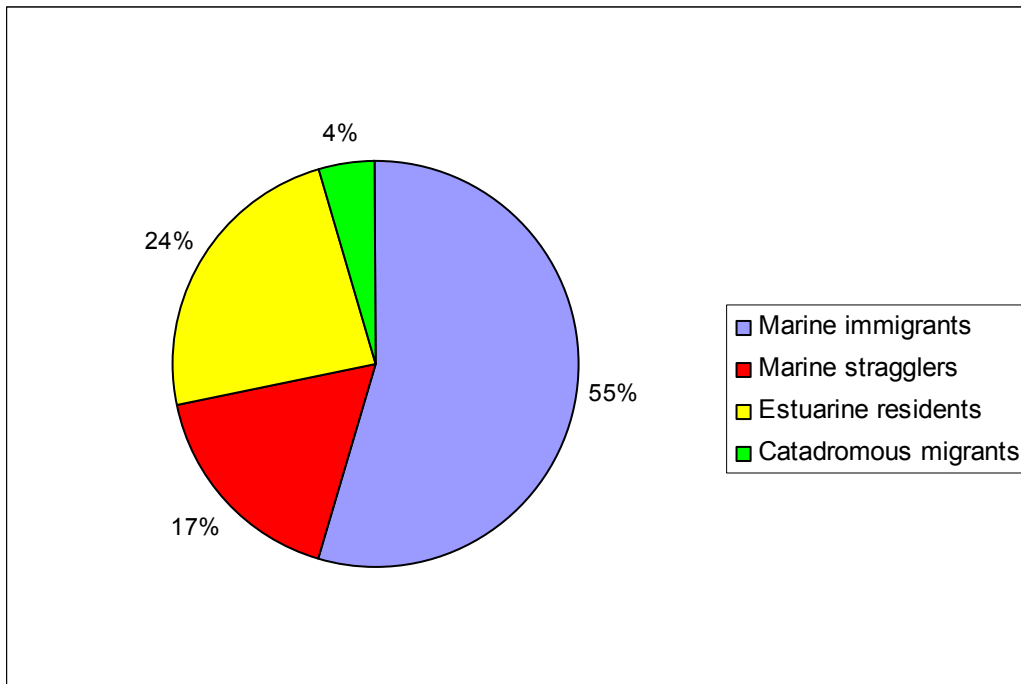


Figure H-2 Fish species groupings in the Kromme Estuary analysed according to life history traits of the various taxa (data from Harrison unpublished).

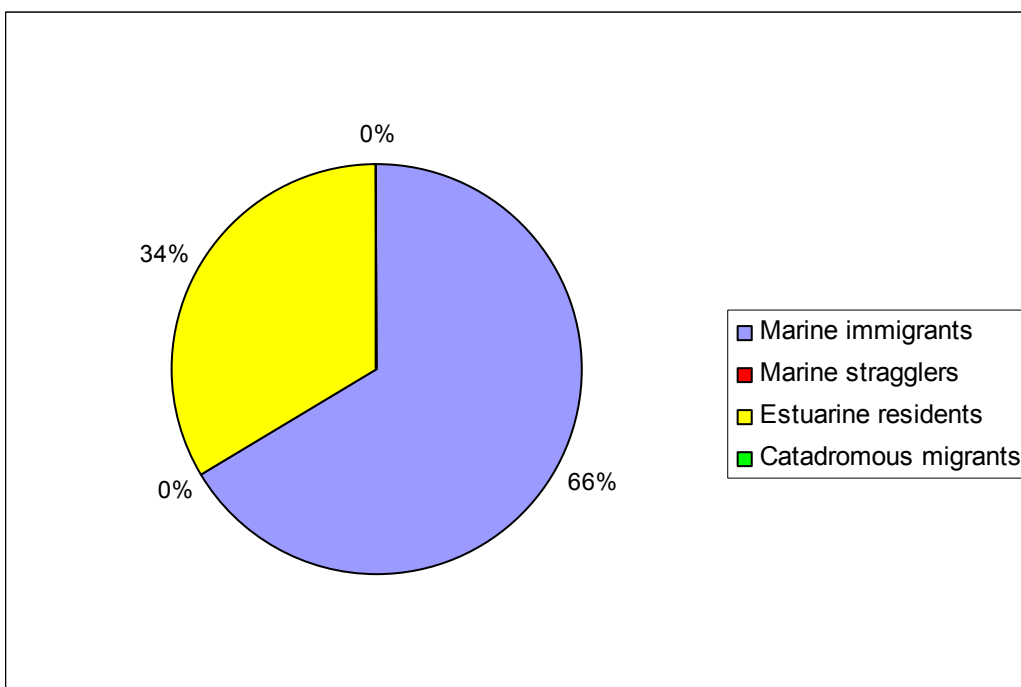


Figure H-3 Fish species groupings in the Kromme Estuary analysed according to relative abundance of the various taxa (data from Harrison unpublished).

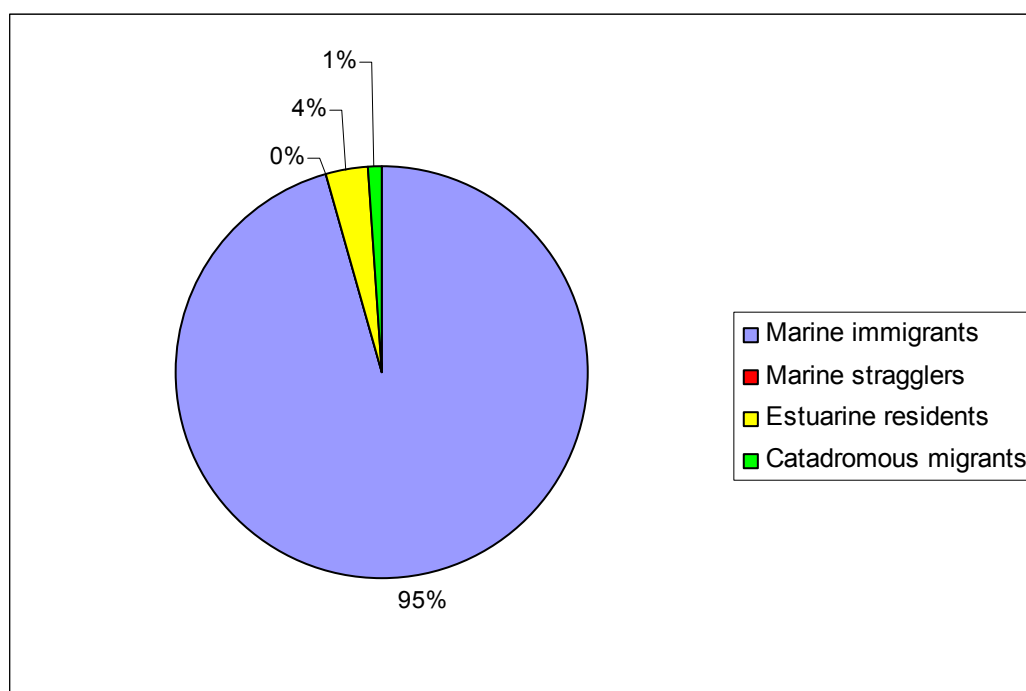


Figure H-4 Fish species groupings in the Kromme Estuary analysed according to relative biomass of the various taxa (data from Harrison unpublished).

In the absence of a perennial river flow and presence of major impoundments, the Kromme Estuary is receiving only a fraction of the nutrient and organic matter input from the catchment when compared to the pristine state. The lowered food resources arising from the above would inevitably lead to a reduced fish carrying capacity for the system, especially the plankton associated fish species. This change in food web structure is reflected in the work of Baird and Heymans (1996) who concluded that the Kromme Estuary has changed from a plankton-dominated system to one dominated by submerged benthic vegetation and macrobenthic invertebrates in response to reduced freshwater inflows. Thus macrophyte associated fish species such as *Rhabdosargus holubi* and *Monodactylus falciformis* would have benefited from the altered regime (Hanekom and Baird, 1984), whereas planktivorous fish species such as *Gilchristella aestuaria* and *Atherina breviceps* would have declined in both abundance and biomass. This shift from a pelagic to a benthic dominated food web is reflected in the difference between the pelagic: benthic biomass ratios in the Swartkops and Kromme estuaries, with the former ratio being 1:3 and the latter 1:2193 (Schlacher and Wooldridge, 1996).

Despite the major reduction in river flow entering the Kromme Estuary, the estuarine clupeid *Gilchristella aestuaria* still dominates the larval fish assemblage (Melville-Smith, 1981). This indicates that the plankton food chain in the estuary may be reduced but is intact and responds positively to natural inflows of freshwater. Rainfall associated run-off from the catchment of the Geelhoutboom tributary (Figure H-1) during an experimental release of freshwater from the Impofu Dam triggered a spawning by estuary resident fish species (e.g. *G. aestuaria*) in this part of the system (Strydom and Whitfield, 2000).

2.2 Conclusions

Based on this review, the following conclusions can be reached:

- (1) The Kromme Estuary supports a rich and diverse ichthyofauna. In comparison with other permanently open estuaries in the region, this system ranks highly as a suitable fish habitat.
- (2) Poor zooplankton resources as a result of reduced river inflow have contributed to a reduction in the abundance and biomass of planktivorous fish species in the estuary.
- (3) Expansion of eelgrass (*Zostera capensis*) beds up the estuary has increased the available nursery and foraging area for certain fish species but reduced available habitat for others.
- (4) The Kromme Estuary acts as a conduit for immigrating anguillid eel larvae and emigrating adult eels. However the construction of major impoundments, especially the Impofu Dam, would have resulted in much of the catchment being unavailable for eel colonisation.

2.3 Further studies

Research that documents the influence of elevated river flows on the fish assemblages within the Kromme Estuary is urgently required. At present our knowledge on this aspect is limited to a single experimental release of 2 million m³ of water from the Impofu Dam, a release that was shown to have a minimal effect on the functioning of the biota in the estuary.

2.4 Acknowledgements

The use of unpublished fish information supplied by Dr Trevor Harrison is gratefully acknowledged.

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APPENDIX I

BIRDS

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1. INTRODUCTION

This study forms part of the estuarine freshwater reserve determination for the Kromme River Estuary, in which specialist studies will contribute towards describing the present state of the estuary in terms of health, and the probable state of the estuary under a number of possible future scenarios. The Resource Directed Measures (RDM) methodology used will also set the desired future Management Class (desired future state of health) of the estuary from an ecological perspective.

In the case of the Kromme Estuary, the RDM process is being carried out at a comprehensive level, the methods for which are described in detail in DWAF (2004). Runoff scenarios for the natural and present situation are used to evaluate the present ecological status of the estuary and to determine the recommended ecological reserve category (ERC). These runoff scenarios, together with a series of five possible future run-off scenarios are then evaluated to derive the Reserve and Resource Quality Objectives for the estuary.

Three possible states of the Kromme Estuary, and their prevalence under the seven different runoff scenarios is summarised in Tables I-1 and I-2.

Table I-1 Summary of five possible states of the Kromme Estuary (DWAF, 2005).

	State 1	State 2	State 3
General description	Marine	Salinity gradient	Fresh
Typical flow	< 1 m ³ /s	1-8 m ³ /s	> 8 m ³ /s
Mouth	Open	Open	Open
Tidal amplitude	0.3 (neap) – 1.5 (spring)	0.3 (neap) – 1.5 (spring)	0.3 (neap) – 1.5 (spring)
Water retention time	1-2 tidal cycles	1-3 days	1-2 days
Salinity distribution	Close to 35ppt throughout	Fairly even gradient	Largely fresh with steep gradient near mouth
Turbidity	Low – secchi ~1	0.3 - 1	0.3 – 1
Dissolved Inorganic Nitrogen (DIN)	<50 µg/l (<7 µM)	Increase with decreasing salinity	Increase with decreasing salinity
Dissolved Reactive Phosphate-P (PO ₄ -P)	<10 µg/l (< 3 µM)	Very slight decrease with decreasing salinity	Very slight decrease with decreasing salinity
Dissolved Reactive Silicate (SiO ₄ -Si)	200 – 900 µg/l	Increase with decreasing salinity	Increase with decreasing salinity

Table I-2 Summary of the average flows (m³/s) and predominant states (state 1 = red and orange, state 2 = green) in each month for the reference condition, present condition and five possible future scenarios (DWAF, 2005)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Reference	2.83	1.98	1.11	0.59	0.59	0.78	0.95	1.06	1.53	2.11	2.58	2.73
Present	0.36	0.30	0.19	0.15	0.13	0.14	0.14	0.15	0.18	0.22	0.29	0.35
Scenario 1	0.30	2.14	0.11	0.08	0.06	0.06	0.09	0.09	0.14	0.18	0.25	0.30
Scenario 2	2.17	0.22	0.11	1.94	0.06	0.06	0.09	0.09	0.13	0.18	0.24	0.31
Scenario 3	0.36	0.30	0.19	0.15	0.13	0.14	0.14	0.15	0.18	0.22	0.29	0.35
Scenario 4	0.30	2.14	0.11	0.08	0.06	0.06	0.09	0.09	0.14	0.18	0.25	0.30
Scenario 5	2.07	1.08	0.11	0.08	0.06	0.06	0.09	0.09	0.13	0.18	0.24	0.30

The **terms of reference** for the specialist bird study were as follows:

1. Describe the avifaunal community based on site visits (one winter and three summer counts) 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;
5. 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;
6. Predict the effect of each of the five future scenarios on birds; and
7. Complete the RDM specialist templates.

2. STUDY AREA AND METHODS

This study is based on existing count data as well as primary field data. One summer count exists for about 1979 (Underhill and Cooper, 1984). Co-ordinated Waterbird Counts (CWAC) data, consisting of a mid-winter and mid-summer count each year, were available for 1998 onward, and were obtained in raw form (CWAC data supplied by Yvonne Craig). In addition, four counts were conducted on the estuary between February 2004 and January 2005, one in mid-winter (July), when bird numbers are usually close to their minimum, and three during summer (December, January and February), when bird numbers are typically maximal or approaching their maximum. In all counts (this study and previous data), birds were counted from the estuary mouth to the top of the estuary (about 10-12km up the Kromme River), including the navigable portion of the Geelhoutboom tributary. In this study, the estuary was divided into counting sections in order to determine the distribution of birds along the estuary (Figure I-1).

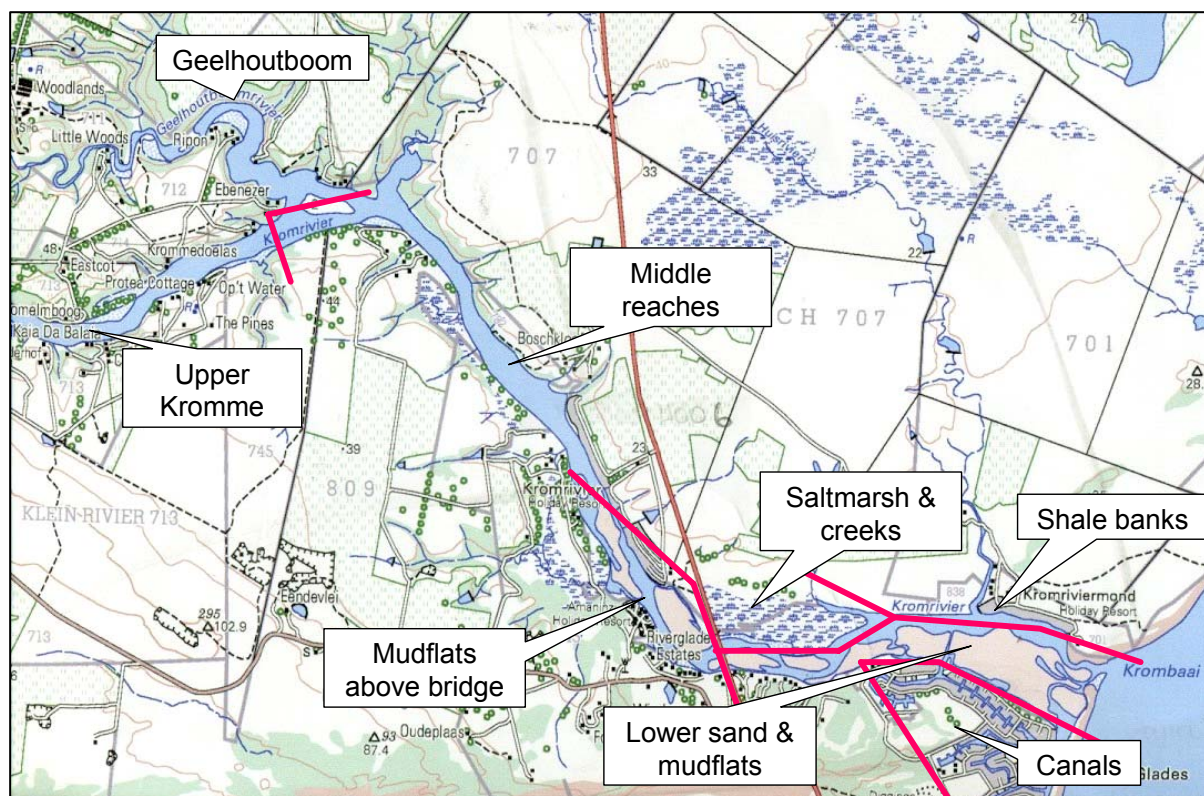


Figure I-1 Map of the Kromme Estuary showing the Geelhoutboom tributary and the divisions between main counting areas (red lines).

Habitats along the Kromme Estuary are described in Bezuidenhout *et al.* (2005). In summary, the estuary is dominated by a channel area of 103 ha, with 65 ha of saltmarsh, 37 ha of intertidal mud or sand flats, 12ha of *Zostera* beds and 3 ha of reedmarsh.

3. IMPORTANCE OF THE KROMME RIVER ESTUARY FOR BIRDS

The Kromme is one of 28 permanently open estuaries in the Warm Temperate zone (roughly Cape Point to the Mbashe River). Largely because of its substantial size of about 240 ha, which is in the top 10% of estuaries in the country, the Kromme Estuary is fairly important for estuarine biodiversity on a national scale. It ranks twentieth of all South African estuaries in terms of its overall conservation importance (Turpie, 2004). This index takes size, estuary type rarity and biodiversity (plants, invertebrates, fish, birds) into account.

The estuary is ranked 22nd out of 258 estuaries in terms of its avifauna (Turpie, 2004, which updates Turpie *et al.*, 2002), which places it in the second top 10% percentile. This score is calculated using the 1979 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 1979 count data are very similar to the 1998-2005 data (see section 7). This ranking does not make the Kromme a very high priority estuary for birds, but it is certainly highly significant at a regional level.

The estuary has a fairly typical composition of birds compared with other permanently open South African estuaries. It is one of relatively few estuaries that support a permanent population of Goliath Heron, and it regularly supports relatively rare waders such as (Greater) Sand Plover and Ruff. Two Red Data species – African Black Oystercatcher and Caspian Tern occur regularly on the estuary.

4. PRESENT STATUS OF AVIFAUNA

4.1 Taxonomic composition

Nine orders are represented on the estuary, with Charadriiformes, making up over half (53%) of the waterbird species recorded on the estuary (Table I-3). Other groups are relatively evenly represented. A total of 23 species are long-distance migrants. The taxonomic make-up is typical of most estuaries, except that the waterfowl (e.g. ducks, rails) are poorly represented. This was also noted by Bickerton and Pierce (1988).

Table I-3 Numbers of species of different groups that have been recorded on the estuary (Non-passerine waterbirds, excluding vagrants).

Order	Common names	Total	Migratory
Podicipediformes	Grebes	1	
Pelecaniformes	Cormorants, darters	4	
Ciconiiformes	Herons, egrets, ibis, spoonbill...	8	
Pheonicopteriformes	Flamingos	1	
Anseriformes	Ducks	6	
Falconiformes	Birds of prey	3	1
Gruiformes	Rails, crakes, coots..	3	
Charadriiformes	Waders	25	16
	Gulls	1	
	Terns	8	5
Alcediniformes	Kingfishers	4	

4.2 Species richness and abundance

A total of 64 non-passerine waterbird species have been recorded on the Kromme River estuary (excluding vagrants), with 51 of these species being recorded during summer, and 55 in winter (Table I-4). The average number of non-passerine waterbird species recorded in single count is 34 in summer and 32 in winter. Mean and maximum counts recorded over the past eight years are summarised in Table I-4.

Table I-4 Waterbird species recorded on the Kromme Estuary from 1998 – 2005 (CWAC data and this study), giving mean and maximum numbers counted during mid summer (Feb) and mid-winter (Jun/Jul).

	Summer		Winter	
	1998-2005		1998-2004	
	Mean	Max	Mean	Max
Dabchick			1	6
Whitebreasted Cormorant	19	47	33	63
Cape Cormorant	3	10	28	38
Reed Cormorant	18	29	72	131
Darter	1	3	3	7
Grey Heron	8	15	10	13
Goliath Heron	1	4	1	4
Purple Heron			0	1
Great White Egret	0	1		
Little Egret	15	28	37	49
Black Crowned Night Heron	0	2		
Hamerkop	0	1		
Sacred Ibis	7	29	38	70
African Spoonbill	2	10	8	21

	Summer		Winter	
	1998-2005		1998-2004	
	Mean	Max	Mean	Max
Greater Flamingo	0	2	1	6
Egyptian Goose	3	13	5	11
South African Shelduck				
Yellowbilled Duck	5	16	12	46
Cape Teal			0	2
Redbilled Teal	1	8		
Cape Shoveller			1	2
Spurwinged Goose	3	14	3	11
African Fish Eagle	0	1	0	1
African Marsh Harrier			1	2
Osprey	1	2	1	3
Black Crake			0	2
Moorhen			0	2
Redknobbed Coot			0	1
African Black Oystercatcher	8	14	6	7
Ringed Plover	64	138	0	0
Whitefrontd Plover	90	201	79	174
Kittlitz's Plover	29	110	33	111
Threebanded Plover	0	1	1	2
Mongolian Plover			1	2
Sand Plover	1	3	0	1
Grey Plover	120	192	27	55
Blacksmith Plover	23	46	21	90
Turnstone	9	31	3	10
Common Sandpiper	4	9	1	3
Wood Sandpiper	1	6		
Marsh Sandpiper	2	9		
Greenshank	27	45	12	32
Knot	3	10	5	38
Curlew Sandpiper	138	220		
Little Stint	144	325	1	4
Sanderling	64	100	5	28
Ruff	116	264		
Bartailed Godwit	1	2	0	1
Curlew	0	1	0	2
Whimbrel	72	148	15	25
Ethiopian Snipe	0	1		
Avocet			1	9
Blackwinged Stilt			3	12
Water Dikkop	38	78	54	63
Kelp Gull	224	745	77	120
Greyheaded Gull			0	1
Hartlaub's Gull				
Caspian Tern	3	8	4	8
Swift Tern	20	120	2	6
Sandwich Tern	63	180		
Common Tern	3011	13000	20	88
Arctic Tern	5	37		
Little Tern	15	33	0	1
Whitewinged Tern				
Antarctic Tern			29	184
Roseate Tern			0	3

	Summer		Winter	
	1998-2005		1998-2004	
	Mean	Max	Mean	Max
Pied Kingfisher	10	14	20	29
Giant Kingfisher	1	2	3	5
Malachite Kingfisher	0	3	3	6
Half-collared Kingfisher	0	1	1	5
Unidentified Terns	24	80	2	13
Unidentified Ducks	3	27	1	4
Unidentified Waders	39	82	17	57
Cape Wagtail	45	88	49	70
Total per count	4516		809	
Total excl marine cormorants and terns	1377		692	

No monthly counts have been carried out at the Kromme Estuary, but based on trends at other estuaries such as the Swartkops, bird numbers are expected to be maximal in March and minimal in mid-winter. The estuary supports an average of about 4 500 birds in mid-summer and 700 in mid-winter. Excluding terns, the numbers of which are highly variable, the estuary supports an average of about 1 400 birds in summer and 700 in winter. Up to 13 000 terns have been recorded at the tern roost near the mouth.

4.3 Community composition

In summer, terns are the most numerous group occurring on the estuary, but their numbers fluctuate from very small numbers to estimated flock sizes of up to 13 000 birds. Flock sizes of under 3 000 birds are more usual, and are dominated by the Common Tern, a migrant summer visitor.

Apart from terns, the avifauna in summer is consistently dominated by waders (plovers, sandpipers, dikkops, etc), which make up about 80% of the non-tern numbers, Kelp Gulls, making up 15% (Figure I-2). About 85% of the waders in summer are Palearctic migrants (from sub-Arctic and Arctic breeding grounds). The remaining waders are resident species: about 180-190 resident waders (e.g. Whitefronted Plovers, Kittlitz's Plover, Water Dikkop) occur on the estuary year round.

In winter, the avifauna is dominated by resident species. Only 30% of waders remain on the estuary on average (Figure I-2), comprising the resident species plus some immature migrant waders. Most terns are absent. Gull numbers also decrease dramatically in winter. However, numbers of cormorants (including darters), wading birds (herons, ibises, spoonbills etc), waterfowl and kingfishers increase during winter (Figure I-2). Thus there is a more even representation of different groups on the estuary in winter.

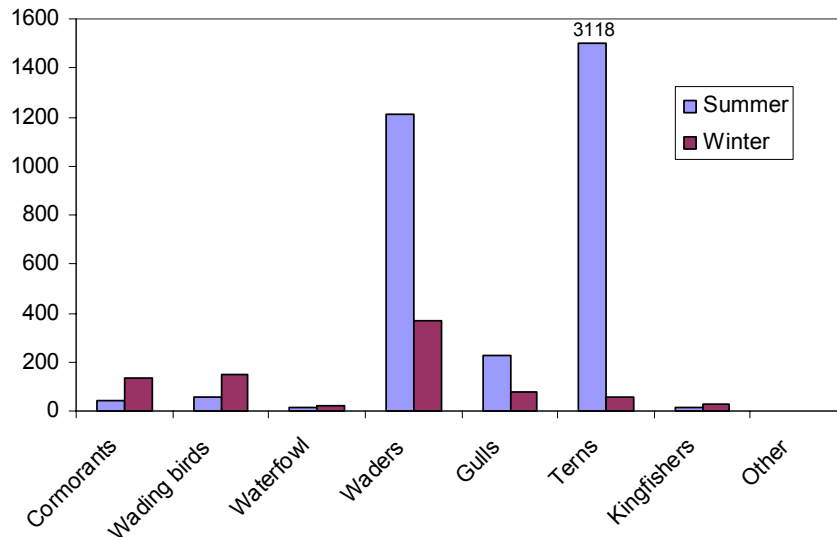


Figure I-2 Avifaunal community composition in summer and winter in terms of broad taxonomic groupings. Note the full extent of the bar for terns in summer is not shown.

4.4 Spatial patterns in distribution

In summer, about 97%, 2% and 1% of birds are found in the lower, middle and upper reaches, respectively, on average. Not including terns, the distribution is 89%, 7% and 2%, respectively. In winter 68% of birds are in the lower reaches, with 19% and 13% in the middle and upper reaches, respectively (Figure I-3). Spatial variation in community composition along the estuary is linked to habitat differences.

The lower estuary is characterised by large areas of intertidal sand and mudflats and channels fringed with rocky (shale) banks, and a large saltmarsh with creeks. The intertidal areas are dominated by waders, terns and gulls, with the latter two groups being mainly restricted to the sandier banks, and waders making more use of muddy areas. The saltmarshes, creeks and shale banks in the lower estuary also support wading birds such as egrets and herons, but numbers of birds are much lower (Figure I-4).

Above the bridge, the middle reaches up to the confluence of the Kromme and Geelhoutboom are characterised by narrow or absent intertidal mudflat areas, and rocky banks. Small patches of reeds *Phragmites australis* and overhanging bush also occur here. These reaches tend to feature wading birds, cormorants, kingfishers and certain waders such as dikkops.

The upper estuary is mostly fringed with overhanging terrestrial vegetation, apart from small patches of intertidal mudflats and a significant area of saltmarsh in the Geelhoutboom. The estuary becomes increasingly river-like in appearance above the confluence. Wading birds and kingfishers are found along the margins, in addition to channel-feeding species such as cormorants, birds of prey and waterfowl tend to be restricted to these upper reaches. The winter numbers and composition of birds in the upper estuary is very similar to that in summer, except for a complete absence of migratory species.

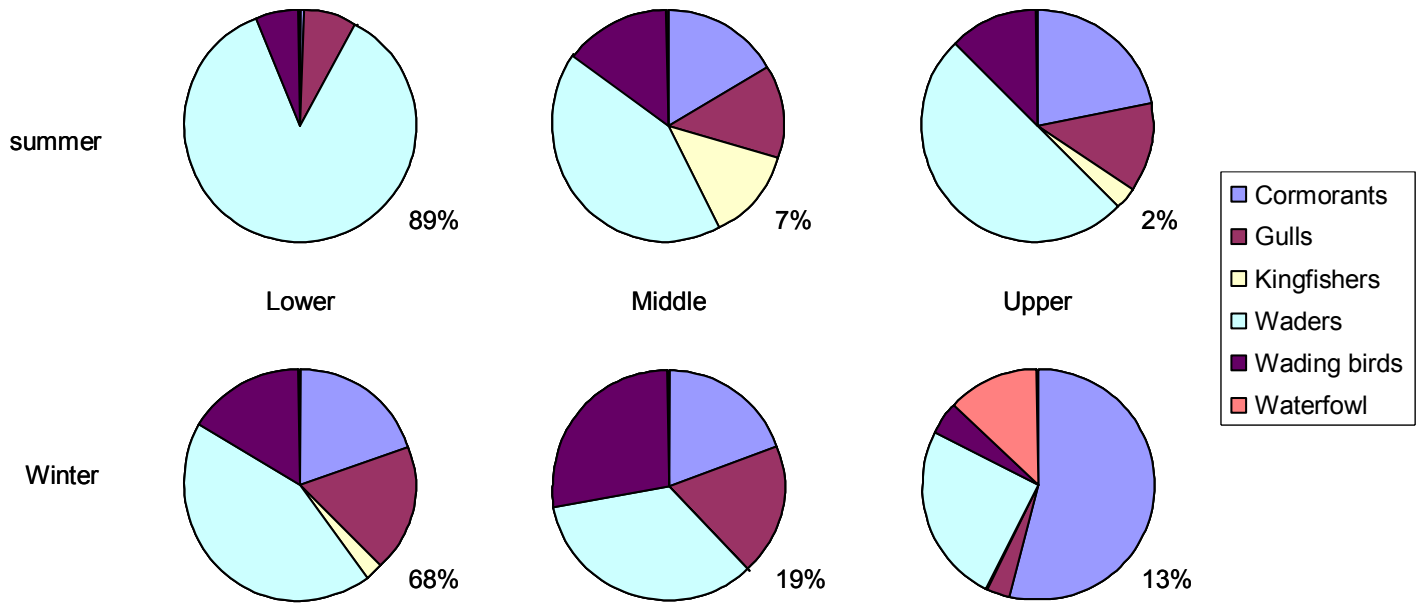


Figure I-3 Distribution of different groups of species along the estuary, excluding terns (which dominate the lower estuary in summer). Percentages are the percentage of total numbers on the estuary in each season.

Whereas numbers of birds in the lower estuary are dramatically reduced in winter, numbers increase in the middle reaches and the small numbers in the upper reaches (about 30 in summer) double in winter (Figure I-4). The Geelhoutboom tributary is more important for birds than the Kromme above the confluence (Figure I-4).

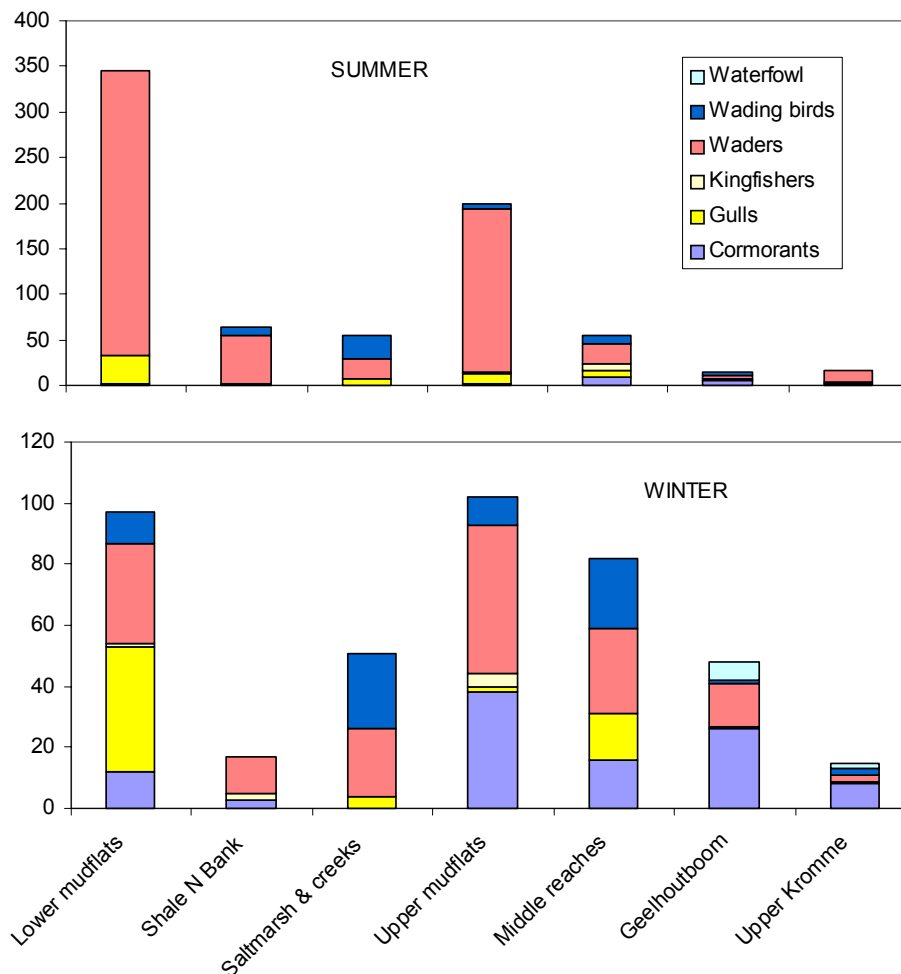


Figure I-4 Detailed distribution of different groups of species along the estuary, with lower and upper reaches broken down into component counting areas. Note differences in scale.

4.5 Dietary guilds and use of habitats

While most species feed in the estuary, some of the more abundant species do not use the estuary as their main feeding area, or feed there at all. These include most of the terns, and probably some gulls. The sandbanks in the lower estuary are important roosting areas for terns and gulls. These areas are thought to be attractive to the birds in that they provide relatively safe roost sites. Egyptian and Spurwing Geese use the upper estuary for resting and breeding, but not as a feeding habitat.

Among the feeding birds, the avifauna is dominated by invertebrate feeders (mostly waders) in summer (74%), with generalist Kelp Gulls making up about 60% of the 'piscivore' category (Figure I-5). There is a more even distribution of trophic groups in winter, when invertebrate feeders make up less than half of the bird numbers. Herbivorous birds make up a very small proportion of the avifauna.

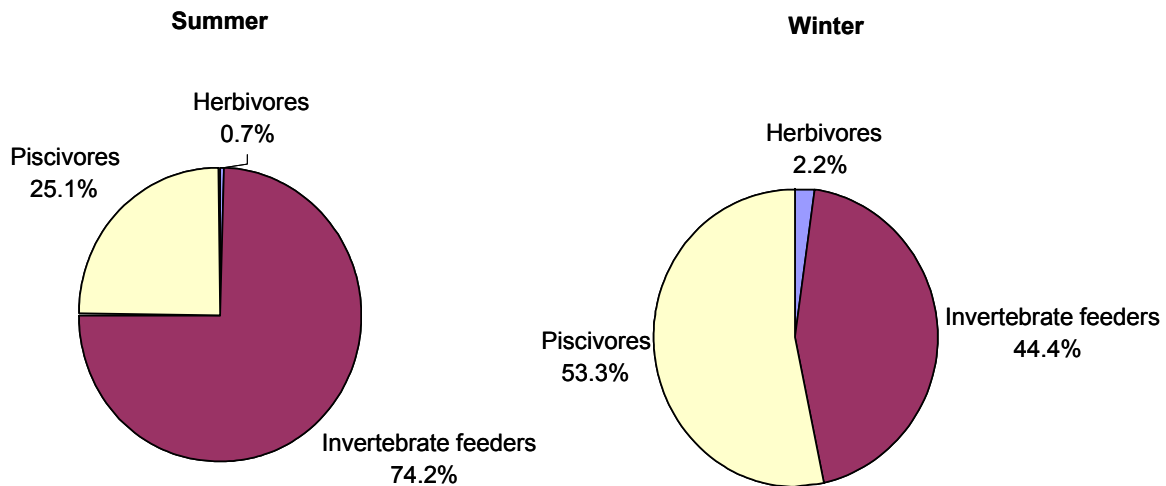


Figure I-5 Guild composition of feeding birds on the estuary in summer and winter

Intertidal mudflats support most of the waders in the lower estuary. The large number of invertebrate feeders is due to the relatively large intertidal area of the estuary, although the area where estuarine mud predominates 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). Waders are associated with the intertidal areas of the estuary, particularly the mudflats. Waders are opportunistic foragers whose diets reflect the macroinvertebrate fauna, and are typically dominated by prawns (*Upogebia*), crabs (e.g. *Hymenosoma*), polychaets (e.g. *Ceratonereis*), and amphipods.

Saltmarshes are less favourable as feeding habitats for waders, with the exception of the muddy creeks. Nevertheless, the detritus produced by the saltmarshes is important for invertebrate productivity elsewhere in the estuary.

Reed marshes support a characteristic suite of species from a range of dietary guilds that use the reeds for food or shelter. This typically freshwater habitat is scarce here, and this suite of species is not well represented on the Kromme Estuary.

The river channel is dominated by piscivorous waterbirds (e.g. pelicans, cormorants, darters and kingfishers) and waterfowl, and also used by birds of prey. Waterfowl are particularly scarce in the Kromme Estuary, making up only about 1% of birds in summer and 3% in winter (excluding terns). Only four species have been recorded (Yellowbilled Duck, Redbilled Teal, Egyptian Goose, Spurwing Goose). While the first two feed in the estuary (on predominantly aquatic vegetation and invertebrates, respectively), the Egyptian and Spurwinged Geese feed in agricultural fields, and not in the estuary itself. The river channel is dominated by piscivorous birds. Nevertheless, their relatively low proportion in the estuary suggests that the estuary is not particularly productive in terms of fish. Based on discussions with S. Lamberth (MCM – DEAT, Cape Town) for the Breede Estuary, it is probable that Reed Cormorants and Grey Heron feed mainly on *Gilchristella*, gobies, freshwater mullet and Cape stumpnose, cormorants and egrets in the lower estuary rely on gobies; Kingfishers rely mostly on *Gilchristella*, and Fish eagles on mullets and grunter. Although individuals of most piscivorous species were observed feeding in the estuary, many of the gulls and nearly all terns counted in the estuary probably do not feed there, and use the estuary mainly as a safe roosting area.

4.6 Inter-annual variation in abundance

Numbers of birds on the Kromme have remained relatively constant over the past decade, though they may have increased in some cases relative to numbers in 1979. Winter numbers of cormorants appear to have been increasing over the past few years (Figure I-6), and waterfowl numbers have also increased slightly. High numbers of Cormorants, waterfowl and kingfishers in

winter 1998 are probably connected to the experimental release of 5 million m³ of water from the Impofu dam in that year. The effect is seen quite clearly for Yellowbilled Duck and Redbilled Teal, and interestingly, the invertebrate feeding teal was abundant in the following year (Figure I-7).

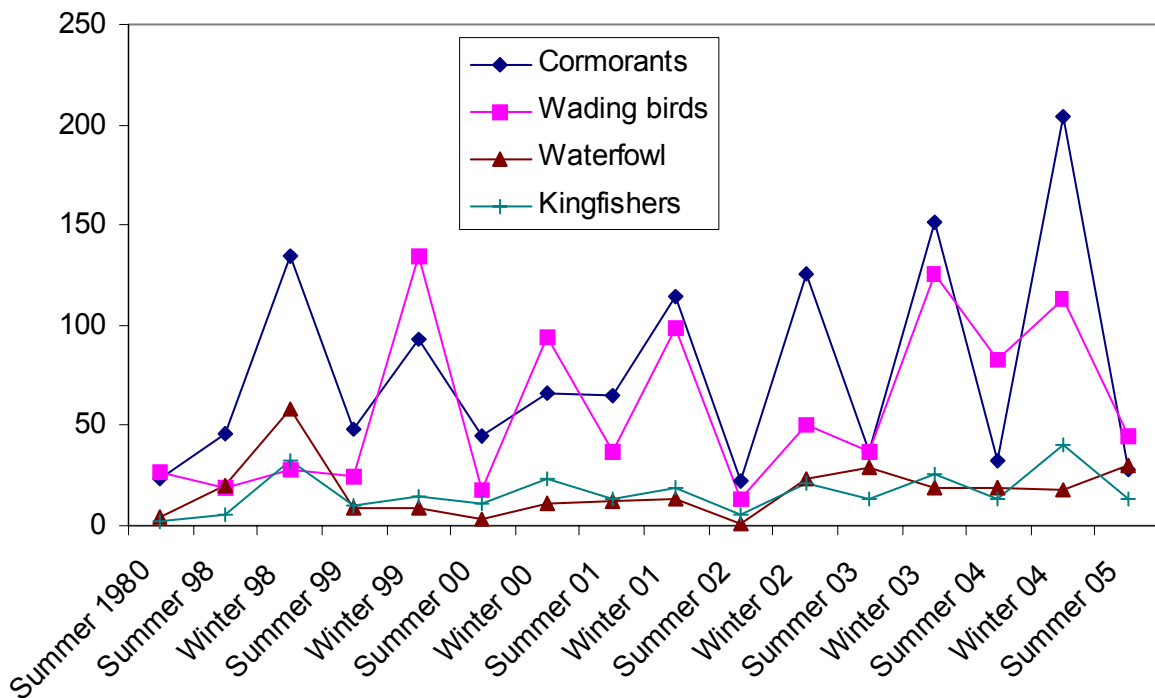


Figure I-6 Variation in the numbers of cormorants, wading birds, waterfowl and kingfishers on the Kromme Estuary, from summer and winter CWAC counts, and compared with data from Underhill and Cooper (1984).

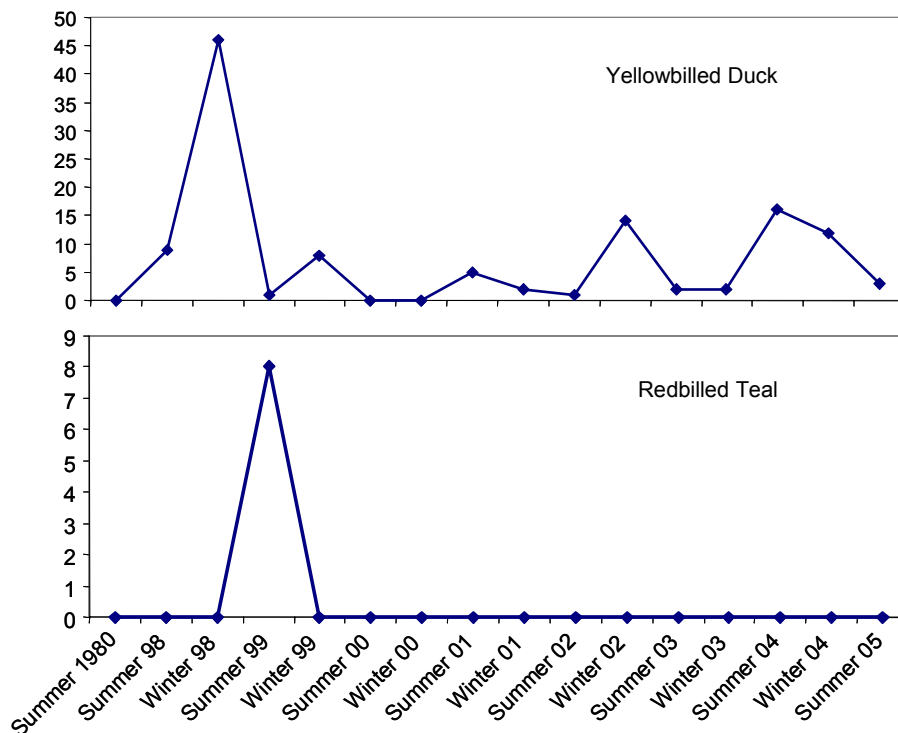


Figure I-7 Changes in numbers of Yellowbilled Ducks and Redbilled Teal on the Kromme Estuary. An experimental release from the Impofu Dam was conducted in 1998.

There is no discernable change in the numbers of waders, though gull numbers appear to have been high in recent years (Figure I-8).

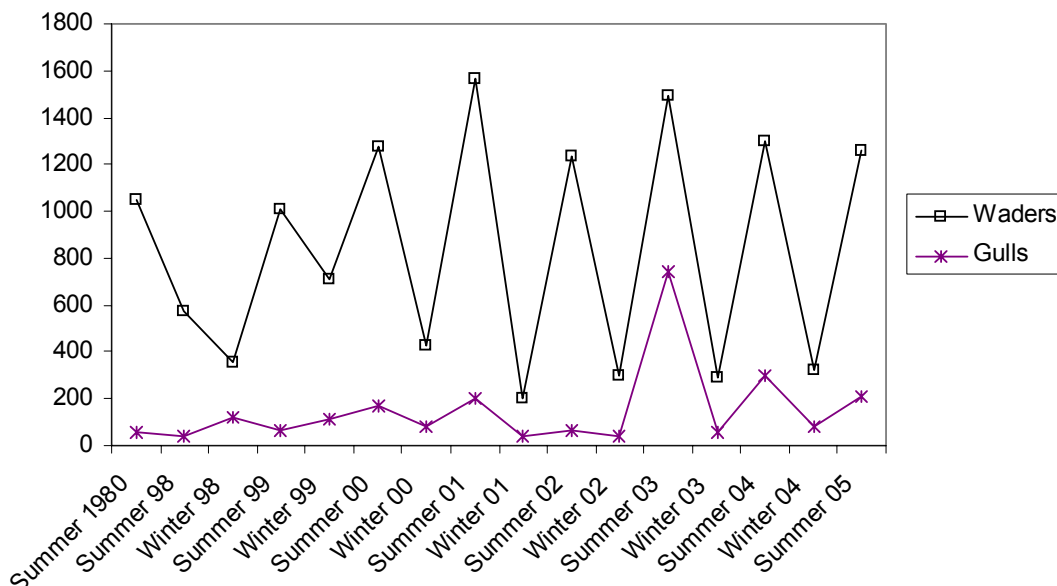


Figure I-8 Variation in the numbers of waders and gulls on the Kromme Estuary, from summer and winter CWAC counts, and compared with data from Underhill and Cooper (1984).

There may have been some small changes in individual species. For example, among the resident waders, numbers of Three-banded Plovers appear to have decreased generally since 1979, whereas numbers of Whitefronted and Kittlitz's Plovers have increased (Figure I-9).

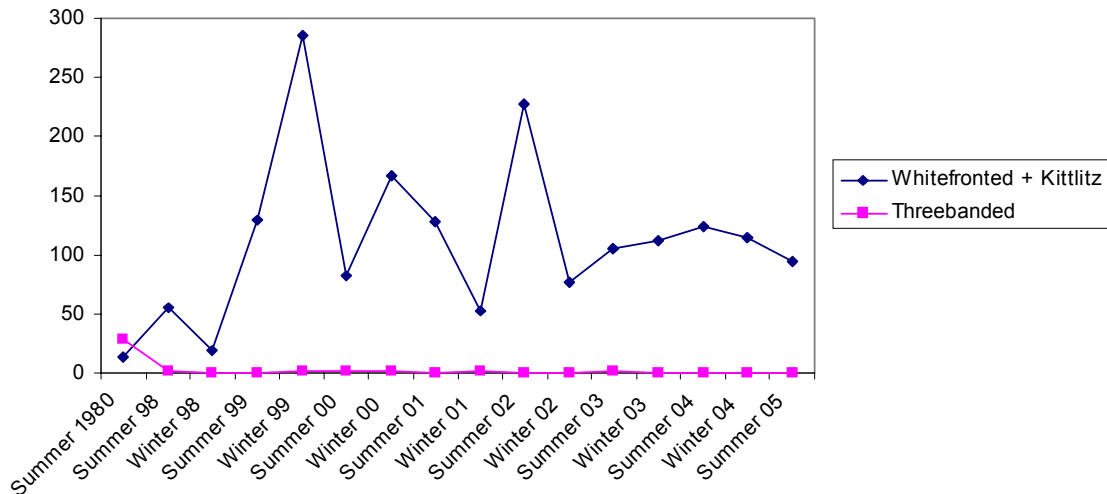


Figure I-9 Changes in numbers of resident Whitefronted and Kittlitz's Plovers compared with numbers of Threebanded Plovers on the Kromme Estuary.

Numbers of terns on the estuary fluctuate dramatically from summer to summer (Figure I-10). These fluctuations would be exogenously determined, however, and are probably related to the abundance of food in the nearshore areas.

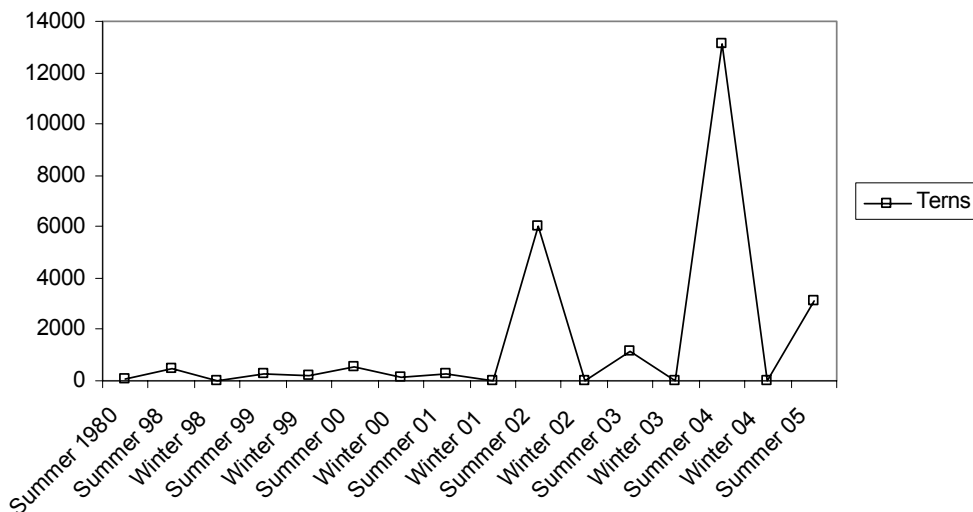


Figure I-10 Variation in the numbers of terns on the Kromme Estuary, from summer and winter CWAC counts, and compared with data from Underhill and Cooper (1984).

5. FACTORS INFLUENCING AVIFAUNAL COMMUNITY STRUCTURE AND ABUNDANCE

It is difficult to accurately predict the impact of changes in estuarine characteristics on bird assemblages (Hockey and Turpie, 1999a; 1999b), 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 (Figure I-11). These relationships may vary seasonally, from estuary to estuary, or between biogeographical zones. Difficulties in prediction are also compounded by variability due to external factors such as breeding success on distant breeding grounds. Very few quantitative studies have been made of the influence of abiotic and biotic factors on bird community structure and abundance in South African estuaries.

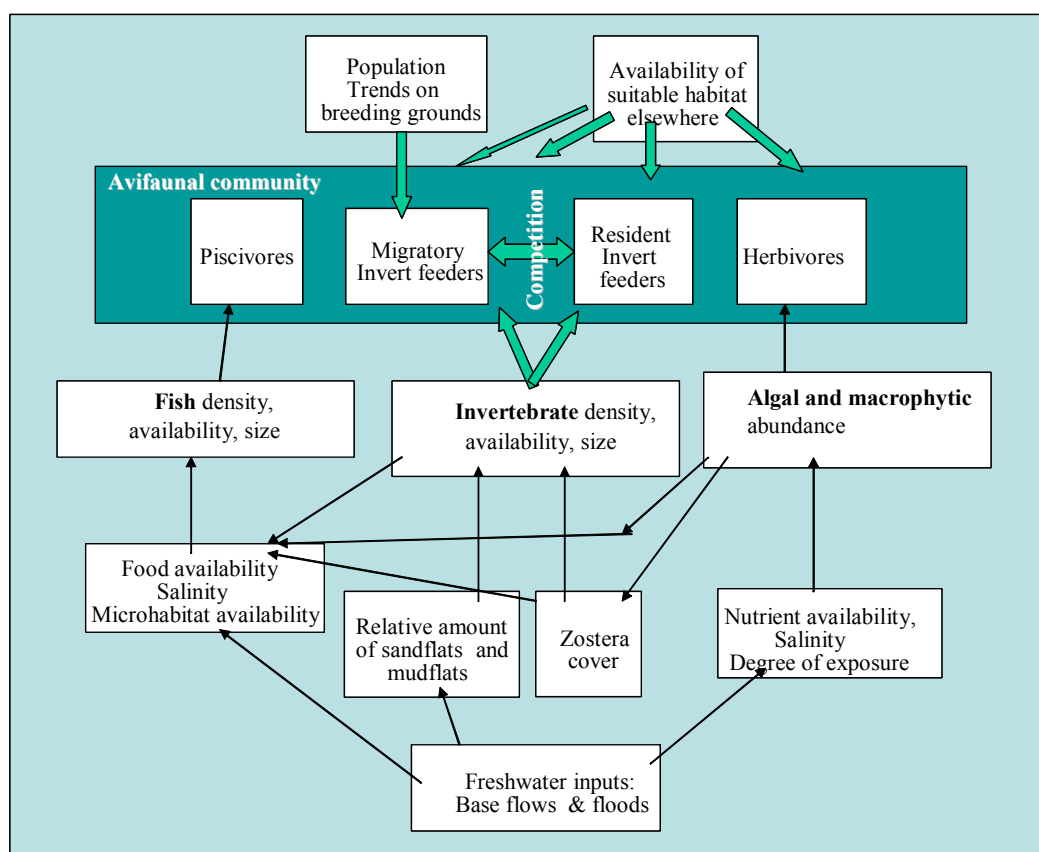


Figure I-11 A simplified example of the types of relationships used in predicting the structure of an estuarine avifaunal community. Assumptions are made about the nature of relationships for each of the arrows depicted (from Turpie, 2000).

A complex array of variables is expected to influence the bird community (Figure I-11, Hockey and Turpie, 1999a; 1999b). Apart from external influences, different trophic groups of birds are probably influenced primarily by the availability (or catchability) of food (plants, invertebrates or fish), which in turn is influenced by the 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 and Hockey, 1997).

Figure I-11 only concentrates on the trophic interactions. Other variables, such as availability of roosting, perching or breeding sites, may feature strongly in determining the presence and abundance of certain species.

Where the composition and productivity of a 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 that wader densities are negatively correlated with sediment sand fraction, because the latter is negatively correlated with invertebrate density/availability.

In some cases, predictions about the avifaunal community can be made directly from the estimates of the other specialists. In cases where insufficient information is given, the bird specialist is forced to second-guess the responses of the other biotic groups before estimating the avifaunal response.

6. THE REFERENCE CONDITION

The estuary has been affected by the construction of the Kromme River (Churchill) Dam in 1943/8 and Impofu (Elandsjagt) Dam in 1982/3/4, which have dramatically reduced river flow, as well as the construction of numerous jetties along its length and associated increases in recreational use (Baird and Heymans, 1996; Bickerton and Pierce, 1988; Basson and Beck, 2005). Before the construction of the second dam in 1982, mean annual runoff into the estuary was 117 Mm³. Average runoff was reduced to 1.3 Mm³ after the dam (Baird and Heymans, 1996).

The dramatic reduction in flow has led to the estuary changing from one in which a salinity gradient existed to an estuary which has fairly uniform salinities close to that of seawater. Presumably the reduction in flow has led to a decrease in scouring of the estuary, and the dam will have reduced fine sediment transport into the estuary. Marine sediments would have encroached into the estuary. This will have led to an overall increase in intertidal area in the lower estuary, but with a decrease in muddy area. However, since this is likely to have always been a marine-dominated system, the changes have probably not been very dramatic.

In addition to flow effects, there have been losses of habitat due to the construction of the road bridge. Human disturbance effects on birds may have been far more significant.

The estuary's avifauna has not been well-studied in the past, with regular counts only having taken place since 1998. These counts are compared with a single 1979 count in Table I-5. Although the 1979 count does not represent the reference condition, it does predate the Impofu Dam. The data suggest that there may have been a slight increase in the number of birds, and numbers of a few species seem to differ substantially, but by and large the counts are fairly similar. The degree of expected natural variability in count data means that it is difficult to draw any firm conclusions on this basis.

It is unlikely that there has been any absolute change in species richness, nor any major change in diversity in the sense of 'evenness' (See community composition below). Certain species such as Oystercatcher might have become rarer, because of human disturbance rather than flow related changes. Bird biomass might be more heavily skewed towards the mouth in the present state than in the reference condition. In the reference condition the upper reaches would probably have been more productive and the middle reaches with fewer structures and less disturbance. Community composition is likely to have changed measurably from the reference condition, mainly due to changes in habitat and invertebrate communities. The loss of freshwater habitat from the upper reaches of the Kromme and Geelhoutboom appears to have discouraged the presence of waterfowl, which might have been common in the past. Decreased reed and sedge habitats on Geelhoutboom will have resulted in fewer reedbed birds, though this may be compensated to some extent by the increase in reeds in the lower estuary. The loss of saltmarsh may have been a deterrent to waders and wading birds that roost and feed in those habitats, and the loss would be greater if the roadbridge also displaced creek areas. Tripling of the area of *Zostera* is likely to have led to a change in the composition of waders in particular. The resultant increase in small invertebrate species and loss of large species (*Upogebia*) would have encouraged smaller, tactile foraging birds over larger, visually foraging waders. Thus the relative proportion of larger species such as Whimbrel and Curlew is expected to have decreased. Changes in fish composition will not have affected piscivorous birds unless they involve changes in overall biomass of small to medium sized fish (details not provided above). The minor changes in turbidity are unlikely to have had a significant effect.

Table I-5 A comparison of count data from summer 1979 (Underhill and Cooper, 1984), before the construction of the dam in 1984, and summer 1998-2005 (this study), with noteworthy differences highlighted in bold.

Year	1979	1998-2005		Year	1979	1998-2005	
		Mean	Max			Mean	Max
Whitebreasted Cormorant	13	19	47	Turnstone	18	9	31
Cape Cormorant		3	10	Common Sandpiper	9	4	9
Reed Cormorant	11	18	29	Wood Sandpiper	8	1	6
Darter		1	3	Marsh Sandpiper		2	9
Grey Heron	7	8	15	Greenshank	45	27	45
Goliath Heron		1	4	Knot	27	3	10
Great White Egret	1	0	1	Curlew Sandpiper	371	138	220
Little Egret	3	15	28	Little Stint	30	144	325
Blkcrn Night Heron		0	2	Sanderling	115	64	100
Hamerkop		0	1	Ruff	72	116	264
Sacred Ibis	16	7	29	Bartailed Godwit	3	1	2
Hadeda Ibis		2	6	Curlew		0	1
African Spoonbill		2	10	Whimbrel	47	72	148
Greater Flamingo		0	2	Ethiopian Snipe		0	1
Egyptian Goose		3	13	Water Dikkop		38	78
S African Shelduck	4			Kelp Gull	52	224	745
Yellowbilled Duck		5	16	Hartlaub's Gull	1		
Redbilled Teal		1	8	Caspian Tern		3	8
Spurwinged Goose		3	14	Swift Tern		20	120
African Fish Eagle		0	1	Sandwich Tern	2	63	180
Osprey		1	2	Common Tern	36	3011	13000
African Black Oystercatcher	4	8	14	Arctic Tern		5	37
Ringed Plover	82	64	138	Little Tern		15	33
Whitefrontd Plover	11	90	201	Whitewinged Tern	1		
Kittlitz's Plover	3	29	110	Pied Kingfisher	2	10	14
Threebanded Plover	28	0	1	Giant Kingfisher		1	2
Sand Plover	4	1	3	Malachite Kingfisher		0	3
Grey Plover	110	120	192	Halfcollared Kingfisher		0	1
Blacksmith Plover	4	23	46				
Total per count					1173	4516	
Total excl marine cormorants and terns					1121	1377	

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 70% of natural (Table I-6).

Table I-6 Calculation of the biotic health score for birds.

Variable	Score	Motivation	Confidence
1. Species richness	80 (90%)	There has been no absolute loss of habitat or food type, but a dramatic reduction in freshwater habitat may have led to loss of some species	M
2a. Abundance/Biomass	80	There has been a net loss in productivity of most important food species and a massive increase in human disturbance	M
2b. Community composition	70	Community composition is thought to have shifted towards smaller species, with loss or decreased numbers of freshwater and disturbance-sensitive species	M
Bird score	70		

7. EFFECT OF FUTURE DEVELOPMENT SCENARIOS

Five future development scenarios are evaluated here (see Table I-2 for summary of flows for each scenario). Based on the other specialist reports (Basson and Beck, 2005; Bezuidenhout *et al.*, 2005; Wooldridge, 2005; Whitfield, 2005), it is assumed that change from a predominance of state 1 (marine dominated) to a predominance of state 3 (freshwater dominated) inherent in the scenarios will lead to a change in the composition of the avifauna as follows:

- There is a small change in intertidal area, with muddy sediments returning and sand deposition decreasing, favouring waders
- Reedbed areas increase slightly, favouring reedbed species
- Degraded saltmarsh areas recover, leading to increased overall productivity
- Invertebrate macrobenthos increases, favouring waders
- Fish fauna changes from marine species dominated (e.g. harders), to more estuarine species dominated, with expansion of REI zone also leading to increase in smaller fish, favouring piscivorous birds.
- Freshwater habitat and productivity of freshwater plants and invertebrates increases, favouring waterfowl

The changes in health under each of the scenarios is summarised as follows (see DWAF, 2005 for details of other components for each scenario).

7.1 Scenario 1

This is expected to be similar to the Present State, with possible slight effects during the high flow period and possibly a slight increase in piscivorous birds in response to increased fish recruitment.

Variable	Score	Motivation	Confidence
1. Species richness	85 (93%)	There may be a slight increase in the appearance of waterfowl species during spring	M
2a. Abundance/Biomass	85	Piscivorous species may become more abundant, particularly during spring because of increases in smaller species (<i>Gilchristella aestuaria</i> and juvenile marine fish species); wader and wading bird abundance could increase slightly if the increase in saltmarsh productivity is significant	M
2b. Community composition	75	The composition will be very similar to the present state for most of the year, but might differ slightly from the present during spring	M
Bird Score	75		

7.2 Scenario 2

This is expected to be similar to the Present State, with possible slight effects during the high flow period and possibly a slight increase in piscivorous birds in response to increased fish recruitment.

Variable	Score	Motivation	Confidence
1. Species richness	85 (90%)	There may be a slight increase in the appearance of waterfowl species during spring and summer	M
2a. Abundance/Biomass	90	Piscivorous species may become more abundant, particularly during spring; wader and wading bird abundance could increase slightly if the increase in saltmarsh productivity is significant	M
2b. Community composition	80	The composition will be very similar to the present state for most of the year, but might differ slightly from the present during spring	M
Bird score	80		

7.3 Scenario 3

The bird community is unlikely to show any significant changes relative to the Present State.

Variable	Score	Motivation	Confidence
1. Species richness	80 (90%)	Bird species richness will be similar to the present state, though some waterfowl species may occur more commonly in the Geelhoutboom	H
2a. Abundance/Biomass	82	Small increases could occur in the Geelhoutboom but the overall change will be small relative to present state	M
2b. Community composition	72	Species composition will remain very similar to the present state, with possible very small increase in numbers of waterfowl.	M
Bird score	72		

7.4 Scenario 4

The avifaunal community remains similar to the Present State, but with slight increases in the occurrence of waterfowl, piscivorous birds, and possibly waders as a result of increased invertebrate productivity.

Variable	Score	Motivation	Confidence
1. Species richness	85 (93%)	Certain species such as waterfowl may occur more frequently in the Geelhoutboom and Kromme above the confluence	H
2a. Abundance	87	Small increase in abundance of piscivores and possibly other marsh users and waders compared to Scenario 1	M
2b. Community composition	77	A slight change in community composition due to the above	M
Bird score	77		

7.5 Scenario 5

Similar to the present state, with possible slight effects during the high flow period and possibly a slight increase in piscivorous birds in response to increased fish recruitment.

Variable	Score	Motivation	Confidence
1. Species richness	85 (90%)	Certain species such as waterfowl may occur more frequently in the Geelhoutboom and Kromme above the confluence	H
2a. Abundance/Biomass	88	Small increase in abundance of water fowl, piscivores and possibly other marsh users and waders relative to Scenario 4	M
2b. Community composition	78	A slight change in community composition due to the above	M
Bird Score	78		

The scenarios are summarised in Table I-7. Overall, the scenarios offer very little in the way of improvement of the estuary, and there are very minor differences between them. The fine scale nature of the different scenarios is a bad match to the coarse scale understanding of the relationships between the biotic and abiotic components of their estuary and their responses to changes in conditions.

Table I-7 Summary of estimated effects of the five scenarios on the component health scores for birds. Scenarios are listed in order of their degree of change from the present situation.

Scenario	Richness	Abundance	Community composition	Comment
Present (2 Mm ³)	80	80	70	Loss of habitat, loss of invert productivity affecting waders, loss of fish biomass affecting wading birds
3 (G-flow)	80	80	70	No measurable change from present
1 (5 Mm ³)	85	85	75	Waterfowl more frequent, waders and piscivores increase slightly in abundance
4 (5 Mm ³ + G-flow)	85	85	75	No measurable change from Scenario 1
5 (7.5 Mm ³)	85	88	78	Very slight increase in trend from Scenario 1
2 (10 Mm ³)	85	90	80	Slight increase in trend from Scenario 1

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APPENDIX J

Details on Simulation of Recommended Estuarine Flow Requirement Scenario

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1. EFFECT OF PROPOSED EWR RELEASES FROM THE IMPOFU DAM ON THE YIELD OF THE IMPOFU / CHURCHILL SYSTEM

1.1 Objectives

This analysis investigates the impact of Scenario 6, arising from the estuary workshop, on the yield of the system. Scenario 6 represents the ecological flows required for the Kromme Estuary to meet the Recommended Ecological Category, as identified at the Specialist Workshop (23 – 25 February 2005). To test the sensitivity of the yield model for evaporative requirements and drought flows, an additional Scenario 7 was generated (although not scored by the workshop). This scenario included the required ecological flows for the period October to March (i.e. similar to that of Scenario 6), but allowed for zero flow releases from April to September and in drought periods (Table J-1).

Table J-1 Ecological flows for the two scenarios

Month	Scenario 6		Scenario 7		
	Normal Flows	Damage control	Normal Flows	Damage control	Zero Flows ⁽¹⁾
	N1	D1	N2	D2	
Oct	5m ³ /s for 6 days and 1m ³ /s for 25 days		5m ³ /s for 6 days and 1m ³ /s for 25 days		
Nov	1m ³ /s for a month	0.2m ³ /s for a month	1m ³ /s for a month	0.2m ³ /s for a month	
Dec	0.7m ³ /s for a month	0.2m ³ /s for a month	0.7m ³ /s for a month	0.2m ³ /s for a month	
Jan	0.6m ³ /s for a month	0.2m ³ /s for a month	0.6m ³ /s for a month	0.2m ³ /s for a month	
Feb	0.2m ³ /s for a month	0.2m ³ /s for a month	0.2m ³ /s for a month	0.2m ³ /s for a month	
Mar	0.2m ³ /s for a month		0.2m ³ /s for a month		
Apr	0.2m ³ /s for a month				
May	0.2m ³ /s for a month				
Jun	0.2m ³ /s for a month				
Jul	0.2m ³ /s for a month				
Aug	0.2m ³ /s for a month				
Sep	0.2m ³ /s for a month				

(1) As an additional concession the damage control flows in scenario 6b were reduced to zero for 1 out of 10 years to increase the yield.

The difference between the mean annual runoff of Scenario 6 (50 million m³/a) and Scenario 7 (49.1 million m³/a) was 0.9 million m³/a. If such a difference in yield would be considered significant, it may be worthwhile to investigate the ecological implications of Scenario 7 as well.

Furthermore, the yield model proved to be sensitive to the assumptions made regarding drought flow releases. In the case of the Kromme, the long drought period (~ 8 years) encountered in the simulated monthly runoff data set influenced the available yield significantly. To test the sensitivity of the yield model, simulated runoff scenarios were produced for two different drought assumptions.

Depending on the drought assumptions, mean annual runoff of Scenario 6 varied between 50 million m³/a and 38.5 million m³/a, while the mean annual runoff for Scenario 7 varied between 49.1 million m³/a and 37.7 million m³/a. This indicates that the yield model is sensitive to drought assumptions.

For the purposes of this study, the more conservative approach was chosen for Scenario 6 (accepted as the Recommended Ecological Flow Scenario), but this needs to be verified once the drought assumptions have been refined.

1.2 Detailed Procedures

The releases specified for these two scenario sets are described in Table J-1.

Typical monthly flows for each year were calculated from the cases in Table J-1 and are shown in Table J-2 below.

Table J-2 Typical Monthly Flows (Mm³)

Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual Total
N1 - Normal IFR for scenario 6 (Mm ³)	4.75	2.59	1.87	1.61	0.49	0.54	0.52	0.54	0.52	0.54	0.54	1.04	15.53
N2 - Normal IFR for scenario 7 (Mm ³)	4.75	2.59	1.87	1.61	0.49	0.54	0.00	0.00	0.00	0.00	0.00	0.00	11.85
D - Drought IFR for scenarios 6 and 7 (Mm ³)	0.00	0.52	0.54	0.54	0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.08
0 -No IFR (Mm ³)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure J-1 shows the storage trajectory of the Impofu and Churchill Dams supplying the historical firm yield for the period from 1927 to 2000 of about 32 million m³/a. Note how the storage is drawn down only over the extreme drought from 1983 to 1992 and to increase the yield it is necessary to reduce the estuary releases by as much as possible over this period. If the curtailed drought IFR was introduced at the same time as curtailing the supply to the urban consumers (say at about 60% of the storage), then nine consecutive years of drought estuary releases would be necessary to maximise the yield. Other scenarios, which were less harsh on the environment, introduced gaps of normal IFR of from 1 to 3 years between the damage control IFR. Table J-3 shows the annual timing of the different releases from the dam for the different scenarios. Other timings of the gap years are possible; for instance it may be possible to have two sequential damage control years before introducing an increased release to the estuary.

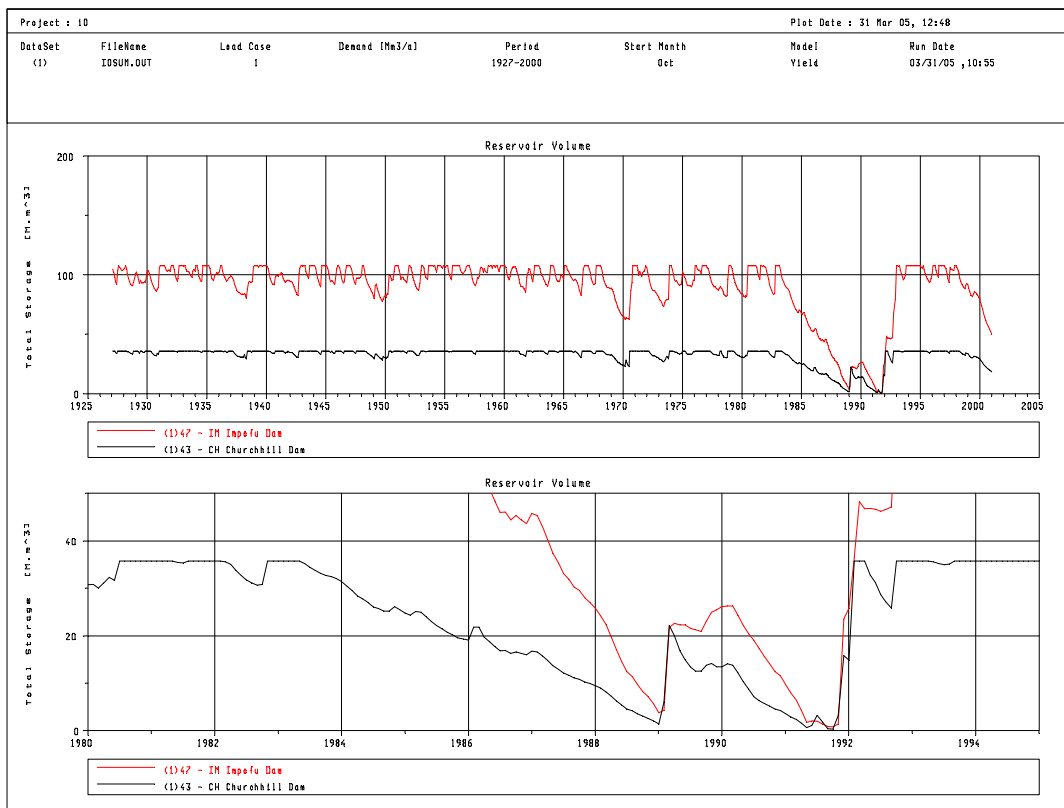


Figure J-1 No EWR Releases: Supplying 32.5Mm³/a from Churchill and Impofu to urban and agricultural consumers

Table J-3 Distribution of drought years for the different scenarios

Year	Existing Scenario 6 Zero gap	Existing Scenario 6 One year drought gap	Existing Scenario 6 Two year drought gap	Existing Scenario 6 Three year drought gap	Existing Scenario 7 Zero gap	Existing Scenario 7 One year drought gap	Existing Scenario 7, Two year drought gap	Existing Scenario 7 Three year drought gap	Existing Scenario 7 (No gap with 0 flow for one year in critical drawdown period)	Existing Scenario 7 One year drought gap with 0 flow for one year in critical drawdown period	Existing Scenario 7 Two year drought gap with 0 flow for one year in critical drawdown period	Existing Scenario 7 Three year drought gap with 0 flow for one year in critical drawdown period
A	B	C	D	E	F	G	H	I	J	K	L	M
1927	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1928	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1929	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1930	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1931	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1932	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1933	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1934	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1935	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1936	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1937	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1938	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1939	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1940	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1941	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1942	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1943	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1944	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1945	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1946	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1947	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1948	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1949	D	D	D	D	D	D	D	D	D	D	D	D
1950	D	N1	N1	N1	D	N2	N2	N2	D	N2	N2	N2
1951	D	D	N1	N1	D	D	N2	N2	D	D	N2	N2
1952	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1953	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1954	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1955	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1956	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1957	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1958	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1959	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1960	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1961	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1962	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1963	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1964	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1965	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1966	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1967	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1968	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1969	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1970	D	D	D	D	D	D	D	D	D	D	D	D
1971	D	N1	N1	N1	D	N2	N2	N2	D	N2	N2	N2
1972	N1	N1	N1	N1	N2	n2	n2	n2	n2	N2	n2	n2
1973	D	D	D	N1	D	D	D	N2	D	D	D	N2
1974	D	N1	N1	D	D	N2	N2	D	D	N2	N2	D
1975	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1976	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1977	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1978	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1979	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1980	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1981	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1982	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1983	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1984	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1985	D	D	D	D	D	D	D	D	D	D	D	0
1986	D	N1	N1	N1	D	N2	N2	N2	D	N2	N2	N2
1987	D	D	N1	N1	D	D	N2	N2	D	D	N2	N2
1988	D	N1	D	N1	D	N2	D	N2	0	N2	0	N2
1989	D	D	N1	D	D	D	N2	D	D	0	N2	D
1990	D	N1	N1	N1	D	N2	N2	N2	D	N2	N2	N2
1991	D	D	D	N1	D	D	D	N2	D	D	D	N2
1992	D	N1	N1	N1	D	N2	N2	N2	D	N2	N2	N2
1993	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	D
1994	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1995	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1996	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1997	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1998	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1999	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
2000	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
2001	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
2002	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
2003	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2

1.3 Results

The yields obtained for the different scenarios sets are provided in Table J-4.

For Scenario 6 set, the IFR release during normal years is about 16 million m³/a, which reduces to a “damage control” volume of 2 million m³/a in drought periods. If the drought IFR is maintained without gaps for the approximately nine years when the system is drawn down below 60% storage, then the reduction in yield is limited to 4.7 million m³/a (Column B of Table J-4). If gaps in the “damage control” releases are introduced by making normal annual releases the yield decreases. For gaps of 1, 2 and 3 years the reduction in the yield increases by 9.4, 10.4 and 12.2 million m³/a respectively.

For the Scenario 7 set, the IFR release during normal years is about 12 million m³/a, which reduces to “damage control” volume of 2 million m³/a in drought periods. If the “damage control” releases are maintained without gaps for the approximately nine years when the system is drawn down below 60% storage, then the reduction in yield is limited to 3.9 million m³/a. If gaps in the drought releases are introduced by making normal annual releases the yield decreases. For gaps of 1, 2 and 3 years the reduction in the yield increases by 7.2, 7.8 and 9.5 million m³/a respectively.

If an additional year of 0 releases is introduced into Scenario 7 the yields increase by approximately 0.3 million m³/a, though the increase will be more for shorter drawdown period.

The reduced historical firm yields obtained for the period from 1927 to 2000 are presented in column C of Table J-4. If the last drought period from 1983 is ignored then the yields will increase and these yields have been estimated in Column D of Table J-4 – simply by applying the reductions determined for the 1983 to 1992 period (Column B) to the historical firm yield for the shorter period of 56.9 million m³/a. If the 1 in 50 yield of 44.1 is used instead of the historical firm yield then the yield estimates in Column E are obtained. A stochastic analysis was not used to determine these 1 in 50 year yields.

The upper window of Figure J-2 shows the dam trajectories for Scenario 6 assuming that the releases are reduced to 2 million m³/a for the full period from 1985 to 1993 and supplying the historical firm yield of 27.8 million m³/a to urban and agricultural consumers. The lower window in Figure J-2 shows the dam trajectories for Scenario 7 also reduced to 2 million m³/a for the full period from 1985 to 1993 and supplying the historical firm yield of 28.6 million m³/a to urban and agricultural users. (The applied historical firm yields have been shaded in column C of Table J-4.) The inflows to the estuary for Scenarios 6 and 7 are provided in Table J-5 and J-6 respectively. The trajectories in the upper and lower window of Figure J-2 are very similar and the dams remain relatively full for most of the period and spill frequently.

To simulate the spills from the Churchill and Impofu Dams more realistically, larger target drafts based on the 1 in 50 year yield were applied to the system. The applied drafts of 41.7 and 42.5 million m³/a for Scenarios 6 and 7 have been highlighted in column E of Table J-4. The associated dam trajectories are illustrated in Figure J-3 and the inflows to the estuary are provided in Tables J-7 and J-8. Additional variants based on these inflows can be obtained by increasing the “damage control” releases to those corresponding with normal years in for some years in the period between 1985 and 1993, which will reduce the yield as indicated in Tables J-3 and J-4.

Figures J-4 and J-5 compare the flow sequence obtained at the estuary for the 4 cases analysed:

1. Scenario 6 (reducing to 2Mm³/a when the storage falls below about 60%) and supplying the historical firm yield (27.8Mm³/a)
2. Scenario 7 (reducing to 2Mm³/a when the storage falls below about 60%) and supplying the historical firm yield (28.6Mm³/a)
3. Scenario 6 (reducing to 2Mm³/a when the storage falls below about 60%) and supplying the approximate 1 in 50 year yield (41.7Mm³/a)
4. Scenario 7 (reducing to 2Mm³/a when the storage falls below about 60%) and supplying the approximate 1 in 50 year yield (42.5Mm³/a)

The upper windows in these figures provide the actual monthly flow sequence while the lower blocks represent the annual average.

Table J-4 Yield results

Scenario/s	Reduction Yield (Mm ³)	Approximate Historical Firm Yield Nov 83 - June 92 (Mm ³)	Historical Firm Yield for period before Nov 83 (Mm ³)	Approximate 1 in 50 year Yield (Mm ³)
(A)	(B)	(C)	(D)	(E)
No EWR Releases ⁽¹⁾		30.2	54.6	44.1
Agricultural releases from Impofu		2.3	2.3	2.3
Sum of no EWR releases and agricultural releases from Impofu		32.5	56.9	46.4
Existing Scenario 6 (No gap)	-4.7	27.8	52.2	41.7
Existing Scenario 6 One year drought gap	-9.4	23.1	47.5	37.0
Existing Scenario 6 Two year drought gap	-10.4	22.1	46.5	36.0
Existing Scenario 6 Three year drought gap	-12.2	20.3	44.7	34.2
Existing Scenario 7 (No gap)	-3.9	28.6	53.0	42.5
Existing Scenario 7 One year drought gap	-7.2	25.3	49.7	39.2
Existing Scenario 7 Two year drought gap	-7.8	24.7	49.1	38.6
Existing Scenario 7 Three year drought gap	-9.5	23.0	47.4	36.9
Existing Scenario 7 (No gap with 0 flow for one year in critical drawdown period)	-3.6	28.9	53.3	42.8
Existing Scenario 7 One year drought gap with 0 flow for one year in critical drawdown period	-7	25.5	49.9	39.4
Existing Scenario 7 Two year drought gap with 0 flow for one year in critical drawdown period	-7.6	24.9	49.3	38.8
Existing Scenario 7 Three year drought gap with 0 flow for one year in critical drawdown period	-9.3	23.2	47.6	37.1

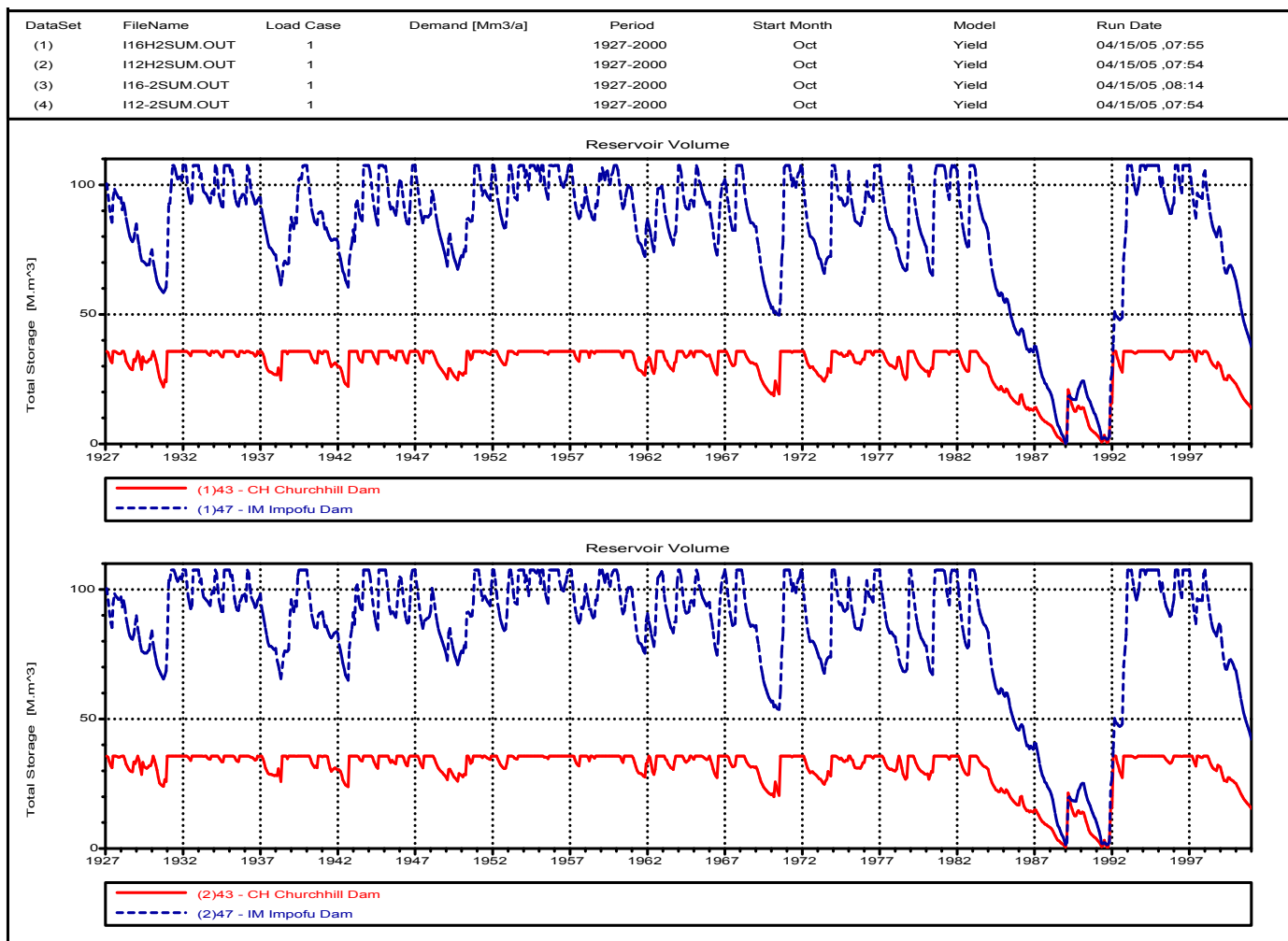


Figure J-2 Storage in the Churchill and Impofu Dams supplying the historical firm yield under Scenario 6 (top) and Scenario 7 (bottom). The releases to the estuary drop to 2 Mm³/a when the storage drops below about 60%.

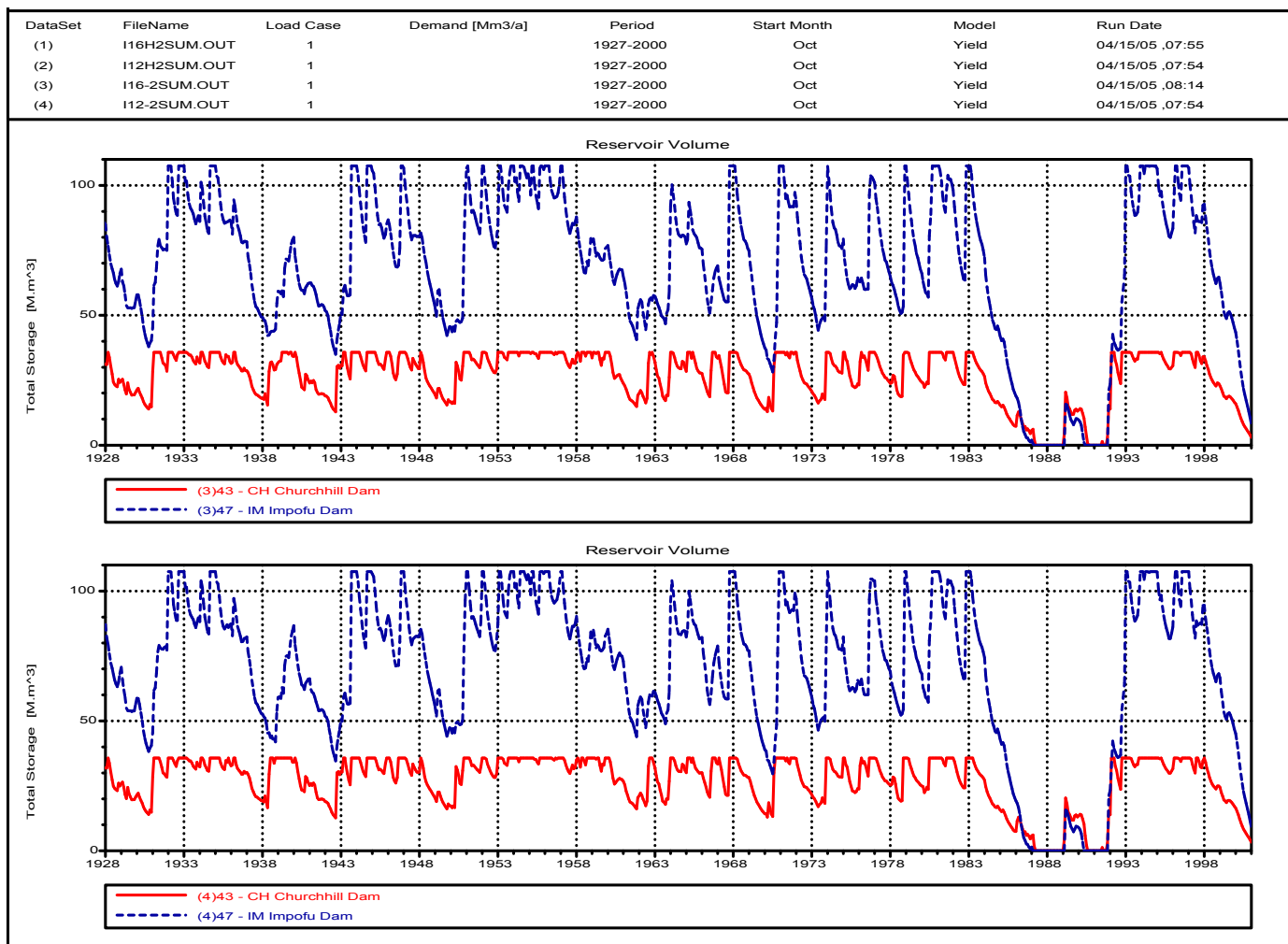


Figure J-3 Storage in the Churchill and Impofu Dams supplying the approximate 1 in 50 year yield under Scenario 6 (top) and Scenario 7 (bottom). The releases to the estuary drop to 2 Mm³/a when the storage drops below about 60%.

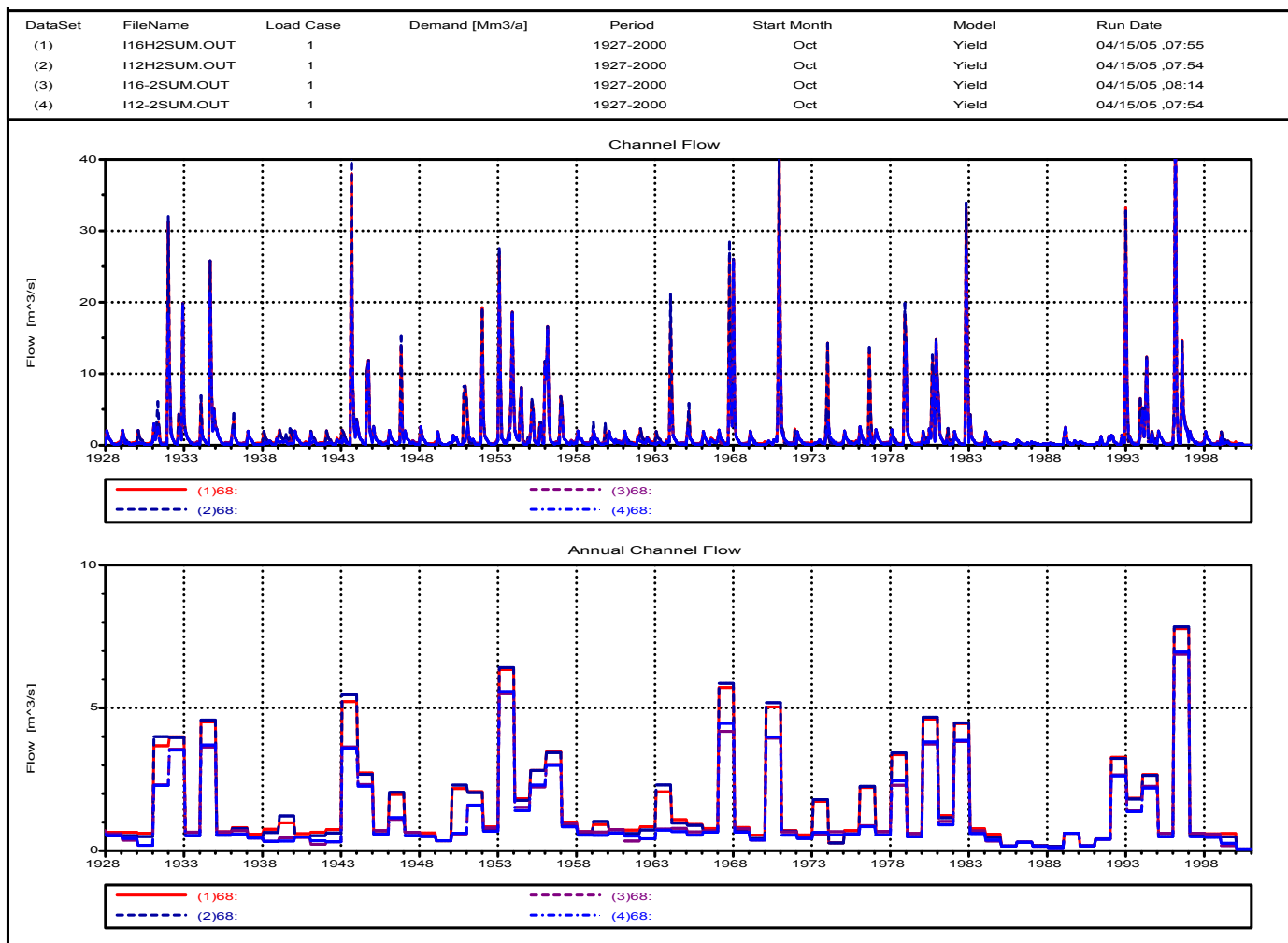


Figure J-4 Flows at the estuary for different scenarios and target drafts

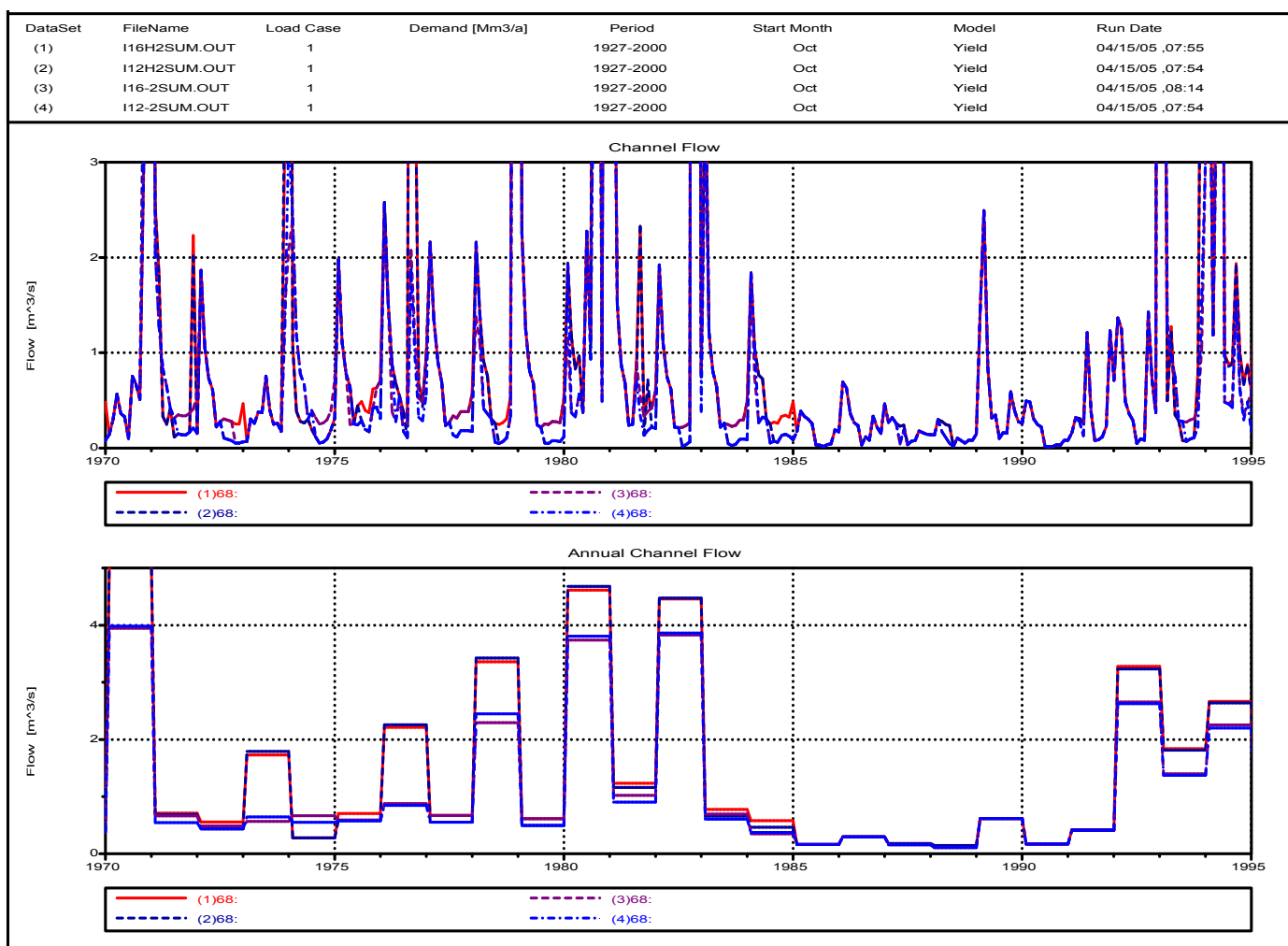


Figure J-5 Flows at the estuary for different scenarios and target drafts for 1970 to 1990

1.4 Selection of sequences for analysis in the Kromme Estuary

The flow sequence at the estuary is affected by both the release from the Impofu Dam during droughts and the magnitude of the normal abstraction from the Churchill/Impofu System:

- a) Releases from Impofu Dam. In the 1980s, the Kromme River was subjected to a protracted drought. In this period, reducing the releases from the Impofu Dam to the estuary from the "normal" requirement to say a "damage control" requirement would have increased the yield from the system but could also have impacted negatively on the ecology of the estuary. The yield of the system would be maximised if the estuarine releases and urban demands were curtailed at the same time when say the system storage dropped to about 60%. In the 1980s these reduced releases could have been applied for about 8 years. Increasing the releases to the estuary during this period could provide respite to the estuary but would impact on the yield. How many consecutive years of "damage" control or drought releases can be tolerated by the estuary will have a significant impact on the yield.
- b) Magnitude of normal abstraction from the system. The greater the abstraction from the Churchill/Impofu system the less the inflows to the estuary because the dams will be more severely drawn down and spill less often. The demands on the system were increased to approximate demands that would require some restrictions during 1 in 50 year drought and more severe curtailments during more severe droughts such as the 1980s drought. Guided by the above influences, a conservative approach was taken when selecting the estuarine inflow sequence for further analysis. The flow sequence adopted for the estuarine analysis was based on scenario 6 in which the releases from Impofu Dam were reduced to the damage control value for an extended period of about 8 years. The demand was increased from the historical firm yield to the 1 in 50 year demand, which reduced the spills from about 50 (Table J-6) to 38 million m³/a (Table J-7).

Table J-5 Scenario 6 - System supplying the historical firm yield and reducing the releases from Impofu to 2 million m³/annum during droughts

Scenario 6 Reducing to 2Mm3/a supplying HFY													
File : 68-I16H2.NSI													
Units : [Mm3]													
Descrip. : Estuary Inflow for 1927 to 2000													
Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1927	5.01	2.81	2.01	1.68	0.58	3.22	1.79	0.81	0.75	0.72	0.79	1.57	21.7
1928	5.42	3.56	2.31	1.77	0.57	0.60	0.57	0.66	0.68	1.05	1.05	2.09	20.3
1929	5.56	3.01	2.09	1.70	0.90	0.91	0.78	0.76	0.86	0.89	1.18	1.70	20.3
1930	5.53	3.02	2.06	1.82	0.60	0.65	0.64	0.64	0.61	0.85	0.84	2.23	19.5
1931	7.92	3.97	3.73	8.69	6.16	0.94	0.77	0.71	0.74	0.90	0.84	80.73	116.1
1932	27.70	5.73	2.61	1.82	0.60	0.68	0.72	11.58	7.50	2.99	53.26	10.77	125.9
1933	5.48	3.65	2.31	1.83	0.70	0.84	0.73	0.70	0.68	1.13	1.07	1.42	20.5
1934	15.72	3.69	2.17	1.71	0.57	0.62	0.73	69.06	20.99	6.33	13.68	7.10	142.4
1935	5.95	3.68	2.48	1.86	0.59	0.67	0.65	1.00	0.87	0.93	0.89	1.34	20.9
1936	5.47	8.79	3.01	1.86	0.60	0.70	0.65	0.62	0.73	0.85	0.83	1.48	25.6
1937	5.18	2.98	2.18	1.81	0.58	0.59	0.66	0.76	0.74	0.75	0.74	1.34	18.3
1938	5.14	3.14	2.17	1.72	1.38	1.44	1.01	0.85	0.75	0.85	2.85	2.53	23.8
1939	5.63	3.34	2.59	2.11	1.30	1.52	1.06	0.90	1.13	5.47	2.11	3.80	30.9
1940	5.28	2.97	2.06	1.73	0.57	0.64	0.69	0.68	1.20	1.00	0.84	1.33	19.0
1941	5.25	2.97	2.88	2.25	0.70	0.66	0.65	0.95	0.95	0.94	0.93	1.35	20.5
1942	5.35	3.02	2.17	1.92	0.66	0.67	0.66	0.67	2.49	1.85	1.54	2.47	23.5
1943	5.63	4.52	2.99	1.94	0.68	0.96	0.91	101.82	23.88	8.13	3.92	9.43	164.8
1944	6.05	3.17	2.14	1.73	0.57	0.59	0.57	27.67	30.79	6.51	4.24	1.95	86.0
1945	6.62	3.42	2.15	1.73	0.56	1.36	0.95	0.70	0.65	1.08	1.22	1.63	22.1
1946	5.50	3.01	2.06	1.70	0.53	0.88	0.84	1.27	1.52	37.05	5.79	2.21	62.4
1947	5.38	3.06	2.14	1.74	0.59	0.70	1.63	1.17	0.85	0.85	0.84	1.46	20.4
1948	6.85	3.60	2.18	1.75	0.58	0.61	0.60	0.61	0.57	0.58	0.59	1.13	19.7
1949	0.09	4.84	2.26	0.68	0.56	0.05	0.09	0.12	0.09	0.46	0.93	0.81	11.0
1950	1.01	3.55	1.87	3.12	1.48	0.25	0.14	0.21	0.31	18.08	22.17	16.59	68.8
1951	8.37	1.05	0.79	0.71	1.99	0.65	0.18	0.22	0.26	0.28	0.94	49.85	65.3
1952	10.75	3.42	2.30	1.78	0.61	0.63	0.60	0.61	0.69	1.00	1.38	2.74	26.5
1953	70.91	24.32	2.52	1.85	0.57	1.62	1.15	3.89	7.93	17.44	49.93	17.89	200.0
1954	5.56	3.08	2.15	1.77	14.33	21.66	1.76	1.40	0.80	0.86	2.19	1.98	57.5
1955	5.35	15.85	13.41	1.83	0.72	0.88	0.74	8.27	8.17	1.98	1.19	30.28	88.7
1956	26.09	43.01	10.64	2.16	0.95	0.97	0.89	1.06	1.24	1.24	3.24	17.63	109.1
1957	15.29	3.21	2.12	1.69	0.52	0.76	0.68	1.80	1.33	0.97	1.44	1.82	31.6
1958	5.32	2.92	2.08	2.31	0.86	0.74	0.93	0.93	0.83	0.91	1.35	1.75	20.9
1959	5.54	3.02	2.17	2.23	0.80	0.66	0.65	0.81	0.86	6.22	2.59	3.48	29.0
1960	5.18	2.88	2.05	1.75	0.67	2.07	1.45	1.72	1.41	1.33	1.27	1.56	23.3
1961	5.20	2.88	2.01	1.70	0.56	1.00	0.99	0.84	0.73	0.74	3.54	2.68	22.9
1962	6.18	3.38	2.17	2.12	0.73	2.92	2.51	1.63	1.22	1.17	1.11	1.49	26.6
1963	5.09	2.93	2.44	2.08	0.71	0.75	0.69	0.68	1.88	1.50	1.77	44.69	65.2
1964	19.91	3.58	2.30	1.77	0.54	0.70	0.73	0.92	0.91	0.90	0.85	1.30	34.4
1965	6.15	12.35	2.44	1.91	0.73	0.68	0.61	0.66	0.63	0.64	0.84	1.39	29.0
1966	5.10	2.99	2.14	1.73	0.54	0.61	2.53	2.26	1.56	1.48	1.45	2.30	24.7
1967	5.64	3.07	2.13	1.72	0.56	0.63	0.98	0.96	67.94	21.09	8.14	67.52	180.4
1968	12.34	3.36	2.22	1.78	0.58	0.65	0.61	0.63	0.69	0.74	0.75	1.34	25.7
1969	5.24	2.92	2.01	1.70	0.58	0.61	0.56	0.57	0.56	0.57	0.70	1.24	17.3
1970	0.38	0.78	1.51	0.97	0.80	0.27	1.96	1.79	1.32	7.94	109.69	31.34	158.7
1971	6.81	4.77	0.89	0.67	1.04	0.31	0.39	0.37	0.36	0.45	5.98	0.40	22.4
1972	5.00	2.75	1.96	1.65	0.54	0.74	0.79	0.78	0.72	0.68	0.68	1.20	17.5
1973	0.18	0.79	0.70	1.01	0.90	2.02	1.03	0.67	0.67	0.46	9.07	37.04	54.5
1974	2.92	1.00	0.75	0.70	0.73	0.52	0.31	0.14	0.16	0.25	0.50	0.81	8.8
1975	5.31	2.88	2.08	1.73	0.64	1.18	1.26	1.06	0.96	1.66	1.69	1.84	22.3
1976	6.92	3.98	2.36	1.82	1.32	1.01	0.80	34.59	11.41	1.84	1.30	2.51	69.8
1977	5.79	3.53	2.43	1.85	0.57	0.72	0.87	0.84	0.99	1.03	1.03	1.48	21.1
1978	5.79	3.64	2.44	2.03	0.74	0.70	0.64	0.71	0.79	1.44	48.98	38.14	106.0
1979	6.08	3.24	2.18	1.82	0.60	0.58	0.66	0.66	0.72	0.74	0.71	1.34	19.3
1980	5.19	3.03	2.22	2.59	0.90	6.09	2.94	30.99	26.08	2.36	39.61	23.55	145.5
1981	15.95	3.91	2.34	1.82	0.58	0.67	2.34	6.21	0.86	1.52	1.12	1.57	38.9
1982	5.15	2.85	2.01	1.66	0.53	0.57	0.56	0.63	0.69	88.41	35.54	2.03	140.6
1983	11.53	3.14	2.15	1.72	0.55	0.70	0.63	0.60	0.62	0.78	0.79	1.27	24.5
1984	4.93	2.72	2.05	1.94	0.73	0.68	0.70	0.70	0.86	0.92	0.87	1.26	18.4
1985	0.46	1.00	0.89	0.81	0.62	0.09	0.08	0.05	0.09	0.12	0.51	0.44	5.1
1986	1.85	1.63	0.96	0.71	0.57	0.09	0.31	0.22	0.86	0.58	0.41	1.20	9.4
1987	0.72	0.83	0.70	0.61	0.60	0.09	0.18	0.21	0.46	0.43	0.39	0.36	5.6
1988	0.36	0.77	0.74	0.66	0.57	0.05	0.27	0.21	0.14	0.22	0.22	0.38	4.6
1989	3.87	6.46	2.27	0.84	0.84	0.27	0.41	0.42	1.53	1.05	0.74	0.67	19.4
1990	1.32	1.25	0.82	0.66	0.54	0.05	0.04	0.05	0.09	0.09	0.21	0.21	5.3
1991	0.43	0.83	0.83	0.70	3.03	1.02	0.21	0.23	0.31	0.61	3.29	1.84	13.3
1992	3.66	3.25	1.31	0.96	0.70	0.12	0.25	0.22	3.70	1.91	0.99	86.32	103.4
1993	21.79	1.29	3.41	0.93	0.70	0.21	0.18	0.25	0.28	2.19	17.54	9.20	58.0
1994	14.04	3.08	13.29	33.06	2.39	2.36	2.33	5.18	2.59	1.83	2.34	1.57	84.1
1995	5.29	3.10	2.67	2.00	0.68	0.70	0.64	0.62	0.57	0.70	0.93	1.48	19.4
1996	13.76	134.43	18.38	1.95	0.62	0.68	37.93	12.85	9.30	7.19	5.96	2.28	245.3
1997	5.24	2.93	2.04	1.77	0.57	1.14	0.85	0.72	0.69	0.72	1.13	1.56	19.4
1998	5.11	2.93	2.17	1.78	0.58	0.63	0.64	0.66	0.62	1.21	1.01	1.31	18.6
1999	4.92	2.66	2.05	1.88	0.98	1.50	1.10	0.84	0.73	0.68	0.66	1.20	19.2
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
AVE :	7.55	5.94	2.67	2.14	1.02	1.16	1.34	4.84	3.64	3.94	6.78	9.02	50.0
SD :	9.23	16.16	2.86	3.77	1.74	2.56	4.35	15.18	9.62	11.43	16.79	18.01	52.5

Table J-6 **Scenario 7 – System supplying the historical firm yield and reducing the releases from Impofu to 2 million m³/annum during droughts**

Scenario 7 Reducing to 2Mm3/a supplying HFY													
File	: 68-I12H2.NSI												
Units	: [Mm3]												
Descrip.	: Estuary Inflow for 1927 to 2000												
Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1927	5.01	2.81	2.01	1.68	0.58	3.22	1.27	0.27	0.23	0.19	0.25	0.53	18.1
1928	5.42	3.56	2.31	1.77	0.57	0.60	0.05	0.12	0.16	0.52	0.52	1.05	16.7
1929	5.56	3.01	2.09	1.70	0.90	0.91	0.26	0.22	0.34	0.35	0.64	0.66	16.6
1930	5.53	3.02	2.06	1.82	0.60	0.65	0.12	0.10	0.09	0.32	0.30	1.19	15.8
1931	7.92	3.97	6.67	16.32	6.08	0.94	0.25	0.17	0.22	0.37	0.30	82.97	126.2
1932	27.62	5.65	2.61	1.82	0.60	0.68	0.20	11.69	7.45	2.94	53.20	10.71	125.2
1933	5.48	3.65	2.31	1.83	0.70	0.84	0.21	0.16	0.16	0.59	0.54	0.38	16.9
1934	18.52	3.69	2.17	1.71	0.57	0.62	0.21	69.09	20.93	6.28	13.63	7.04	144.4
1935	5.95	3.68	2.48	1.86	0.59	0.67	0.13	0.47	0.36	0.40	0.35	0.30	17.2
1936	5.47	11.51	3.01	1.86	0.60	0.70	0.13	0.09	0.21	0.32	0.29	0.44	24.6
1937	5.18	2.98	2.18	1.81	0.58	0.59	0.14	0.22	0.22	0.21	0.21	0.30	14.6
1938	5.14	3.14	2.17	1.72	1.38	1.44	0.49	0.32	0.24	0.32	2.31	1.49	20.2
1939	5.63	3.34	2.59	2.11	1.30	4.03	1.67	0.49	5.98	5.58	2.05	3.73	38.5
1940	5.28	2.97	2.06	1.73	0.57	0.64	0.17	0.14	0.68	0.47	0.30	0.30	15.3
1941	5.25	2.97	2.88	2.25	0.70	0.66	0.13	0.41	0.43	0.41	0.39	0.31	16.8
1942	5.35	3.02	2.17	1.92	0.66	0.67	0.14	0.13	1.97	1.32	1.00	1.43	19.8
1943	5.63	4.52	2.99	1.94	0.68	0.96	0.39	110.07	23.83	8.07	3.86	9.36	172.3
1944	6.05	3.17	2.14	1.73	0.57	0.59	0.05	27.62	30.74	6.45	4.18	1.16	84.4
1945	6.99	3.42	2.15	1.73	0.56	1.36	0.43	0.16	0.13	0.55	0.68	0.59	18.8
1946	5.50	3.01	2.06	1.70	0.53	0.88	0.32	0.73	1.01	41.10	5.73	2.15	64.7
1947	5.38	3.06	2.14	1.74	0.59	0.70	1.11	0.63	0.33	0.32	0.30	0.42	16.7
1948	6.85	3.60	2.18	1.75	0.58	0.61	0.08	0.08	0.05	0.05	0.05	0.09	16.0
1949	0.09	4.84	2.26	0.68	0.56	0.05	0.09	0.12	0.09	0.46	0.93	0.81	11.0
1950	1.01	3.55	1.87	3.12	1.48	0.25	0.14	0.21	0.31	22.01	22.11	16.53	72.6
1951	8.29	1.05	0.79	0.71	1.99	0.65	0.18	0.22	0.26	0.28	0.94	49.13	64.5
1952	10.67	3.42	2.30	1.78	0.61	0.63	0.09	0.08	0.17	0.47	0.84	1.71	22.8
1953	73.81	24.25	2.52	1.85	0.57	1.62	0.64	3.35	8.52	17.38	49.88	17.83	202.2
1954	5.56	3.08	2.15	1.77	13.94	21.60	1.71	1.34	0.28	0.33	3.08	0.94	55.8
1955	5.35	16.66	13.33	1.83	0.72	0.88	0.22	8.46	8.12	1.92	0.90	30.44	88.8
1956	26.02	42.93	10.56	2.16	0.95	0.97	0.37	0.53	0.73	0.70	4.85	17.56	108.3
1957	15.21	3.21	2.12	1.69	0.52	0.76	0.16	1.26	0.82	0.44	0.90	0.78	27.9
1958	5.32	2.92	2.08	2.31	0.86	0.74	0.41	0.39	0.31	0.37	2.41	0.72	18.8
1959	8.67	3.02	2.17	2.23	0.80	0.66	0.13	0.27	0.34	8.12	2.53	3.41	32.4
1960	5.18	2.88	2.05	1.75	0.67	2.07	0.93	1.19	0.89	0.79	0.73	0.52	19.6
1961	5.20	2.88	2.01	1.70	0.56	1.00	0.47	0.30	0.21	0.21	3.01	1.64	19.2
1962	6.18	3.38	2.17	2.12	0.73	2.92	1.99	1.09	0.71	0.64	0.57	0.45	23.0
1963	5.09	2.93	2.44	2.08	0.71	0.75	0.18	0.14	1.36	0.96	1.24	54.82	72.7
1964	19.83	3.58	2.30	1.77	0.54	0.70	0.21	0.39	0.39	0.36	0.31	0.27	30.6
1965	6.15	15.15	2.44	1.91	0.73	0.68	0.09	0.12	0.12	0.10	0.31	0.36	28.2
1966	5.10	2.99	2.14	1.73	0.54	0.61	2.01	1.73	1.05	0.94	0.91	1.68	21.4
1967	5.64	3.07	2.13	1.72	0.56	0.63	0.46	0.42	73.70	21.03	8.08	67.45	184.9
1968	12.26	3.36	2.22	1.78	0.58	0.65	0.09	0.09	0.18	0.21	0.21	0.30	21.9
1969	5.24	2.92	2.01	1.70	0.58	0.61	0.05	0.04	0.04	0.04	0.16	0.21	13.6
1970	0.38	0.78	1.51	0.97	0.80	0.27	1.96	1.79	1.32	12.03	110.50	31.27	163.6
1971	6.73	4.69	0.89	0.67	1.04	0.31	0.39	0.37	0.36	0.45	5.40	0.40	21.7
1972	5.00	2.75	1.96	1.65	0.54	0.74	0.27	0.25	0.20	0.14	0.14	0.17	13.8
1973	0.18	0.79	0.70	1.01	0.90	2.02	1.03	0.67	0.67	0.46	11.09	36.97	56.5
1974	2.84	1.00	0.75	0.70	0.73	0.52	0.31	0.14	0.16	0.25	0.50	0.81	8.7
1975	5.31	2.88	2.08	1.73	0.64	1.18	0.74	0.52	0.44	1.12	1.15	0.80	18.6
1976	6.92	3.98	2.36	1.82	1.32	1.01	0.28	36.69	11.35	1.78	1.16	2.53	71.2
1977	5.79	3.53	2.43	1.85	0.57	0.72	0.36	0.31	0.47	0.49	0.49	0.45	17.5
1978	5.79	3.64	2.44	2.03	0.74	0.70	0.12	0.18	0.27	0.90	53.21	38.07	108.1
1979	6.08	3.24	2.18	1.82	0.60	0.58	0.14	0.12	0.20	0.20	0.18	0.31	15.7
1980	5.19	3.03	2.22	2.59	0.90	6.09	2.42	33.78	26.03	2.31	39.55	23.49	147.6
1981	15.87	3.91	2.34	1.82	0.58	0.67	1.82	6.24	0.34	1.92	0.59	0.53	36.6
1982	5.15	2.85	2.01	1.66	0.53	0.57	0.05	0.09	0.17	90.74	35.48	1.93	141.2
1983	11.48	3.14	2.15	1.72	0.55	0.70	0.12	0.07	0.10	0.25	0.25	0.23	20.8
1984	4.93	2.72	2.05	1.94	0.73	0.68	0.18	0.16	0.34	0.39	0.33	0.22	14.7
1985	0.46	1.00	0.89	0.81	0.62	0.09	0.08	0.05	0.09	0.12	0.51	0.44	5.1
1986	1.85	1.63	0.96	0.71	0.57	0.09	0.31	0.22	0.86	0.58	0.41	1.20	9.4
1987	0.72	0.83	0.70	0.61	0.60	0.09	0.18	0.21	0.46	0.43	0.39	0.36	5.6
1988	0.36	0.77	0.74	0.66	0.57	0.05	0.27	0.21	0.14	0.22	0.22	0.38	4.6
1989	3.87	6.46	2.27	0.84	0.84	0.27	0.41	0.42	1.53	1.05	0.74	0.67	19.4
1990	1.32	1.25	0.82	0.66	0.54	0.05	0.04	0.05	0.09	0.09	0.21	0.21	5.3
1991	0.43	0.83	0.83	0.70	3.03	1.02	0.21	0.23	0.31	0.61	3.29	1.84	13.3
1992	3.66	3.25	1.31	0.96	0.70	0.12	0.25	0.22	3.70	1.91	0.99	84.90	102.0
1993	21.72	1.29	3.26	0.93	0.70	0.21	0.18	0.25	0.28	1.75	17.48	9.14	57.2
1994	13.96	3.08	13.13	32.98	2.32	2.29	2.28	5.13	2.54	1.78	2.28	1.50	83.3
1995	5.29	3.10	2.67	2.00	0.68	0.70	0.12	0.09	0.05	0.17	0.39	0.45	15.7
1996	16.57	134.35	18.30	1.95	0.62	0.68	37.65	12.79	9.25	7.13	5.90	2.21	247.4
1997	5.24	2.93	2.04	1.77	0.57	1.14	0.33	0.18	0.18	0.18	0.60	1.34	16.5
1998	5.11	2.93	2.17	1.78	0.58	0.63	0.12	0.12	0.10	0.68	0.48	0.27	15.0
1999	4.92	2.66	2.05	1.88	0.98	1.50	0.59	0.30	0.21	0.14	0.12	0.17	15.5
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
AVE :	7.70	6.02	2.70	2.24	1.01	1.19	0.97	4.69	3.47	3.85	6.62	8.61	49.1
SD :	9.56	16.18	2.88	4.04	1.70	2.58	4.36	16.12	10.24	12.02	17.09	18.56	54.5

Table J-7 **Scenario 6 – System supplying the 1 in 50 year yield and reducing the releases from Impofu to 2 million m³/annum during droughts**

Scenario 6 Reducing to 2Mm3/a supplying 1 in 50 Dem													
File	: 68-I16-2.NSI												
Units	: [Mm3]												
Descrip.	: Estuary Inflow for 1927 to 2000												
Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1927	5.00	2.81	2.01	1.68	0.58	3.22	1.79	0.81	0.75	0.72	0.79	1.57	21.7
1928	5.41	3.56	2.31	1.77	0.57	0.60	0.57	0.12	0.16	0.52	1.05	2.09	18.7
1929	5.55	0.93	0.75	0.63	0.90	0.38	0.26	0.22	0.34	0.35	0.64	0.66	11.6
1930	0.77	0.95	0.72	0.75	0.60	0.12	0.12	0.10	0.09	0.32	0.30	1.19	6.0
1931	7.91	1.90	3.73	6.68	2.30	0.94	0.77	0.71	0.74	0.90	0.84	45.32	72.7
1932	26.32	4.46	2.61	1.82	0.60	0.68	0.72	4.39	6.54	2.00	52.27	9.63	112.0
1933	5.47	3.65	2.31	1.83	0.70	0.84	0.73	0.70	0.68	1.13	1.07	1.42	20.5
1934	6.85	3.69	2.17	1.71	0.57	0.62	0.73	54.39	20.03	5.35	12.69	5.96	114.7
1935	5.94	3.68	2.48	1.86	0.59	0.67	0.65	1.00	0.87	0.93	0.89	1.34	20.9
1936	5.46	5.36	3.01	1.86	0.60	0.70	0.65	0.62	0.73	0.85	0.83	1.48	22.2
1937	5.18	2.98	2.18	1.81	0.58	0.05	0.14	0.22	0.22	0.21	0.21	0.30	14.1
1938	0.39	1.07	0.83	0.65	1.38	0.90	0.49	0.32	0.24	0.32	2.31	1.49	10.4
1939	0.87	1.27	1.25	1.04	1.30	1.52	1.06	0.90	1.13	1.26	1.05	1.82	14.5
1940	5.27	2.97	2.06	1.73	0.57	0.10	0.17	0.14	0.68	0.47	0.30	0.30	14.8
1941	0.50	0.90	1.54	1.18	0.70	0.12	0.13	0.41	0.43	0.41	0.39	0.31	7.0
1942	0.60	0.95	0.83	0.85	0.66	0.13	0.14	0.13	1.97	1.32	1.00	1.43	10.0
1943	0.88	2.45	1.65	0.87	0.68	0.42	0.39	66.12	22.92	7.14	2.92	8.29	114.7
1944	6.04	3.17	2.14	1.73	0.57	0.59	0.57	17.89	29.83	5.51	3.24	1.95	73.2
1945	6.61	3.42	2.15	1.73	0.56	1.36	0.95	0.70	0.65	1.08	1.22	1.63	22.1
1946	5.49	3.01	2.06	1.70	0.53	0.88	0.84	1.27	1.52	10.72	4.80	1.91	34.7
1947	5.37	3.06	2.14	1.74	0.59	0.70	1.63	1.17	0.85	0.85	0.84	1.46	20.4
1948	6.84	3.60	2.18	1.75	0.58	0.61	0.60	0.08	0.05	0.05	0.05	0.09	16.5
1949	0.09	4.84	2.26	0.68	0.56	0.05	0.09	0.12	0.09	0.46	0.93	0.81	11.0
1950	1.01	3.55	1.87	3.12	1.48	0.25	0.14	0.21	0.31	1.78	1.90	3.05	18.7
1951	6.17	3.12	2.13	1.78	1.99	1.19	0.70	0.76	0.78	0.82	1.48	29.66	50.6
1952	9.37	3.42	2.30	1.78	0.61	0.63	0.60	0.61	0.69	1.00	1.38	2.74	25.1
1953	56.96	22.99	2.52	1.85	0.57	1.62	1.15	3.89	2.46	13.82	48.94	16.75	173.5
1954	5.54	3.08	2.15	1.77	7.69	20.48	0.88	0.82	0.80	0.86	1.83	1.98	47.9
1955	5.33	8.94	12.03	1.83	0.72	0.87	0.74	3.34	6.39	1.17	1.19	27.96	70.5
1956	24.71	41.67	9.26	2.16	0.95	0.97	0.89	1.06	1.24	1.24	1.35	9.67	95.2
1957	13.91	3.21	2.12	1.69	0.52	0.76	0.68	1.79	1.33	0.97	1.44	1.82	30.3
1958	5.31	2.92	2.08	2.31	0.86	0.74	0.93	0.93	0.83	0.91	1.35	1.75	20.9
1959	5.53	3.02	2.17	2.23	0.80	0.66	0.65	0.81	0.86	1.18	1.15	1.69	20.8
1960	5.17	2.88	2.05	1.75	0.67	2.07	1.45	1.72	1.41	1.33	1.27	1.56	23.3
1961	1.77	0.81	0.68	0.63	0.56	0.47	0.47	0.30	0.21	0.21	3.01	1.64	10.7
1962	1.43	1.30	0.84	1.05	0.73	2.38	1.99	1.09	0.71	0.64	0.57	0.45	13.2
1963	0.34	0.85	1.10	1.01	0.71	0.21	0.18	0.14	1.36	0.96	1.24	15.89	24.0
1964	10.32	3.58	2.30	1.77	0.54	0.70	0.73	0.92	0.91	0.90	0.85	1.30	24.8
1965	6.14	4.17	2.44	1.91	0.73	0.68	0.61	0.66	0.64	0.64	0.84	1.39	20.8
1966	5.09	2.99	2.12	0.66	0.54	0.08	2.01	1.73	1.56	1.48	1.45	2.30	22.0
1967	5.63	0.99	0.79	0.65	0.56	0.09	0.46	0.42	28.72	20.10	7.15	66.38	131.9
1968	10.96	3.36	2.21	1.78	0.58	0.65	0.61	0.63	0.69	0.74	0.75	1.34	24.3
1969	5.23	2.92	2.00	0.63	0.58	0.08	0.05	0.04	0.04	0.04	0.16	0.21	12.0
1970	0.38	0.78	1.51	0.97	0.80	0.27	1.96	1.79	1.32	8.47	76.06	30.20	124.5
1971	5.53	3.34	2.23	1.74	1.04	0.84	0.91	0.90	0.87	0.98	1.10	1.43	20.9
1972	4.99	2.75	1.96	1.65	0.54	0.74	0.79	0.78	0.72	0.14	0.14	0.17	15.4
1973	0.18	0.79	0.70	1.01	0.90	2.02	1.03	0.67	0.67	0.46	3.98	5.40	17.8
1974	6.44	3.07	2.09	1.78	0.73	1.06	0.83	0.68	0.68	0.79	1.04	1.85	21.0
1975	5.30	2.88	2.08	0.66	0.64	0.65	0.74	0.52	0.44	1.12	1.69	1.84	18.6
1976	6.14	3.98	1.02	0.74	1.32	0.47	0.28	5.56	3.01	1.40	1.30	2.50	27.7
1977	5.78	3.53	2.43	1.85	0.57	0.72	0.87	0.84	0.99	1.03	1.03	1.48	21.1
1978	3.69	2.85	1.11	0.96	0.74	0.16	0.12	0.18	0.27	0.90	24.41	36.99	72.4
1979	6.07	3.24	2.18	1.82	0.60	0.58	0.66	0.66	0.72	0.74	0.71	1.34	19.3
1980	3.09	0.96	0.88	1.52	0.90	6.09	2.94	14.15	25.12	1.48	38.51	22.41	118.1
1981	14.57	3.91	2.34	1.82	0.58	0.67	2.34	1.46	0.86	1.03	1.12	1.57	32.3
1982	5.14	2.85	2.01	1.66	0.53	0.57	0.56	0.63	0.69	69.56	34.55	2.03	120.8
1983	9.01	3.14	2.15	1.72	0.55	0.70	0.64	0.60	0.62	0.78	0.79	1.27	22.0
1984	4.92	1.93	0.71	0.87	0.73	0.14	0.18	0.16	0.34	0.39	0.33	0.22	10.9
1985	0.46	1.00	0.89	0.81	0.62	0.09	0.08	0.05	0.09	0.12	0.51	0.44	5.1
1986	1.85	1.63	0.96	0.71	0.57	0.09	0.31	0.22	0.86	0.58	0.41	1.20	9.4
1987	0.72	0.83	0.70	0.11	0.47	0.09	0.18	0.21	0.46	0.43	0.39	0.36	5.0
1988	0.36	0.77	0.45	0.30	0.12	0.05	0.27	0.21	0.14	0.22	0.22	0.38	3.5
1989	3.87	6.46	2.27	0.84	0.84	0.27	0.41	0.42	1.53	1.05	0.74	0.67	19.4
1990	1.32	1.25	0.82	0.66	0.54	0.05	0.04	0.05	0.09	0.09	0.21	0.21	5.3
1991	0.43	0.83	0.74	0.35	3.03	1.02	0.21	0.23	0.31	0.61	3.29	1.84	12.9
1992	3.66	3.25	1.31	0.96	0.70	0.12	0.25	0.22	3.70	1.91	0.99	66.70	83.8
1993	20.42	3.36	2.58	2.00	0.70	0.74	0.70	0.79	0.80	1.12	2.84	8.06	44.1
1994	12.65	3.08	10.57	31.67	1.16	1.24	1.30	4.19	1.63	0.94	1.26	1.49	71.2
1995	5.28	3.10	2.67	2.00	0.68	0.70	0.64	0.62	0.57	0.70	0.93	1.48	19.4
1996	8.07	122.49	17.00	1.95	0.62	0.68	33.15	11.85	8.34	6.20	4.97	1.82	217.1
1997	5.23	2.93	2.04	1.77	0.57	1.14	0.85	0.72	0.69	0.72	1.13	1.56	19.4
1998	5.10	2.93	2.17	1.78	0.58	0.63	0.64	0.66	0.10	1.21	1.01	1.31	18.1
1999	0.16	0.59	0.71	0.81	0.98	0.96	0.59	0.30	0.21	0.14	0.12	0.17	5.7
2000	0.00	0.52	0.54	0.54	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.1
AVE :	6.16	5.13	2.33	1.87	0.86	1.02	1.14	3.04	2.71	2.69	5.08	6.49	38.5
SD :	7.81	14.80	2.57	3.61	0.91	2.45	3.81	10.09	6.36	8.51	13.17	13.49	43.1

Table J-8 **Scenario 7 – System supplying the 1 in 50 year yield and reducing the releases from Impofu to 2 million m³/annum during droughts**

Scenario 7 Reducing to 2Mm3/a supplying 1 in 50 Dem													
File : 68-I12-2.NSI													
Units : [Mm3]													
Descrip. : Estuary Inflow for 1927 to 2000													
Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1927	5.00	2.81	2.01	1.68	0.58	3.22	1.27	0.27	0.23	0.19	0.25	0.53	18.1
1928	5.41	3.56	2.31	1.77	0.57	0.60	0.05	0.12	0.16	0.52	0.52	1.05	16.6
1929	5.55	3.01	0.75	0.63	0.90	0.38	0.26	0.22	0.34	0.35	0.64	0.66	13.7
1930	0.77	0.95	0.72	0.75	0.60	0.12	0.12	0.10	0.09	0.32	0.30	1.19	6.0
1931	7.91	1.90	3.73	6.68	2.30	0.94	0.25	0.17	0.22	0.37	0.30	47.47	72.3
1932	26.24	4.46	2.61	1.82	0.60	0.68	0.20	4.42	6.49	1.94	52.21	9.56	111.2
1933	5.47	3.65	2.31	1.83	0.70	0.84	0.21	0.16	0.16	0.59	0.54	0.38	16.8
1934	6.85	3.69	2.17	1.71	0.57	0.62	0.21	57.17	19.97	5.29	12.64	5.89	116.8
1935	5.94	3.68	2.48	1.86	0.59	0.67	0.13	0.47	0.36	0.40	0.35	0.30	17.2
1936	5.46	5.36	3.01	1.86	0.60	0.70	0.13	0.09	0.21	0.32	0.29	0.44	18.5
1937	5.18	2.98	2.18	1.81	0.58	0.05	0.14	0.22	0.22	0.21	0.21	0.30	14.1
1938	0.39	1.07	0.83	0.65	1.38	0.90	0.49	0.32	0.24	0.32	2.31	1.49	10.4
1939	0.87	1.27	1.25	1.04	1.30	1.52	0.54	0.36	0.61	0.72	0.52	0.78	10.8
1940	5.27	2.97	2.06	1.73	0.57	0.64	0.17	0.14	0.68	0.47	0.30	0.30	15.3
1941	4.48	0.90	1.54	1.18	0.70	0.12	0.13	0.41	0.43	0.41	0.39	0.31	11.0
1942	0.60	0.95	0.83	0.85	0.66	0.13	0.14	0.13	1.97	1.32	1.00	1.43	10.0
1943	0.88	2.45	1.65	0.87	0.68	0.42	0.39	64.95	22.87	7.08	2.87	8.22	113.3
1944	6.04	3.17	2.14	1.73	0.57	0.59	0.05	17.85	29.78	5.46	3.19	0.91	71.5
1945	6.61	3.42	2.15	1.73	0.56	1.36	0.43	0.16	0.13	0.55	0.68	0.59	18.4
1946	5.49	3.01	2.06	1.70	0.53	0.88	0.32	0.73	1.01	15.36	4.74	1.01	36.8
1947	5.37	3.06	2.14	1.74	0.59	0.70	1.11	0.63	0.33	0.32	0.30	0.42	16.7
1948	6.84	3.60	2.18	1.75	0.58	0.61	0.08	0.08	0.05	0.05	0.05	0.09	16.0
1949	0.09	4.84	2.26	0.68	0.56	0.05	0.09	0.12	0.09	0.46	0.93	0.81	11.0
1950	1.01	3.55	1.87	3.12	1.48	0.25	0.14	0.21	0.31	1.78	1.37	4.29	19.4
1951	6.91	3.12	2.13	1.78	1.99	1.19	0.18	0.22	0.26	0.28	0.94	31.60	50.6
1952	9.29	3.42	2.30	1.78	0.61	0.63	0.09	0.08	0.17	0.47	0.84	1.71	21.4
1953	59.86	22.91	2.52	1.85	0.57	1.62	0.64	3.35	1.94	14.88	48.89	16.68	175.7
1954	5.54	3.08	2.15	1.77	7.31	20.42	0.75	0.35	0.28	0.33	1.29	0.94	44.2
1955	5.33	11.67	11.95	1.83	0.72	0.87	0.22	2.80	7.06	0.93	0.65	28.56	72.6
1956	24.63	41.60	9.18	2.16	0.95	0.97	0.37	0.53	0.73	0.70	0.82	11.75	94.4
1957	13.83	3.21	2.12	1.69	0.52	0.76	0.16	1.26	0.82	0.44	0.90	0.78	26.5
1958	5.31	2.92	2.08	2.31	0.86	0.74	0.41	0.39	0.31	0.37	0.81	0.72	17.2
1959	5.53	3.02	2.17	2.23	0.80	0.66	0.13	0.27	0.34	0.65	0.62	0.66	17.1
1960	5.17	2.88	2.05	1.75	0.67	2.07	0.93	1.19	0.89	0.79	0.73	0.52	19.6
1961	5.19	2.88	0.68	0.63	0.56	0.47	0.47	0.30	0.21	0.21	3.01	1.64	16.2
1962	1.43	1.30	0.84	1.05	0.73	2.38	1.99	1.09	0.71	0.64	0.57	0.45	13.2
1963	0.34	0.85	1.10	1.01	0.71	0.21	0.18	0.14	1.36	0.96	1.24	14.86	23.0
1964	10.32	3.58	2.30	1.77	0.54	0.70	0.21	0.39	0.39	0.36	0.31	0.27	21.1
1965	6.14	4.17	2.44	1.91	0.73	0.68	0.09	0.12	0.12	0.10	0.31	0.36	17.2
1966	5.09	2.99	2.14	1.73	0.54	0.08	2.01	1.73	1.05	0.94	0.91	1.27	20.5
1967	5.63	3.07	2.13	1.72	0.56	0.09	0.46	0.42	33.18	20.04	7.09	66.31	140.7
1968	10.88	3.36	2.21	1.78	0.58	0.65	0.09	0.09	0.18	0.21	0.21	0.30	20.5
1969	5.23	2.92	2.01	0.63	0.58	0.08	0.05	0.04	0.04	0.04	0.16	0.21	12.0
1970	0.38	0.78	1.51	0.97	0.80	0.27	1.96	1.79	1.32	7.94	77.87	30.13	125.7
1971	5.53	3.33	2.23	1.74	1.04	0.84	0.39	0.37	0.36	0.45	0.56	0.40	17.2
1972	4.99	2.75	1.96	1.65	0.54	0.74	0.27	0.25	0.20	0.14	0.14	0.17	13.8
1973	0.18	0.79	0.70	1.01	0.90	2.02	1.03	0.67	0.67	0.46	3.45	8.46	20.3
1974	6.44	3.07	2.09	1.78	0.73	1.06	0.31	0.14	0.16	0.25	0.50	0.81	17.3
1975	5.30	2.88	2.08	1.73	0.64	0.65	0.74	0.52	0.44	1.12	1.15	0.80	18.1
1976	6.90	3.98	2.36	0.74	1.32	0.47	0.28	5.02	2.49	0.86	0.77	1.46	26.7
1977	5.78	3.53	2.43	1.85	0.57	0.72	0.36	0.31	0.47	0.49	0.49	0.45	17.4
1978	5.78	3.64	1.11	0.96	0.74	0.16	0.12	0.18	0.27	0.90	26.40	36.93	77.2
1979	6.07	3.24	2.18	1.82	0.60	0.58	0.14	0.12	0.20	0.20	0.18	0.31	15.6
1980	5.18	0.96	0.88	1.52	0.90	6.09	2.42	14.88	25.07	1.32	38.56	22.34	120.1
1981	14.49	3.91	2.34	1.82	0.58	0.67	1.82	0.92	0.34	0.50	0.59	0.53	28.5
1982	5.14	2.85	2.01	1.66	0.53	0.57	0.05	0.09	0.17	73.36	34.49	0.99	121.9
1983	9.90	3.14	2.15	1.72	0.55	0.70	0.12	0.07	0.10	0.25	0.25	0.23	19.2
1984	4.92	2.72	0.71	0.87	0.73	0.14	0.18	0.16	0.34	0.39	0.33	0.22	11.7
1985	0.46	1.00	0.89	0.81	0.62	0.09	0.08	0.05	0.09	0.12	0.51	0.44	5.1
1986	1.85	1.63	0.96	0.71	0.57	0.09	0.31	0.22	0.86	0.58	0.41	1.20	9.4
1987	0.72	0.83	0.70	0.16	0.47	0.09	0.18	0.21	0.46	0.43	0.39	0.36	5.0
1988	0.36	0.77	0.45	0.30	0.12	0.05	0.27	0.21	0.14	0.22	0.22	0.38	3.5
1989	3.87	6.46	2.27	0.84	0.84	0.27	0.41	0.42	1.53	1.05	0.74	0.67	19.4
1990	1.32	1.25	0.82	0.66	0.54	0.05	0.04	0.05	0.09	0.09	0.21	0.21	5.3
1991	0.43	0.83	0.74	0.35	3.03	1.02	0.21	0.23	0.31	0.61	3.29	1.84	12.9
1992	3.66	3.25	1.31	0.96	0.70	0.12	0.25	0.22	3.70	1.91	0.99	65.72	82.8
1993	20.33	3.36	2.58	2.00	0.70	0.74	0.18	0.25	0.28	0.58	4.30	8.00	43.3
1994	12.58	3.08	10.42	31.60	1.16	1.24	1.10	4.14	1.58	0.79	1.29	0.45	69.4
1995	5.28	3.10	2.67	2.00	0.68	0.70	0.12	0.09	0.05	0.17	0.39	0.45	15.7
1996	8.07	126.20	16.92	1.95	0.62	0.68	32.88	11.80	8.29	6.14	4.91	1.07	219.5
1997	5.23	2.93	2.04	1.77	0.57	1.14	0.33	0.18	0.18	0.18	0.60	0.53	15.7
1998	5.10	2.93	2.17	1.78	0.58	0.63	0.12	0.12	0.10	0.68	0.48	0.27	15.0
1999	2.81	0.59	0.71	0.81	0.98	0.96	0.59	0.30	0.21	0.14	0.12	0.17	8.4
2000	0.00	0.52	0.54	0.54	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.1
AVE :	6.41	5.32	2.36	1.91	0.85	1.02	0.86	2.81	2.53	2.57	4.89	6.14	37.7
SD :	7.99	15.19	2.54	3.60	0.87	2.44	3.81	10.26	6.69	9.06	13.42	13.74	44.1