



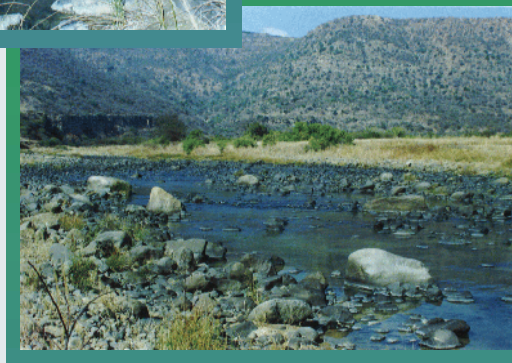
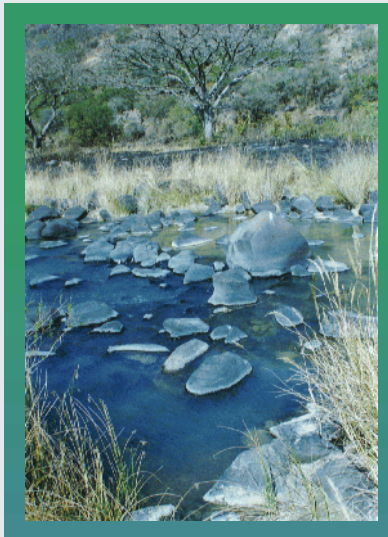
Republic of South Africa
Department of Water Affairs and Forestry

**THUKELA WATER PROJECT
DECISION SUPPORT PHASE**

RESERVE DETERMINATION MODEL

**APPENDICES TO THUKELA
ESTUARINE FLOW
REQUIREMENTS**

March 2004



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Prepared by
IWR Source-to-Sea



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Appendix A

Inventory of data available for Intermediate Ecological Reserve determination on Thukela Estuary

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1 DATA AVAILABILITY ON HYDRODYNAMICS AND WATER QUALITY

Required data	Availability	Comment
Simulated monthly runoff data (at the head of the estuary) for Present State, Reference Condition, as well as selected future runoff scenarios over a 50 to 70 year period.	Yes	Provided by Institute for Water Resources (Dr Denis Hughes).
Aerial photographs of estuary (earliest available year as well as most recent).	Yes	Available at CSIR, Stellenbosch.
Measured river inflow data (gauging stations) at the head of the estuary over a 5-year period.	Yes	Mandini gauging station.
Continuous water level recordings near mouth of the estuary.	Limited	Local fishermen recorded state of the mouth for the period 1992 to 1995.
Longitudinal salinity and temperature profiles (<i>in situ</i>) taken on a spring high and low tide at (river flow data must be collected during these periods as well): end of low flow season (i.e. period of maximum seawater intrusion). peak of high flow season (i.e. period of maximum flushing by river water).	Some	Longitudinal salinity and temperature profiles (<i>in situ</i>) were not available for a closed phase, i.e. State 1.
Water quality measurements (i.e. system variables and nutrients) taken along the length of the estuary (surface and bottom samples) on a spring high tide at: end of low flow season. peak of high flow season.	Some	Longitudinal salinity and temperature profiles (<i>in situ</i>) were not available for a closed phase, i.e. State 1.
Measurements of organic content and toxic substances (e.g. trace metals and hydrocarbons) in sediments along length of the estuary.	Yes	
Water quality (e.g. system variables, nutrients and toxic substances) measurements on river water entering at the head of the estuary.	Some	Data on inputs from the Mandini. Industrial, in particular, suspended solids/turbidity and inorganic nutrients were not available. Suspended solid/turbidity data were also not available for the upper catchment, as represented by the Mandini monitoring station.
Water quality (e.g. system variables, nutrients and toxic substances) measurements of nearshore seawater.	Some	Obtained from SA water quality guideline documents.

2 DATA AVAILABILITY ON SEDIMENT PROCESSES

Required data	Availability	Comment
<p>Simulated flood hydrographs for present state, reference conditions and future runoff scenarios: 1:1, 1:2, 1:5 floods (influencing aspects such as flood plain inundation). 1:20, 1:50, 1:100, 1:200 year floods (influencing sediment dynamics).</p>	<p>Present and future state available</p>	
<p>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).</p>	<p>1 set available</p>	
<p>Series of cross-section profiles (collected at about 500 to 1000m intervals), taken every 3 years to quantify the sediment deposition rate in an estuary.</p>	<p>2 sets available</p>	
<p>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.</p>	<p>1 set, but not after major flood</p>	

3 DATA AVAILABILITY ON MICROALGAE

Required data	Availability	Comment
Chlorophyll-a measurements taken at 5 stations (at least) at the surface, 0.5 m and 1 m depths thereafter. Cell counts of dominant phytoplankton groups i.e. flagellates, dinoflagellates, diatoms and blue-green algae. Measurements should be taken coinciding with typically high and low flow conditions.	Yes	Only one field visit in August.
Intertidal and subtidal benthic chlorophyll-a measurements taken at 5 stations. Epipellic diatoms need to be collected for identification. Measurements should be taken coinciding with a typical high and low flow condition (in temporarily closed estuaries measurements must include open as well as closed mouth conditions).	Yes	One field visit in August 2001. Only four sites (too shallow to get to site 5). Subtidal and intertidal chl-a measured. Collected subtidal scrapes for total benthic cell counts due to sandy sediment. Measured Ash Free Dry weight.
Simultaneous measurements of flow, light, salinity, temperature, nutrients and substrate type (for benthic microalgae) need to be taken at the sampling stations during both the phytoplankton and benthic microalgal surveys.	Yes	CSIR (Environmentek) sampled these variables at same time and sites as the microalgal survey.

4 DATA AVAILABILITY ON MACROPHYTES

Required data	Availability	Comment
Aerial photographs of the estuary (ideally 1:5000 scale) reflecting the Present State, as well as the Reference Condition. Orthophoto maps of the area.	Yes	Oblique colour aerial photographs available for 1996 and 2001. Orthophotomaps for 1992.
Number of plant community types, identification and total number of macrophyte species, number of rare or endangered species or those with limited populations documented during a field visit.	Yes	Field visits in June 1996 and August 2001.
Permanent transects (a fix monitoring station that can be used to measure change in vegetation in response to changes in salinity and inundation patterns) Measurements of percentage plant cover along an elevation gradient. Measurements of salinity, water level, sediment moisture content and turbidity	No	No major changes expected, therefore considered unnecessary.

5 DATA AVAILABILITY ON INVERTEBRATES

Required data	Availability	Comment
Derive preliminary sediment map of the estuary.	Yes	Data from Previous study 1997-1998 and current study (CRUZ, CSIR- August 2001 and February 2002).
Obtain a preliminary determination of the extent and distribution of shallows and tidally exposed substrates.	Yes	Obtained during low (08/01) and high (02/02) conditions.
For six benthic sites, collect sediment samples for analysis of grain size and organic content.	Yes	Data from Previous study 1997-1998 and current study (CRUZ, CSIR- August 2001 and February 2002).
Determine the longitudinal distribution of salinity, as well as other system variables (e.g. temperature, pH and dissolved oxygen and turbidity) at each of the six benthic sampling sites.	Yes	Data from Previous study 1997-1998 and current study (CRUZ, CSIR- August 2001 and February 2002).
During a spring tide (preferably for both low flow and high flow conditions), collect a set of six benthic samples each consisting of five grabs. Collect two each from sand, mud and interface substrates. If possible, spread sites for each between upper and lower reaches of the estuary. One mud sample should be in an organically rich area. Species should be identified to the lowest taxon possible and densities (animal/m ²) must also be determined.	Yes	Seasonal data from previous study (1997-1998) but obtained during a different mouth morphology phase. Further seasonal data required for one year to examine inter-annual variability.
During a spring tide (preferably at both low and high water and for both low flow and high flow conditions), collect two sets of beam trawl samples (i.e. over mud and sand). Lay two sets of five, baited prawn/crab traps overnight, one each in the upper and lower reaches of the estuary. Species should be identified to the lowest taxon possible and densities (animal/m ²) must also be determined. Samples should be collected every second week under low and high flow conditions for at least two months each (i.e. five sampling sessions under the two flow scenarios).	Yes	Paucity of Macrocrustacean data. Collections only once during low (08/01) and high (02/02) flow conditions.
Survey as much shoreline for signs of crabs and prawns and record observations.	Yes	
During spring tides (preferably at both low and high water and for both low flow and high flow conditions), collect three samples, at night, one each from the upper, middle and lower reaches of the estuary for zooplankton. Samples should be collected every second week under low and high flow conditions for at least two months each (i.e. five sampling sessions under the two flow scenarios).	Yes	Paucity of Zooplankton data. Collections only once during low (08/01) and high (02/02) flow conditions.

6 DATA AVAILABILITY ON FISH

Required data	Availability	Comment
Collect three sets of small and large seine and gill net samples, one each from the lower, middle and upper reaches of the estuary. Depending on the size and depth of the estuary, it may be necessary to also undertake cast netting, particularly in smaller systems.	Yes	High river flows resulted in gill nets being swept out to sea and may have limited the effectiveness of those that were not lost. The limited number of sampling occasions prevented the determination of seasonal or inter-annual trends.
Information on fish gained during the macrocrustacean beam trawls should also be used.	No	No macrocrustacean beam trawls were conducted but teleosts recorded during the invertebrate sampling programme were included in the fish specialist report.

7 DATA AVAILABILITY ON BIRDS

Required data	Availability	Comment
During a summer spring tide, undertake one full count of all water-associated birds, covering as much of the estuarine area as possible. All birds should be identified to species level and the total number of each counted.	Yes	The counts are undertaken on summer spring low tide when the feeding areas are exposed. From a bird perspective the collection of only one sample does not provide anything in terms of data to make predictions on. Monthly counts at a minimum are required. A set of such data was collected in 1998.

Appendix B

Proposed changes to the RDM methodologies for estuaries

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1 PROPOSED CHANGES

After each RDM workshop a list of possible improvements to the RDM methodology for estuaries provided. The following list was recorded at the Thukela Specialist Workshop in June 2002:

1. The manner in which the predicted changes in abiotic and biotic characteristics of the estuary are assessed for different future runoff scenarios may not address cumulative changes adequately. It is recommended that this be investigated in future revisions of the methodology (Coastal and Environmental Services).
2. It is recommended that the biotic component: *Invertebrates*, be split into 3 sub-components, *i.e. zooplankton, macroinvertebrates and macrocrustacean*. The motivation for this split is that these sub-component behave distinctly different from on another to change in estuaries and should therefore be dealt with separately (CRUZ).
3. The current technique may not be addressing the uniqueness of specific faunal groups sufficiently (CRUZ).
4. More seasonal data than that stipulated in the intermediate data requirement guidelines is required if any realistic understanding of a system is to be achieved (CRUZ).
5. The manner in which confidence limits is rated need to be clarified (?).
6. All scores in the Estuarine Health Index should be in percentages. If the parameter requires a non-linear function then this should be embedded into the Excel spreadsheet (used at workshops to calculate scores) rather than relying on the consultants to convert percentages into scores.

Appendix C

Physical Dynamics and Water Quality

S Taljaard (Water Quality), L van Niekerk and P Huizinga (Hydrodynamics)
CSIR, Environmentek, P O Box 320, 7599 Stellenbosch
G Basson and Julia Beck (Sediment dynamics)

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ACKNOWLEDGEMENTS

The information provided by Mr N Naidoo of Sappi Stanger on open and closed mouth conditions and river flows played an important role in assessing the relationship between run-off and river mouth conditions.

Important was also the river flow data provided by the Department of Water Affairs and Forestry and the simulated run-off data for virgin, present and future run-off scenarios.

1 BRIEF

Since 1994 the Department of Water Affairs and Forestry (DWAF) has been investigating options for augmenting supplies of water to the Vaal River System (VRS). Investigations were originally conceived as the Vaal Augmentation Planning Study (VAPS) and involved evaluations of alternative inter-basin transfers of water from four catchments to the VRS. Included as part of the VAPS was the Tugela Vaal Transfer Scheme (TVTS) which, at a pre-feasibility level of detail, proved to be a favoured option worthy of additional investigation. This led to the commissioning of the Thukela Water Project (TWP) Feasibility Study in December 1996.

The Thukela Water Project Feasibility Study was designed to evaluate all factors which may affect the viability of development proposals on the Thukela River to a sufficient level of detail to:

- Identify all the issues likely to affect implementation and to define and evaluate all of the actions required to address these issues.
- Provide an estimate of cost with sufficient accuracy and reliability to ensure that management decisions can be made with confidence.

For a variety of reasons, such as the changing legislative environment in water resource and environmental management during the course of the study, it became apparent that the TWP Feasibility Study would not deliver unqualified development proposals complying in all respects with the National Water Act, No. 36 of 1998, and the National Environmental Management Act, 1998. This has necessitated additional investigations, originally planned to occur prior to the commissioning of Detailed Design and Project Implementation. This led to the definition of a TWP Decision Support Phase comprising a number of inter-related components. However, in the past, it was thought that additional water would be required in the VRS in the foreseeable future. This is no longer the case and a longer-term planning horizon has been adopted. By implication, components of the Decision Support Phase have been modified to address only those aspects that can be considered temporally definitive. As such, the Decision Support Phase, as presently configured, comprises:

- Environmental Reserve Determination as required by the National Water Act, No. 36 of 1998. The study will enable the available transferable yield to the Vaal River System to be confirmed.
- Limited additional environmental investigations to obtain greater confidence in feasibility study findings.
- On-going Public Involvement Programme (PIP) commensurate with the level of activities comprising the Decision Support Phase.

Activities comprising the Decision Support Phase will be managed by the DWAF, with the direct assistance of a Project Management Team (PMT).

2 THE STUDY AREA

The Thukela River rises in the Drakensberg Mountains near Bergville where peaks rise to over 3 000 m MSL (mean sea level). The river flows eastwards to discharge into the Indian Ocean about 95 km north of Durban. Major tributaries include the Little Thukela, Klip, Bushman's, Sundays, Mooi and Buffalo Rivers (the latter being the largest).

The Thukela Catchment has a total area of approximately 29 000 km² and an undeveloped (virgin condition) Mean Annual Runoff (MAR) of 3 865 x 10⁶ m³. The MAR expressed as average unit runoff is about 133 mm which is equivalent to 16% of the Mean Annual Precipitation (MAP) of 840 mm. However, MAP varies from more than 1 500 mm in the Drakensberg to 500 mm and less in the dry central regions of the basin.

Although there are a few large dams and numerous smaller ones in the Thukela River System, they are mainly located in the upper reaches of the Thukela River itself and in some of its tributaries. For the most part, the Thukela River remains comparatively unregulated. Water resource developments within the catchment are generally small and relate primarily to the needs of individual towns. The largest components of existing water development infrastructure are those associated with four inter-basin transfer schemes:

- Tugela-Vaal Project through which water is transferred via the Drakensberg Pumped Storage Scheme to Sterkfontein Dam in the Vaal River Catchment.
- Zaaihoek Scheme through which water is transferred to Majuba Power Station and the Grootdraai Dam in the Vaal River Catchment.
- Mooi-Mgeni Scheme through which water will be transferred to Midmar Dam in the Mgeni River.
- Thukela-Mhlatuze Scheme through which water is transferred to Goedetrouw Dam near Richards Bay.

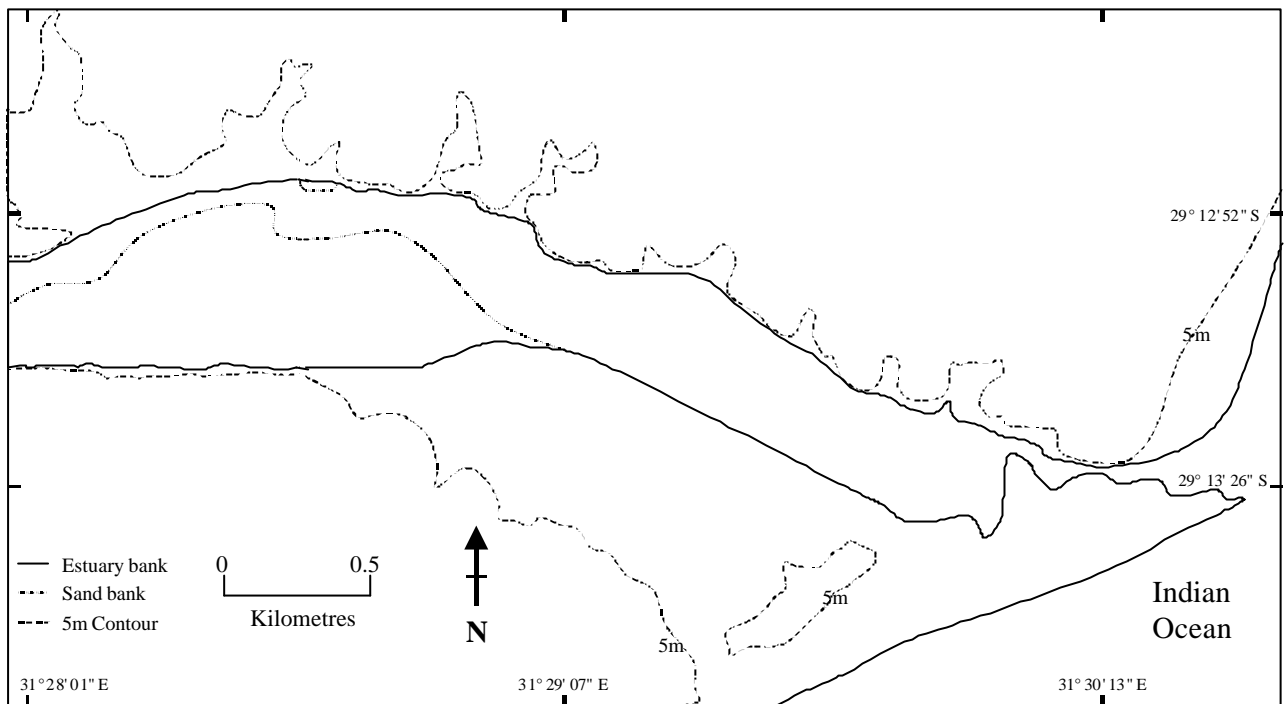
Land uses in the catchment are mainly rural subsistence farming and commercial forestry. It is only on the coastal plain that the river flows through urbanised areas. The only industries associated with the urban development are paper and sugar mills with large scale commercial sugar cane farming along the banks of the lower reaches of the river (Wepener, 2001).

The Thukela River estuary is situated approximately 100 km north of the city of Durban on the east coast of South Africa (29.22°S, 30.50°E; Figure 2.1). Based on the classification by Whitfield (1992), the estuary is one of only two examples of an open river mouth estuarine system in South Africa.

Due to the high riverine runoff, the estuarine area of the Thukela River is small. The surface area of the estuary during low flow periods is approximately 0.6 km². However, changes in river flow cause considerable changes in the morphometry of the estuary, and during periods of high flows the estuary extends out to sea and becomes unconfined by banks (Begg 1978). The axial length is estimated to be 800 m during low flow, with a shoreline length of approximately 2 km. The maximum width during natural flow periods is approximately 350 m with a channel width of 50 m, which increases to over 1,000 m during floods (Begg 1978). Initial observations on the bathymetry of the estuary indicated that it was relatively deep (Begg 1978), but surveys undertaken by the Coastal Research Unit of Zululand (CRUZ) from March 1997 to April 1998 (reported in Archibald 1998) showed an average depth of less than 1.5 m.

According to Begg (1978) the sandbar has a 700 m stable component on the floodplain (carrying a coastal dune forest) extending in a generally northern direction. There is also a 700 m unstable component without vegetation that forms across the mouth. This bar is periodically removed by flood discharges. During flood conditions an offshore bar is formed, directing floodwater into the sea in a southerly direction.

Fig 2.1 The Thukela Estuary



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

- **Downstream boundary:** The estuary mouth.
- **Upstream boundary:** Approximately 6 km for mouth (i.e. extent of tidal influence).
- **Lateral boundaries:** 5 m contour above MSL along the banks.

3 AVAILABLE FIELD DATA

3.1 TOPOGRAPHICAL DATA

Cross sections of the beaches adjacent to the mouth and of the river from the mouth to the old N2 bridge were surveyed during November 1996 by the Department of Water Affairs and Forestry to provide background information for the present study and also to establish a baseline dataset against which future changes can be measured. The locations of these cross sections, as well as the details of all the cross sections and the positions of the reference points used for the survey are provided in Huizinga and Van Niekerk (1997).

The results show that depths below mean sea level are still present at 4.0km upstream of the mouth and depths below + 1.0m MSL 5.0km upstream. This agrees with the observation of a tidal variation of only 0.03m at Section 27 under seasonably strong river flow of approximately 25m³/s during the observations of 1 to 3 June 1996.

Data on the height of the berm at closed mouth conditions are not yet available, but based on information from other estuaries (CSIR, 1990b) it is expected that the berm can build up to levels of approximately + 2.5m MSL. The water levels in the estuary can during such conditions also build up to such levels and from the cross-sectional data it can be observed that the backing up effects will then extent to about 8 km upstream.

3.2 SEDIMENT DATA

The 15-year period used for the simulations was a combination of flows from 1962 to 1967, and 1990 to 2000. This was done since it yielded the longest continuous and representative flow series from observed flow records (primary, break point data of DWAF). Flow data from the following stations were used:

- V6H002 at Thukela Ferry
- V5H002 at Mandini).
- V1H001 for Jana Dam
- V7H020 for Mielietuin Dam

The sediment loads were determined with the aid of a sediment load–discharge rating curve obtained from suspended sediment samples taken between 1971 and 1984 at V5H002 by the DWAF.

Sediment yields for different parts of the Thukela system were available from Dollar (2001), while sediment yield was available form Rooseboom (1992).

3.3 MEASURED RIVER INFLOW

The Mandini Gauging Station (V5H002-A01) (Lat 29°8'26"; Long 31°23'31") was used to obtained measured river inflow data for the estuary. The station gauges inflow form a catchment areas of 28 920km².

3.4 WATER LEVEL DATA

Water level recordings have been collected inside the Tugela Estuary mouth since November 1999, but closure of the mouth has not occurred since then. Sappi at Mandini has in recent years undertaken some monitoring. Information on open and closed mouth conditions was obtained from employees visiting the area for recreational (fishing) purposes.

3.5 WATER QUALITY DATA ON RIVER INFLOW

The water quality specialist team on rivers provided the water quality data for river inflow

(Malan *et al.*, 2002).

Data for river inflow was primarily based on measurements collected by the DWAF at their monitoring point on the Thukela River near Mandini (V5H002), approximately 12km upstream of the head of the estuary. Data sets for the period 1977 to 1982 (n = 116) were used to estimate the water quality for Reference Conditions, while data sets for the period 1995 to 2001 (n = 119) were considered representative of the Present State. Data sets on pH, nitrate/nitrite, reactive phosphate and reactive silicate have been used for this study. Other relevant data sets, e.g. temperature, dissolved oxygen suspended solid concentration and turbidity, however, are not collected at this monitoring point.

It should also be noted that there are a large industrial area (including the Sappi Tugela mill, Mandini, Tugela Rail and the Sumdumbili Sewage Treatment Works), further downstream of the Mandini monitoring point (V5H002) that may also affect water quality entering the estuary from the river. No data, however, could be obtained to properly quantify the potential influence from this area. This is an aspect that should be addressed in future monitoring programmes. Although the Sappi Tugela Mill do collect data at a monitor point further downstream, closer to the estuary (i.e. at Havelock farm, some 8km downstream of the John Ross [N2] bridge), their data sets are limited and, for example do not include important variables such as suspended solids, turbidity or inorganic nutrients. Temperature and dissolved oxygen data for river inflow, however, were obtained for the Sappi Tugela Mill data sets (Malan, *et al.*, 2002).

Simulated concentration-flow curves, to establish relationships between river flow and different water quality variables, were also provided by the river's specialist team (Malan *et al.*, 2002).

3.6 SALINITY/TEMPERATURE AND OTHER WATER QUALITY DATA FOR THE ESTUARY

The following historical data sets on salinity distribution in the Thukela Estuary were used in this study:

- October 1992 (obtained from Trevor Harrison, CSIR, Durban, pers. comm.).
- May 1996 (obtained from Trevor Harrison, CSIR, Durban, pers. comm.).
- November 1997 (obtain from Fiona MacKay, CRUZ, pers. comm.).

As part of this study, salinity profile data were collected from the Thukela Estuary on two occasions on both high and low tides:

- 20 August 2001 (collected by the CSIR, Stellenbosch).
- 12 February 2002 (collected by CRUZ).

The following historical data sets on other water quality variables in the Thukela Estuary were used in this study:

- May 1996 – temperature, pH, suspended solids, turbidity, dissolved oxygen, dissolved inorganic nutrients and trace metals (Archibald, 1997).

As part of this study, water quality data were collected from the Thukela Estuary on two occasions:

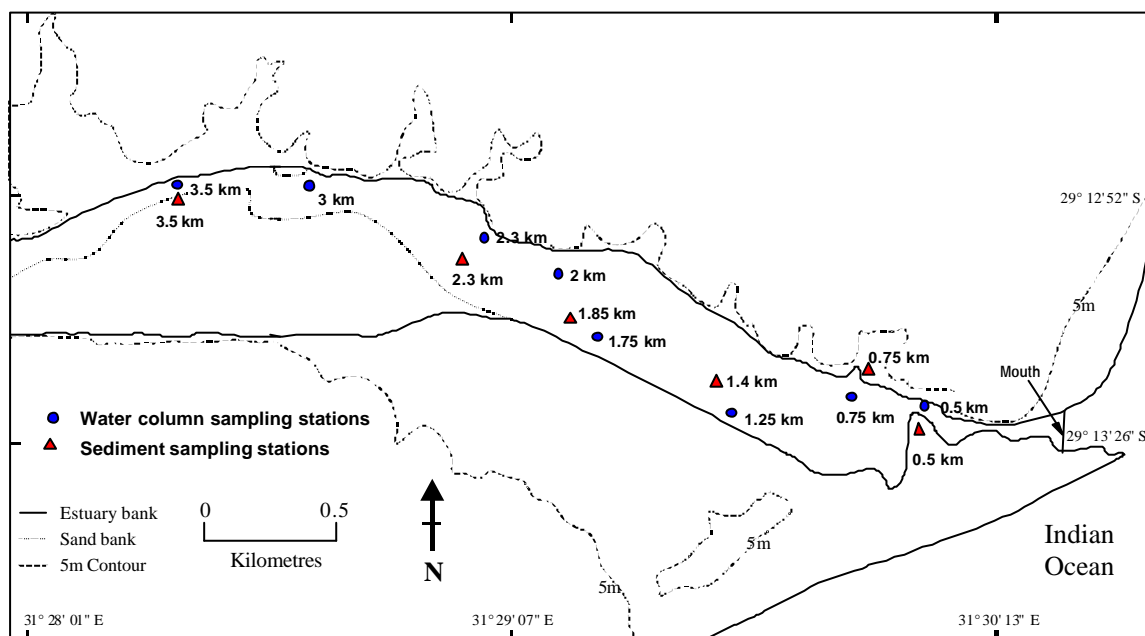
- 20 August 2001 - temperature, pH, suspended solids, turbidity, dissolved oxygen, dissolved inorganic nutrients and trace metals (collected by the CSIR, Stellenbosch).
- 12 February 2002 - temperature, pH, turbidity and dissolved oxygen (collected by CRUZ).

Methodologies used in the CSIR survey of 20 August 2001 are as follows:

- *In situ* measurements of salinity and temperature profiles were taken at the water column stations (Figure 3.1) along the length of the estuaries at approximately 0.5m depth intervals, using a Valeport series 600 MK II CTDS Meter (accuracy 0,2 ppt, 0,2 °C, 0,1m).
- For the other water quality variables, surface and bottom waters were collected at each of the water column sampling stations (Figure 3.1).
- Sediment samples for trace metal analyses were collected from each of the sediment sampling stations (Figure 3.1).
- Dissolved oxygen, turbidity, pH and suspended solid analyses were done by the Marine analytical laboratory at CSIR, Durban.
- Dissolved nutrient and sediment trace metal analyses were done by the marine analytical laboratory at CSIR, Stellenbosch.

An *in situ* logger (Hydrolab Water Quality probe Datasonde 3) was used by CRUZ to record the water quality data (salinity, temperature, pH, turbidity and dissolved oxygen) on 12 February 2002.

Fig 3.1 Sampling stations in the Thukela Estuary - 20 August 2001 (station labels indicate distance from mouth)



4 SIMULATED RUNOFF SCENARIOS FOR THE THUKELA ESTUARY

Simulated data on several scenarios of possible inflows into the Thukela Estuary were provided by the Institute of Water Research, Rhodes University (Dr Dennis Hughes) after liaison meetings between the Reserve team (river and estuary specialists) and the Water Resources Evaluation and Systems Analysis team.

The following approach was agreed upon:

- The Water Resources team would provide three scenarios of natural flows, present day (1995 development) and a 'worst case' scenario based on full development of the system without provision for the Reserve. The full development scenario was to be based on the present understanding of future planned abstractions and transfers.
- The hydrology specialist of the rivers Reserve team would then generate several additional scenarios based on a simulation of conditions that could occur if the river Reserve for ecological categories A, B, C and D were to be satisfied. These additional scenarios need to include flows that would naturally occur in the system through uncontrolled spillages from storage, as well as flows from parts of the system that are not controlled by storage. This was achieved by setting up a reservoir simulation model at the head of the estuary (quaternary catchment V50D), where the 'dummy' reservoir is designed to represent the control in the whole catchment. The version of the reservoir model used allows a high priority downstream flow requirement (the Reserve) to be included. The 'calibration' of the model involves setting the reservoir storage and annual abstraction values such that the pattern of spills would be similar to the worst case scenario generated by the systems model. The main difference between these scenarios and the worst case scenario would then be expected to be in the medium to low flows (Hughes, 2002).

The steps in the procedure were as follows:

- Run the Desktop model to generate time series of Reserve requirements, based on regional parameters, for the outlet of V50D for A, B, C and D ecological categories. Modify the Desktop default results to be consistent with previous IFR results for parts of the Thukela.
- Check the yield of the catchment (based on WR90 yield/storage relationships) for several sizes of the dummy reservoir and use the Desktop model to estimate the reduction in yield due to allowance for the Reserve requirements.
- Establish the reservoir model using natural runoff at the outlet of V50D as inflows to the reservoir and the A, B, C and D ecological Reserves as high priority downstream requirements.
- Examine the simulation results for the B category and several reservoir sizes (using the Desktop determined reduced yield associated with the reservoir sizes for the annual abstraction value) to identify a result that has a similar pattern of medium to high flows as the worst case scenario supplied by the Water Resources team.
- Fix the reservoir size for the other ecological categories and set the annual abstraction value to approximately the reduced yields specified by the Desktop model.
- Check the results using the 'Present State - Hydrology' method which has already been used in the Thukela study to determine the present hydrological state of all the resource units (see Hughes 2001).

The 'Present State – Hydrology' method is based on the comparison of natural and modified 1-month annual duration curves (i.e. flow duration curves constructed from monthly volumes for all months of the year). The method calculates the positive relative difference between the two duration curves at 5 percentage point values (10, 30, 50, 70 and 90%) and then

weights these differences to generate a weighted total difference. An additional factor (Ratio Score) measures the extent to which the differences between the wet and dry season flows have been modified.

The modified hydrological state category is then given by:

Total weighted score	Category
0 to 3	A
>3 to 6	B
>6 to 8	C
>8 to 11	D
>11 to 14	E
>14	F

A summary of the details on the scenarios is listed in Table 4.1.

Table 4.1 Summaries of Scenario provided to the Estuaries Specialist Team

Scenario	MAR ($m^3 * 10^6$)	% MAR
Reference Condition	3753.6	100
Present Day (1995)	2756.4	73.4
Category A River	2494.8	66.5
Category B River	2258.4	60.2
Category C River	2056.8	54.8
Category D River	1915.2	51.0
Worst Case 1	1788.0	47.6
Worst Case 2	1669.2	44.5

The method that has been used to generate the Reserve scenarios appears to have generated reasonably realistic results, without having to expend the resources that would have been necessary to configure the systems model with Reserve requirements at a large number of points. It is, however, not totally realistic to assume that a single dummy reservoir at the outlet of the system will be able to reproduce the pattern of flows that result from complex patterns of abstractions and transfers within the system.

It is apparent that the D Reserve scenario sometimes gives larger high flows than the B Reserve scenario. This is likely to be a result of the overall lower demand on the system resulting in higher storage levels in the reservoir at times. This is an unfortunate artifact of the way in which the Reserve scenarios have been generated and cannot be avoided. It should not, however, be a critical issue and will only affect several months. The main point is that the greatest differences between the three Reserve scenarios lies in their low flow characteristics and not in the high flows. This is consistent with what might be expected in terms of a Reserve at the outlet of a large catchment with distributed storage and abstractions; i.e. managed moderate to low flows and relatively unmanaged high flows (Hughes, 2002).

5 RELATIONSHIP BETWEEN HYDRODYNAMICS AND RIVER INFLOW

5.1 CORRELATION OF MOUTH CONDITIONS AND RIVER FLOW

The dynamics of the mouth is, as is the case with many estuaries, a key aspect in the functioning of the estuary of the Tugela River. The mouth was in the past almost permanently open, but in recent years it has closed more frequently. It is considered a major setback if an estuary mouth, which used to be permanently open, starts closing more often. Increase in occurrence and duration of mouth closure can also have serious consequences for the ecology of an estuary. An evaluation has therefore been undertaken of open and closed mouth conditions of the Tugela Estuary.

A reduction in flow will also affect salinity penetration in an estuary, which is also important for the ecology. Based on available and collected field data an assessment was made on the correlation between river flow and salinity penetration, while open or closed mouth conditions were also taken into account.

Two typical mouth conditions can be observed on the aerial photographs from 14 May 1976 and 2 August 1983 (Figure 5.1). An ebb tidal sand delta deposited as a fan is present in front of the mouth on 14 May 1976, while an almost straight coastline is observed at the mouth for 2 August 1983 with only a small opening.

Figure 5.2 shows a photograph of the mouth taken obliquely on 3 June 1996 during a recent fieldtrip. This shows that the condition of the mouth was at that time very similar to that of 14 May 1976. A sand delta is visible on the photograph and this delta was deposited in front of the mouth during the river floods earlier in 1996. This delta will with time again be eroded by sediment dynamic processes caused by wave action and eventually a mouth condition as was present on 2 August 1983 (Figure 5.1) will return.

The photograph of 2 August 1983 also shows the typical breakerzone configuration often observed at beaches on the coast of northern Natal. It consists of two breakerlines, the main one approximately 100 metres offshore and a lesser but still significant one on the beach itself. This implies considerable wave action at the beach, which causes increased movements of sediments. This in turn causes at incoming tide an increased influx of sediments into the mouth, which can result at closure even at flows of up to 10 m³/s as was observed at the Mgeni Estuary (CSIR, 1990a).

Water level recordings inside an estuary mouth will indirectly provide continuous information on open and closed mouth conditions. Tidal variations shown by such recordings indicate when a mouth is open and closed.

Water level recordings have been collected since 12 November 1999 in the Tugela Estuary, but the mouth has not closed since 25 September 1995 according to available information. The water level recordings have therefore not yet covered a period of mouth closure and conclusions on the dynamics of closures can therefore not yet be drawn from the available recordings.

Some monitoring of the estuary mouth was during the winter periods from 1992 till 1995 undertaken by Sappi at Mandini. Information on open and closed mouth conditions was obtained from employees visiting the area for recreational (fishing) purposes. This information was included in an earlier report, submitted to the Department of Water Affairs and Forestry, which was never published by the department (Huizinga and Van Niekerk, 1997).

More comprehensive daily river flow data is now available for the period during which closed mouth conditions were observed and another evaluation of the correlation between river flow and mouth conditions was therefore undertaken.

The information obtained from Sappi is presented in Tables 5.1, 5.2, 5.3 and 5.4 of daily river flow at Mandini during 1992, 1993, 1994 and 1995 respectively. A shading system is used to indicate whether and to what extent open or closed mouth conditions were observed, or whether such information on the condition of the mouth was available or not.

These data show that mouth closure has been observed at river flows of $7.7 \text{ m}^3/\text{s}$ and lower, but that the mouth normally only stayed closed for a few days. River flow probably caused the water levels in the estuary to increase quickly after closure to levels at which the mouth started overflowing again and it was normally after a few days flushed open again.

Fig 5.1 During high flows fan is deposited, 14 May 1976



Fig 5.2 During low flow period fan is eroded, 2 August 1983



Table 5.1 Correlation between river flow and mouth conditions (Sappi - Mandini) for 1991/10 –1992/9

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	DAY
1	12.50	72.40	19.20	97.90	20.20	49.40	20.00	16.20	* 4.80	5.52	4.36	4.49	1
2	11.70	59.40	17.80	133.00	20.10	48.80	16.00	12.00	* 4.91	5.14	4.52	4.74	2
3	10.60	49.50	20.70	211.00	19.30	84.40	15.50	11.90	4.63	4.86	4.68	4.09	3
4	9.75	44.10	18.00	153.00	58.40	97.10	13.00	9.11	4.60	5.41	4.40	4.10	4
5	8.75	40.90	22.10	117.00	47.10	111.00	13.40	7.60	4.55	5.67	4.88	5.31	5
6	8.30	36.90	22.70	85.80	39.50	90.90	12.50	7.05	4.54	5.81	4.81	13.60	6
7	7.72	32.90	34.70	68.90	34.00	70.20	11.30	6.64	4.95	5.24	4.61	14.40	7
8	7.38	38.70	33.50	59.80	30.00	57.50	10.30	5.83	4.97	4.76	4.13	15.10	8
9	8.27	41.40	30.40	49.70	25.30	46.80	9.57	6.00	5.02	4.64	3.73	15.10	9
10	12.50	36.50	59.40	62.90	21.00	39.70	9.68	5.43	5.08	4.43	4.19	15.70	10
11	14.00	33.00	85.60	94.00	19.10	35.30	14.10	6.06	4.92	4.17	4.16	15.90	11
12	15.00	44.70	80.40	76.30	16.60	30.30	15.50	6.01	4.43	5.75	4.18	14.70	12
13	18.80	117.00	82.90	60.60	15.20	27.90	15.30	5.96	4.48	6.42	4.16	13.60	13
14	35.00	219.00	178.00	50.70	15.80	25.80	16.90	5.78	5.14	6.30	3.95	13.00	14
15	30.70	221.00	125.00	59.90	14.30	23.50	13.70	5.54	5.57	5.42	3.81	11.60	15
16	37.20	139.00	80.10	51.00	12.60	21.30	12.90	5.18	5.51	5.15	4.09	10.70	16
17	45.30	114.00	62.40	49.70	11.00	19.00	14.00	5.50	5.75	5.00	4.00	10.40	17
18	39.80	88.50	82.30	41.20	9.77	16.40	19.80	5.02	5.01	4.71	3.92	10.10	18
19	33.20	72.50	86.60	38.80	96.00	15.00	20.90	4.86	4.99	4.71	4.08	9.90	19
20	30.40	59.70	92.80	30.40	150.00	13.70	18.20	4.74	5.68	4.87	4.05	9.77	20
21	31.30	52.10	77.90	29.00	116.00	71.90	14.30	4.77	5.44	4.78	3.82	9.44	21
22	101.00	53.40	71.80	24.70	176.00	127.00	12.60	4.25	5.66	4.46	3.55	8.02	22
23	109.00	48.00	73.60	22.30	230.00	113.00	12.70	4.60	5.40	4.75	3.19	9.56	23
24	76.30	40.10	70.70	19.60	152.00	79.90	13.80	4.51	5.48	4.33	3.21	10.40	24
25	98.30	34.80	67.90	18.00	132.00	59.30	20.80	4.43	4.99	4.66	2.90	10.20	25
26	160.00	31.00	58.90	16.50	120.00	47.90	25.00	4.55	4.52	4.60	3.22	10.60	26
27	129.00	28.40	103.00	16.30	93.60	39.90	23.20	4.21	5.42	4.61	3.56	10.20	27
28	130.00	26.00	68.60	34.10	75.20	33.00	17.20	4.39	5.53	4.85	3.69	9.42	28
29	100.00	23.40	78.30	27.20	59.30	26.60	13.90	4.77	5.55	3.86	3.81	9.29	29
30	78.20	20.80	76.60	21.70		22.80	17.10	5.07	5.49	3.67	3.86	8.84	30
31	71.00		73.00	23.00		21.00		5.10		4.26	3.73		31

Table 5.2 Correlation between river flow and mouth conditions (Sappi - Mandini) for 1992/10 –1993/9

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	DAY
1	8.56	3.70	9.86	32.80	87.60	74.60	97.20	10.10	4.53	2.39	3.30	1.23	1
2	8.17	4.63	8.86	42.80	105.00	64.00	83.10	10.60	4.07	2.48	2.93	1.03	2
3	6.94	42.00	10.10	69.50	64.80	53.40	62.30	9.51	3.93	2.51	2.32	1.00	3
4	5.79	21.60	10.00	66.50	38.30	45.50	49.30	9.27	3.80	2.59	1.76	0.94	4
5	5.57	18.00	8.41	42.70	30.60	41.10	42.60	8.88	3.81	2.63	1.29	0.64	5
6	5.35	13.70	8.93	35.20	23.60	95.80	70.60	7.79	3.84	2.52	1.47	0.71	6
7	4.51	10.70	8.72	36.30	25.50	190.00	81.40	6.60	3.51	3.02	1.78	1.93	7
8	4.45	10.40	10.10	26.40	37.50	197.00	86.90	7.07	3.17	3.18	1.84	4.36	8
9	4.92	8.90	7.57	18.80	27.50	190.00	83.20	8.14	3.15	3.26	1.96	3.75	9
10	5.27	7.34	6.16	44.90	39.50	176.00	79.90	7.23	3.08	3.27	1.90	2.84	10
11	4.64	7.90	50.30	55.40	108.00	144.00	77.40	7.00	* 2.80	3.18	2.19	2.11	11
12	5.42	17.40	47.00	108.00	135.00	85.50	60.70	6.71	2.87	3.07	3.22	1.97	12
13	4.99	35.60	44.20	92.70	131.00	71.90	47.70	6.09	3.09	2.78	2.86	1.65	13
14	4.01	21.00	34.30	64.40	147.00	134.00	39.20	5.61	* 3.15	2.40	2.61	1.32	14
15	3.49	11.80	58.10	44.60	401.00	130.00	33.70	5.56	2.87	* 2.43	2.58	1.22	15
16	3.09	11.50	48.60	38.50	344.00	224.00	30.90	23.80	2.75	* 2.47	2.46	1.03	16
17	3.20	55.30	39.50	25.40	261.00	231.00	27.40	12.60	2.55	2.35	1.86	0.80	17
18	4.77	47.30	31.60	20.00	206.00	155.00	24.40	10.40	2.34	2.28	2.08	0.78	18
19	7.37	32.50	24.00	15.20	168.00	141.00	23.50	8.21	2.19	2.35	2.44	0.79	19
20	6.18	31.90	18.10	38.30	133.00	106.00	23.40	9.43	2.44	2.33	2.36	0.61	20
21	5.44	24.90	13.70	49.20	113.00	75.80	20.80	9.82	2.54	2.35	2.16	0.46	21
22	4.68	19.30	11.40	35.80	106.00	86.20	20.70	9.53	2.51	* 2.19	2.00	0.41	22
23	4.21	15.90	70.60	27.70	91.60	86.00	18.40	8.99	2.46	2.45	* 1.95	0.59	23
24	4.51	13.30	76.80	19.30	99.00	68.40	16.20	8.54	2.35	2.79	1.89	2.12	24
25	4.60	12.40	73.70	20.50	156.00	52.90	14.80	8.12	2.59	3.01	1.68	31.00	25
26	4.53	20.50	89.40	41.50	129.00	43.90	12.90	7.07	2.63	2.87	1.43	45.90	26
27	4.99	20.70	83.40	49.70	95.50	39.90	11.40	6.32	2.52	2.58	1.26	26.00	27
28	4.59	18.70	62.30	46.00	92.50	33.60	10.60	5.64	2.53	2.54	1.32	13.70	28
29	4.24	16.30	47.20	38.20		33.00	11.70	5.23	2.35	2.64	1.71	9.98	29
30	4.02	11.90	35.60	35.80		86.30	11.80	5.33	* 2.34	* 3.88	1.84	7.46	30
31	4.05		33.80	28.10		149.00		5.08		3.68	* 1.48		31

Open
 Closed
 * Almost closed
 No Information

Table 5.3 Correlation between river flow and mouth conditions (Sappi - Mandini) for 1993/10 –1994/9

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	DAY
1	6.17	25.30	46.60	90.00	126.00	43.20	67.90	19.00	5.50	6.66	7.78	9.71	1
2	5.79	21.10	43.20	80.90	105.00	42.20	56.90	17.70	5.07	6.04	* 7.84	8.79	2
3	6.16	17.40	36.00	81.70	150.00	39.50	72.20	16.50	4.74	* 5.03	8.07	7.96	3
4	10.10	16.70	31.30	70.40	342.00	37.00	70.50	15.90	4.69	4.38	8.79	6.85	4
5	16.70	15.90	24.40	82.60	457.00	39.10	61.50	17.70	4.45	3.87	8.84	6.03	5
6	35.50	15.00	21.60	92.00	457.00	41.10	56.00	20.30	4.42	5.17	8.90	5.45	6
7	194.00	14.60	51.20	72.50	457.00	45.60	42.90	18.40	5.41	5.80	8.26	5.07	7
8	457.00	13.60	54.30	61.30	457.00	49.80	35.50	16.90	5.09	4.53	7.30	4.29	8
9	322.00	15.10	39.20	55.20	440.00	56.70	29.40	16.20	4.55	3.84	6.76	4.00	9
10	192.00	15.20	44.40	50.50	361.00	80.20	25.60	15.10	4.27	3.26	6.37	3.71	10
11	131.00	12.70	47.50	383.00	386.00	85.80	24.30	13.20	4.50	2.79	5.99	3.54	11
12	128.00	12.30	33.90	222.00	351.00	96.50	22.70	12.40	4.54	2.47	5.75	3.32	12
13	90.00	12.40	26.20	209.00	235.00	68.00	23.00	12.00	4.56	2.38	5.61	3.15	13
14	82.70	14.70	21.40	213.00	165.00	55.70	22.00	11.50	4.44	2.28	5.23	3.10	14
15	69.80	58.90	18.40	224.00	148.00	56.20	19.90	11.00	4.15	* 2.23	5.29	3.05	15
16	49.90	65.50	17.20	173.00	132.00	162.00	18.90	10.30	4.33	2.20	5.51	2.99	16
17	39.40	53.90	21.20	129.00	121.00	268.00	17.40	9.83	4.22	2.27	5.54	2.86	17
18	39.70	42.30	20.50	101.00	138.00	145.00	16.30	9.29	3.96	2.40	5.60	2.71	18
19	84.50	35.20	53.50	88.20	125.00	107.00	15.10	9.11	3.89	2.48	5.06	2.57	19
20	74.00	37.20	63.10	144.00	96.80	94.50	14.10	9.22	3.96	2.39	5.71	2.44	20
21	54.20	38.70	51.10	204.00	84.20	81.60	13.40	8.88	3.56	* 2.20	7.53	2.32	21
22	50.40	48.00	37.00	185.00	88.50	70.50	13.50	7.74	* 3.41	2.04	8.49	2.19	22
23	55.20	52.90	37.10	166.00	76.10	61.40	14.60	7.71	3.50	2.21	8.66	1.99	23
24	89.30	43.60	31.60	173.00	72.90	48.40	14.90	7.55	3.29	2.39	9.66	1.78	24
25	167.00	34.60	38.70	289.00	63.30	41.20	30.70	* 6.86	3.13	3.02	11.60	1.75	25
26	70.00	27.50	49.50	214.00	63.80	43.70	37.90	6.54	3.27	5.78	13.10	1.67	26
27	45.60	25.80	47.90	272.00	58.50	36.70	33.30	6.37	2.82	6.64	13.10	1.58	27
28	34.80	28.00	123.00	263.00	51.50	42.60	26.80	5.41	2.54	6.70	* 13.50	1.52	28
29	28.80	40.80	400.00	214.00		55.50	22.20	5.49	2.51	6.91	13.80	1.82	29
30	36.60	34.70	244.00	185.00		47.30	20.00	5.78	2.53	6.78	12.90	* 1.88	30
31	31.60		141.00	160.00		57.10		5.73		6.85	10.70		31

Table 5.4 Correlation between river flow and mouth conditions (Sappi - Mandini) for 1994/10 –1995/9

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	DAY
1	1.76	9.80	2.94	31.30	76.70	10.50	39.50	14.90	4.53	5.82	2.95	0.90	1
2	2.74	9.16	2.55	22.00	46.20	13.80	56.90	14.30	4.24	5.53	2.69	0.87	2
3	5.39	7.56	2.35	15.70	40.10	17.30	61.40	46.20	5.79	5.10	2.48	0.81	3
4	4.77	20.50	2.06	12.50	55.60	52.00	52.20	45.80	5.79	5.08	2.15	0.74	4
5	4.26	41.40	1.71	12.70	55.60	57.80	45.00	46.60	4.71	4.81	1.99	0.65	5
6	3.84	35.10	1.50	10.80	41.70	48.80	37.30	32.80	4.18	4.48	2.39	1.49	6
7	3.45	26.90	11.60	9.10	32.20	39.10	31.70	23.10	4.57	4.13	2.48	1.81	7
8	6.32	20.50	38.60	8.01	23.80	28.40	27.70	19.50	4.96	4.02	2.57	1.68	8
9	7.21	16.20	15.50	7.03	19.50	23.20	37.40	19.80	4.78	5.17	2.26	1.45	9
10	5.93	13.90	18.00	5.80	24.30	45.90	79.60	19.90	4.79	* 5.13	2.09	1.23	10
11	5.27	11.20	12.90	4.73	21.30	47.80	55.30	18.00	4.59	* 4.84	2.16	1.34	11
12	4.81	11.80	64.90	4.09	16.80	32.80	41.20	15.80	4.38	4.40	1.95	1.28	12
13	5.06	11.00	56.60	3.67	13.90	24.60	32.90	13.70	4.25	4.14	2.93	1.19	13
14	* 8.05	12.20	34.20	3.28	22.50	20.30	29.40	12.70	4.02	4.10	4.00	1.19	14
15	8.26	14.10	29.70	14.80	19.90	22.50	27.00	11.90	3.78	3.90	3.15	1.95	15
16	7.74	19.10	26.00	69.40	16.00	25.50	25.40	11.50	3.47	3.89	2.56	4.71	16
17	8.00	18.60	26.00	103.00	13.80	22.80	23.50	11.00	6.53	3.92	2.25	5.35	17
18	8.17	17.60	21.00	84.30	12.60	24.70	21.70	10.20	29.70	3.65	2.00	3.35	18
19	7.58	13.60	16.30	74.60	10.80	23.70	20.00	9.55	17.00	* 3.29	1.73	4.63	19
20	7.57	11.60	13.70	98.40	8.63	21.30	17.80	9.07	14.20	3.03	1.65	3.98	20
21	6.98	10.60	17.50	61.70	19.10	60.00	16.80	8.32	11.70	2.95	1.62	4.42	21
22	7.52	10.40	14.10	63.70	15.90	58.60	15.60	7.73	9.97	2.92	1.64	5.46	22
23	9.49	10.20	11.80	95.90	18.40	39.30	14.60	7.00	9.87	3.17	1.47	8.51	23
24	8.54	8.77	11.70	71.40	32.60	41.00	14.30	7.19	8.66	3.19	1.58	7.15	24
25	7.26	7.53	14.10	50.40	37.00	22.30	13.30	* 6.85	8.25	3.09	1.70	5.71	25
26	6.46	6.51	16.30	36.60	25.10	18.60	12.60	6.31	7.59	2.77	1.48	4.49	26
27	5.39	5.47	16.70	37.70	19.70	19.20	13.90	6.15	7.43	2.57	1.32	3.61	27
28	4.88	4.56	14.80	35.10	14.10	17.30	16.00	7.34	7.01	2.62	1.11	2.98	28
29	6.06	3.97	13.50	25.90		32.60	16.00	6.72	6.75	2.81	0.97	2.40	29
30	7.22	3.36	22.00	24.10		43.40	16.30	6.05	6.40	2.57	1.05	2.22	30
31	8.69		37.80	97.80		37.30		5.19		2.86	0.97		31

Open
 Closed
 * Almost closed
 No Information

From available data of the cross-sections in the lower Tugela River (Huizinga and Van Niekerk, 1997) it is concluded that a volume of approximately 1 million m³ of water can be stored in the estuary between 0 m MSL and + 1.0 m MSL and 2.0 million m³ between +1.0 m MSL and + 2.0 m MSL.

The water level just after closure of an inlet is normally between + 0.5 m MSL and + 1.0 m MSL at South African estuaries and the berm at the mouth can, after closure, build up to levels of approximately + 2.5 m MSL (CSIR, 1990b). The volume of water required to fill the estuary up after breaching is, based on this information, estimated to be approximately 2.5 to 3.5 million m³.

If the berm after closure quickly builds up to a level of + 2.5 m MSL and at a flow rate of 1.0 m³/s, it can take about 30 and 40 days to fill the estuary up to breaching level. At a flow rate of 2.0 m³/s it will take between 15 and 20 days, at 5 m³/s between 6 and 8 days and at 10 m³/s approximately 2 to 4 days.

However, the available data on mouth closures and corresponding river flows (Tables 5.1-5.4) shows that the mouth normally only stays closed for up to 4 days at a time, even at river flows below 2.0 m³/s. This indicates that the water level in the estuary normally increases faster than the level of the berm after closure if the river flow about or higher than 2 m³/s.

Based on this information the following conclusions are drawn on the correlation between river flow and mouth conditions:

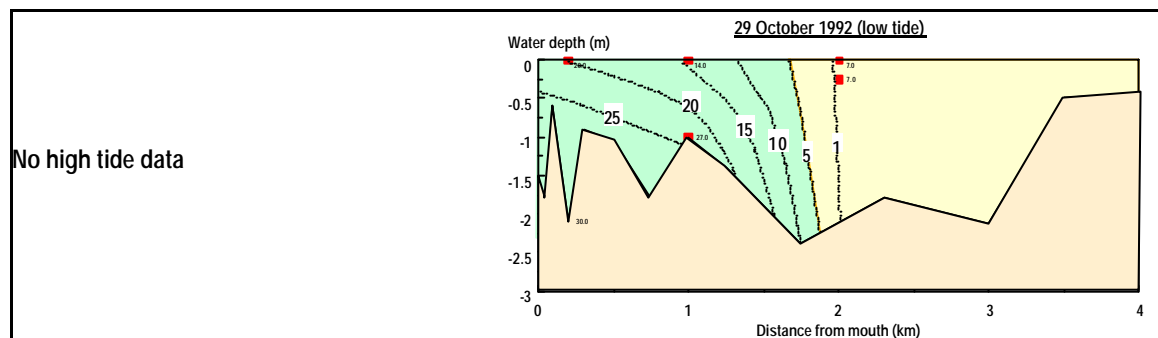
Flow rate (m ³ /s)	Consequence
> 10	The mouth will stay open
5 - 10	The mouth closes occasionally. Water levels build up quickly and breaching occurs probably naturally within 1 to 2 days.
2 - 5	Mouth closure occurs more frequently than at flows higher than 5 m ³ /s, but the mouth breaches normally again within 4 days. This is probably because the water level in the estuary is increased faster than the level of the berm.
1 - 2	Mouth closure will occur. Available data indicates that closures often will be for short periods, but the mouth could stay closed for 15 to 40 days if the berm builds up faster than the water level in the estuary. Mechanical breaching may be required to prevent flooding.
< 1	The mouth will normally be closed, with a slow increase in water levels. A higher berm will build up and the mouth is likely to remain closed for period of up to a few months. Mechanical breaching may be required to prevent flooding.

5.2 RELATIONSHIP BETWEEN SALINITY DISTRIBUTION AND RIVER FLOW

5.2.1 29 October 1992

On 29 October 1992 the river inflow had been below 5 m³/s for most of the month and below 30 m³/s for about 7 months preceding the period the measurements were taken. This allowed saline penetration into the lower 2.0 km of the estuary at low tide (Figure 5.3).

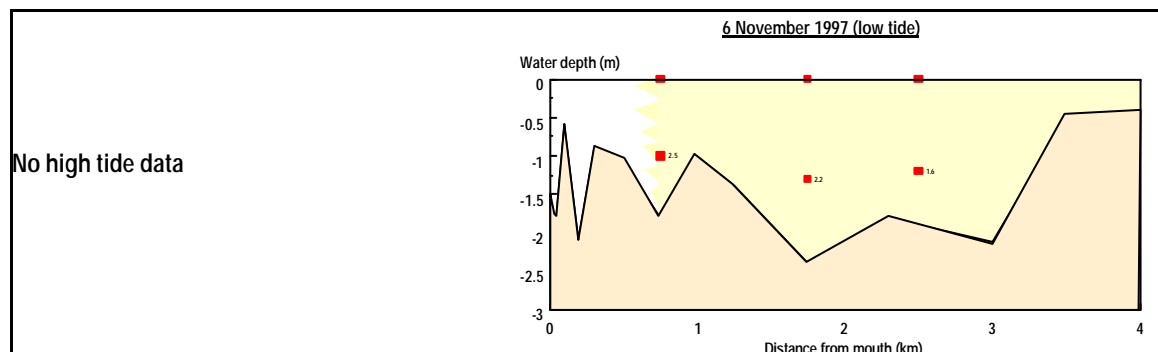
Fig 5.3 Salinity profile (in ppt) taken during 29 October 1992



5.2.2 6 November 1997

On 4 November 1997 the river inflow was 39.8 m³/s. Unfortunately, the gauging station became unreliable the following day (Figure 5.4). Three weeks before the measurements were taken, a high flow event of 150 m³/s occurred which would have reset the system to fresh. In the period following the event, the river flow gradually decreased to flows of about 30 m³/s or slightly less. As can be seen from the salinity profile under these flow conditions no saline intrusion was recorded in the lower reaches of the system.

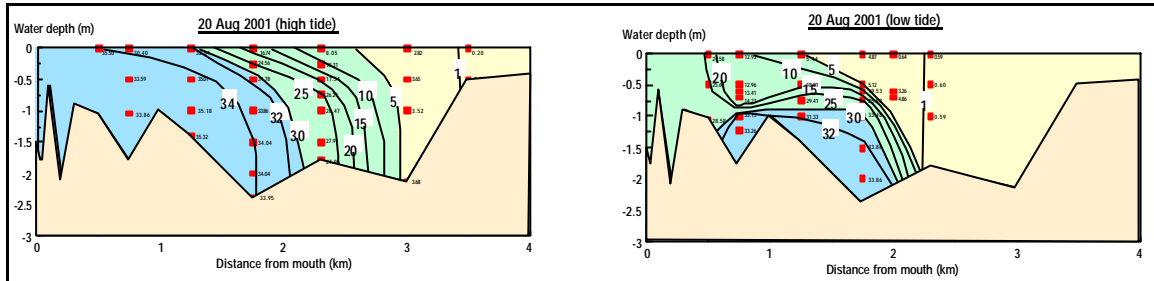
Fig 5.4 Salinity profile (in ppt) taken during 6 November 1997



5.2.3 20 August 2001

On 20 August 2001 the river inflow was measured at 5.95 m³/s. For the preceding 10 days the river inflow was less than 10 m³/s and the preceding 2 month the flows were less than 30 m³/s. This allowed for substantial saline intrusion into the upper reaches of the system. About 3.5 km upstream from the mouth at high tide and about 2.5 km at low tide (Figure 5.5)

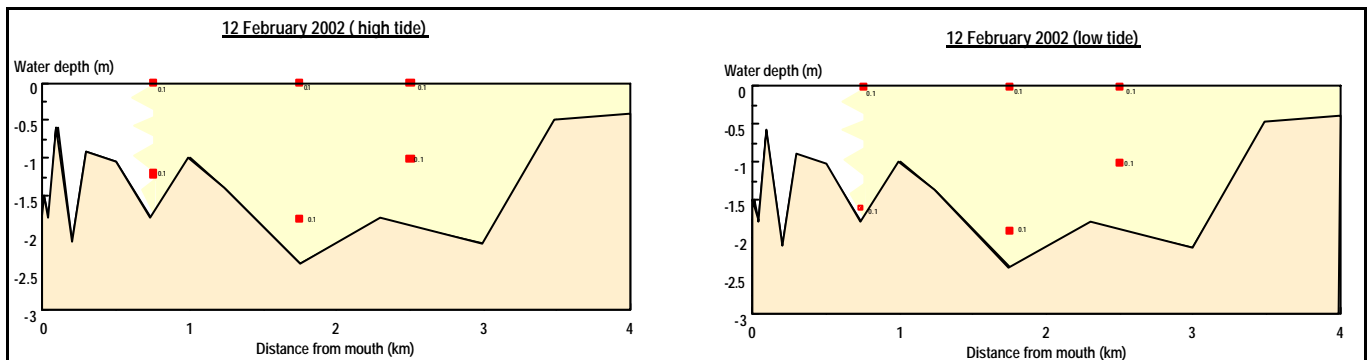
Fig 5.5 Salinity profile (in ppt) taken during 20 August 2001



5.2.4 12 February 2002

On 12 February 2002 the river inflow was about 40 m³/s, resulting in the estuary being well mainly fresh, both the high and low tides (Figure 5.6).

Fig 5.6 Salinity profile (in ppt) taken during 12 February 2002



6 ASSESSMENT OF WATER QUALITY CHARACTERISTICS

For the assessment of spatial and seasonal variations in the water quality (WQ) characteristics of the Thukela Estuary, the relationship between the concentrations of different WQ variables versus salinity, obtained from three surveys, i.e. May 1996, August 2001 and February 2002 were used. Salinities of river and seawater, i.e. the two major water sources of estuaries, are distinctly different. Being a conservative parameter, the relationship with salinity, therefore, can be used as a means of characterising the distribution, transport and fate of other chemical variables within an estuary. For example, a linear relationship would indicate that concentrations along the estuary are a function of the extent of mixing between river and seawater, as well as the concentration of a particular variable in the two sources. To be able to orientate oneself in terms of the spatial distribution of WQ concentrations along the estuary during the different surveys, WQ concentration versus salinity plots should be compared with the corresponding longitudinal salinity profiles provided in Chapter 5.

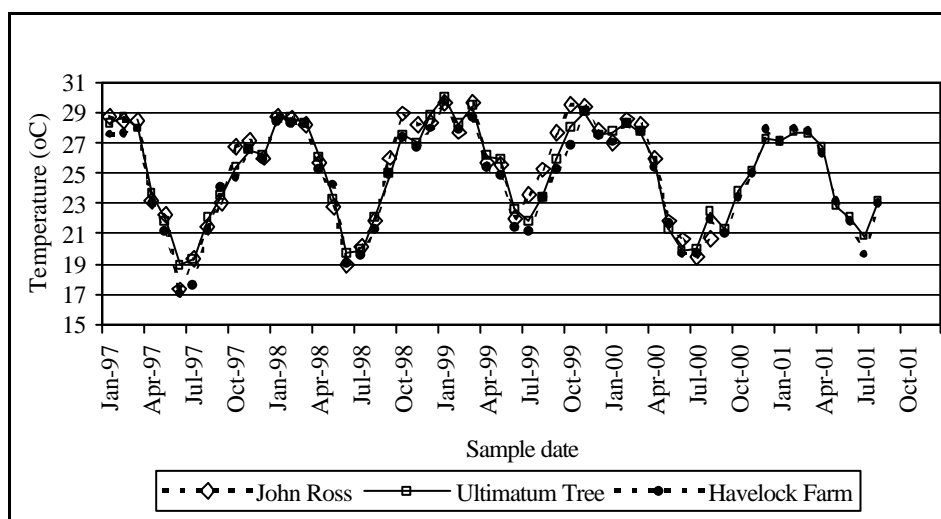
The WQ survey of May 1992 was done at the same time as the high tide salinity profiles of 6 May 1997 (refer to Figure 5.4), the WQ survey in August 2001 was done at the same time as the high salinity profile of 20 August 2001 (refer to Figure 5.5), while the WQ survey in February 2002 was done at the same time as the salinity profiles of 12 February 2002 (Figure 5.6).

6.1 SYSTEM VARIABLES

6.1.1 Temperature

Temperature data are not collected at the Mandini monitoring station (V5H002). Data collected by the Sappi Tugela Mill further down stream (i.e. at Havelock farm, some 8 km downstream of the John Ross [N2] bridge) for the period January 1997 to October 2001 showed a strong seasonal signal with temperatures around 20°C during winter and peaking to around 29°C during summer (Figure 6.1) (Malan *et al.*, 2002).

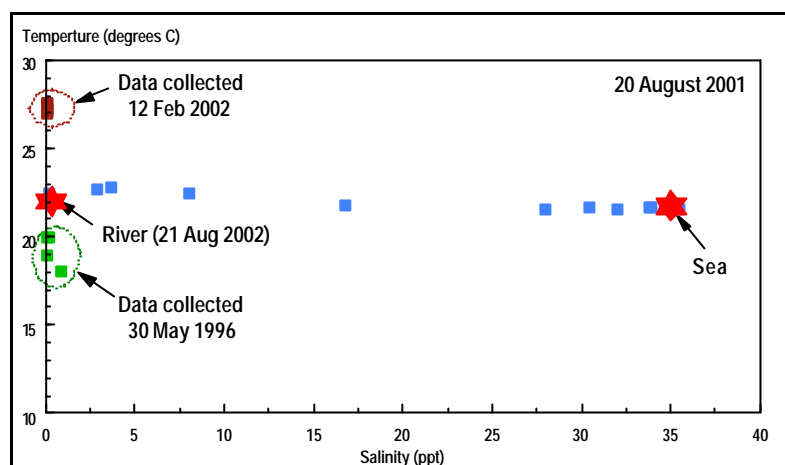
Fig 6.1 Temperature data provided by Sappi Thukela from their monitoring points at John Ross Bridge (North), Ultimatum Tree and Havelock Farm



Surface seawater temperatures along the east coast, where the Thukela Estuary enters the sea, are of tropical origin with maximum temperature of 25°C occurring in February (summer). The difference between summer and winter averages about 4°C (DWAf, 1995).

The relationship between salinity and temperatures measured in the Thukela Estuary during May 1996, August 2001 and February 2002 are given in Figure 6.2.

Fig 6.2 Relationship between salinity and temperatures measured in the Thukela Estuary in May 1996, August 2001 and February 2002



During the August 2001 survey river inflow of about 6 m³/s resulted in a well establish salinity gradient in the estuary. Temperatures of the two water sources (i.e. the sea and the river) were similar, resulting in uniform temperatures throughout the estuary of about 22°C. During both the May 1996 and February 2002 surveys river inflow to the estuary was high (greater than 30 m³/s). At the time temperatures measured in the estuary were therefore representative of river water temperatures at the time, i.e. cooler temperatures in May (winter) and warmer temperatures in February (summer).

Based on the above, it is expected that water temperatures in the Thukela Estuary is seasonal, with winter temperatures around 20°C, peaking at around 29°C during summer.

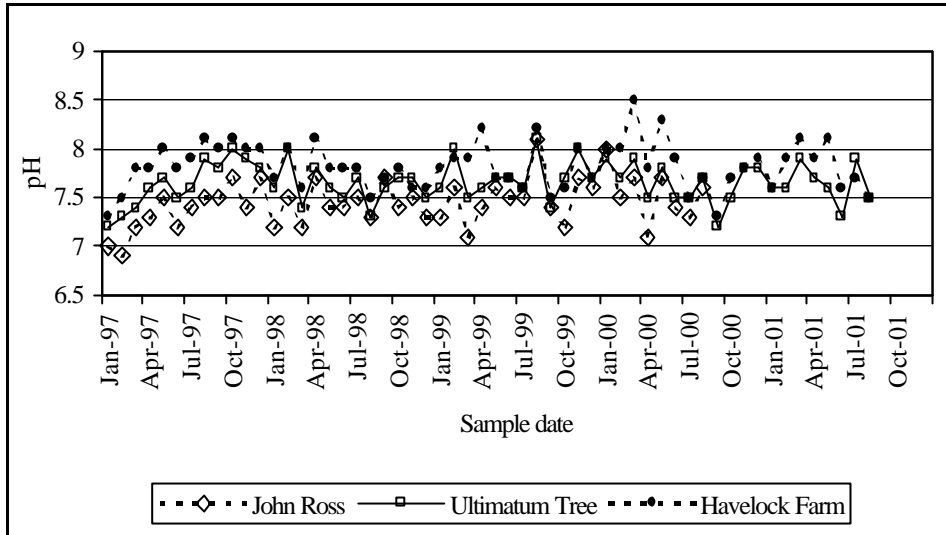
6.1.2 pH

Variation in pH in river inflow under Reference Conditions (1977-1985) and Present State (1995-2001), based on monthly data collected at the Mandini monitoring point (V5H002), are presented in Table 6.1. Results indicate a slight increase in river water pH from the Reference Condition (~ 7) to Present State (~ 8). This could not be explained other than possibly an artifact of changing measuring techniques (Figure 6.3) (Malan *et al.*, 2002).

Table 6.1 pH in river inflow under Reference Condition (1977-1985) and Present State (1995-2001) based on monthly data collected at the Mandini monitoring point (V5H002)

Month	Reference condition			Present state		
	Minimum	Median	Maximum	Minimum	Median	Maximum
January	6.7	7.0	7.6	7.5	8.1	8.4
February	6.6	7.0	7.8	7.3	8.0	8.3
March	6.5	7.0	7.0	7.4	7.9	8.4
April	6.6	7.0	7.5	7.6	8.2	8.4
May	6.5	7.3	7.6	7.8	8.2	8.5
June	6.9	7.4	7.7	8.0	8.3	8.5
July	6.3	7.6	7.8	7.8	8.4	8.7
August	6.6	7.4	7.7	8.4	8.5	8.8
September	6.5	7.3	8.0	8.3	8.6	8.7
October	6.9	7.2	7.7	7.3	8.5	8.6
November	6.5	7.1	7.6	7.4	7.8	8.5
December	6.5	7.1	7.5	7.4	8.2	8.4

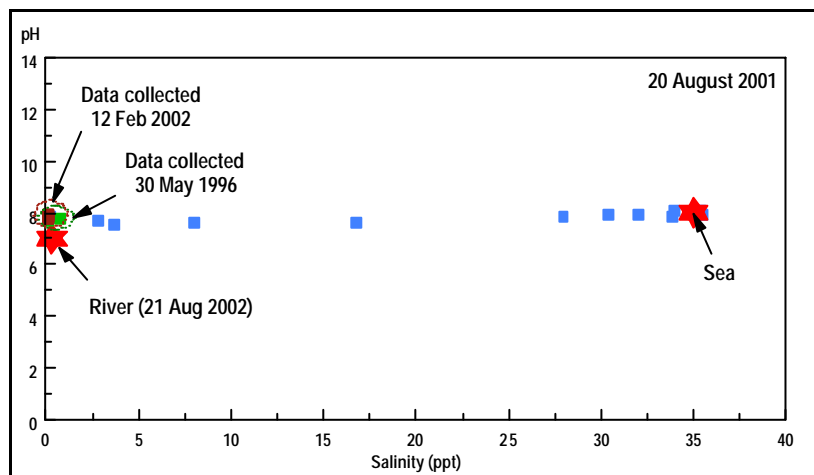
Fig 6.3 pH data provided by Sappi Thukela from their monitoring points at John Ross Bridge (North), Ultimatum Tree and Havelock Farm



The pH of seawater typically ranges between 7.9 and 8.2 (DWAf, 1995).

The relationship between salinity and pH measured in the Thukela Estuary during May 1996, August 2001 and February 2002 are given in Figure 6.4. Results show that pH levels in the estuary were uniform throughout the estuary on all occasions at approximately 8. This is expected as salinities in the river and the sea, the two water sources of the estuary, tend to be similar throughout the year.

Fig 6.4 Relationship between salinity and pH measured in the Thukela Estuary in May 1996, August 2001 and February 2002



From the above, it is expected that pH in the Thukela Estuary are likely to remain fairly uniform, on both spatial and temporal scales, ranging between 7 and 8.

6.1.3 Suspended solids and Turbidity

Suspended solid and turbidity data are not collected at the Mandini monitoring point (V5H002). However, based on measurements collected from the estuary at low salinities (i.e. < 1 ppt, considered to be indicative of concentrations in river inflow) it seems as if concentrations in river inflow tend to increase with higher river flows, as illustrated below. This, however, needs to be confirmed through monitoring.

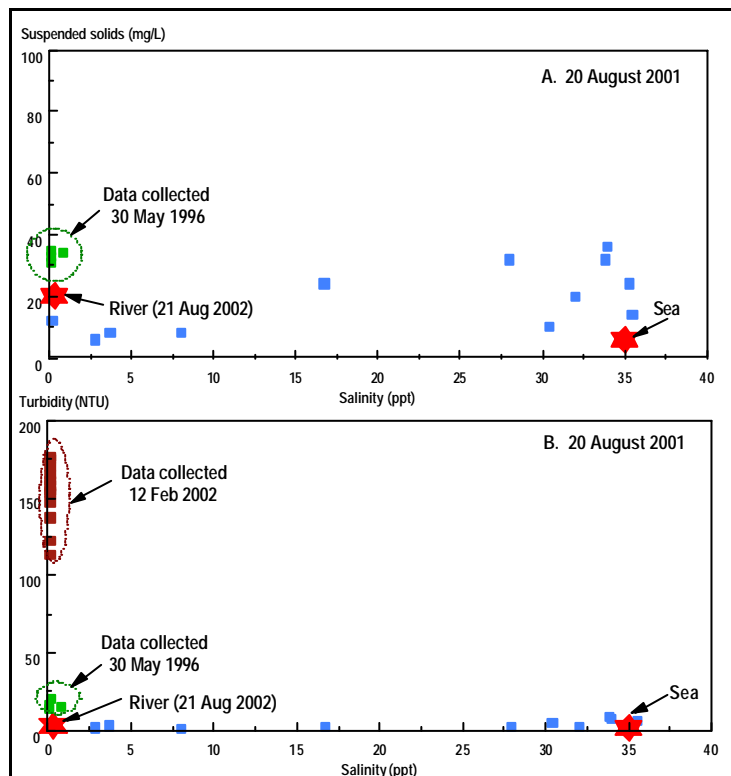
Date	Flow rate (m ³ /s)	Suspended solids (mg/L)	Turbidity (NTU)
20 August 2001	6	16	3
30 May 1996	54	33	16
12 February 2002	40	-	153

Scientists have observed, on a number of occasions, fibre-like suspended material in the estuary which resulted in clogging of fish sampling nets (Dr Alan Whitfield, University of Rhodes, pers. comm. and Fiona MacKay, CRUZ, pers. comm.). Although there are no measured data to confirm the source of this suspended material, it is likely to be associated with industrial discharges in the Mandini area. It is important that this also be confirmed through regular monitoring of effluent and river water quality.

Suspended solid concentrations and turbidity in seawater is site-specific and no data could be obtained for the east coast of South Africa. Based on the once off measurement collected during the August 2001 survey (see below) concentrations were low, i.e. < 10 mg/L. However, it is expected that levels can increase dramatically along this part of the coast during periods of high river discharge (summer).

Suspended solid concentrations and turbidity levels measured in the Thukela Estuary during May 1996, August 2001 and February 2002 are given in Figure 6.5. On none of the occasions was there any apparent correlation between salinity and these variables. However, as mentioned earlier there is probably a tendency for suspended solid concentrations and turbidity levels in the estuary to increase when the river's influence becomes more dominant, i.e. at higher river inflow rates (as reflected in the data of 30 May 1992 and 12 February 2002 when inflows exceeded 30 m³/s).

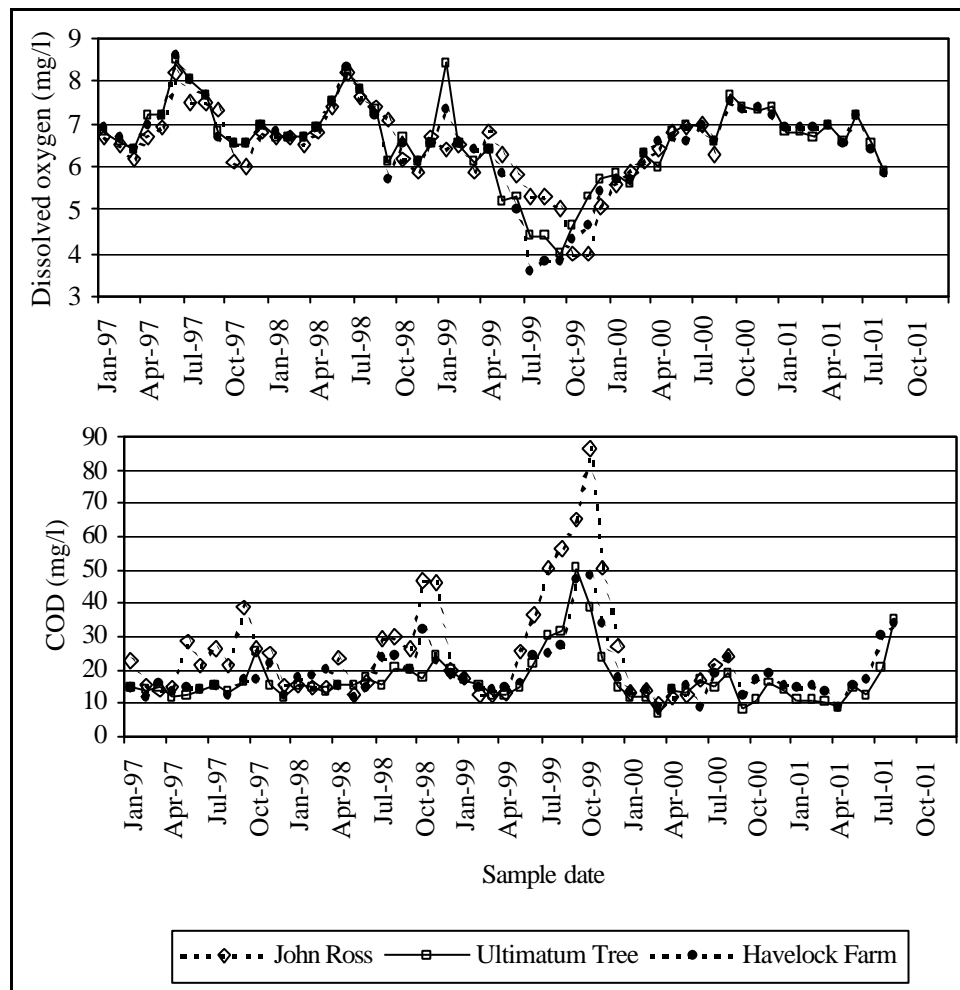
Fig 6.5 Relationship between salinity and [A] Suspended solid concentrations and [B] Turbidity measured in the Thukela Estuary in May 1996, August 2001 and February 2002



6.1.4 Dissolved Oxygen

Dissolved oxygen data are not collected at the Mandini monitoring station (V5H002). Data collected by the Sappi Tugela Mill further down stream (i.e. at Havelock farm, some 8 km downstream of the John Ross [N2] bridge) for the period January 1997 to October 2001 showed that dissolved oxygen concentrations in the river are generally above 6 mg/L (Figure 6.6) (Malan *et al.*, 2002). However, during July-October 1999 levels dropped to 4mg/L, probably as a result of anthropogenic inputs of biodegradable organic matter or reducing substances (as reflected by high chemical oxygen demand concentrations measured at the time). Whether these levels were sustained further downstream or whether re-aeration occurred before the water reached the estuary could not be established.

Fig 6.6 Dissolved oxygen and Chemical Oxygen Demand data provided by Sappi Thukela from their monitoring points at John Ross Bridge (North), Ultimatum Tree and Havelock Farm

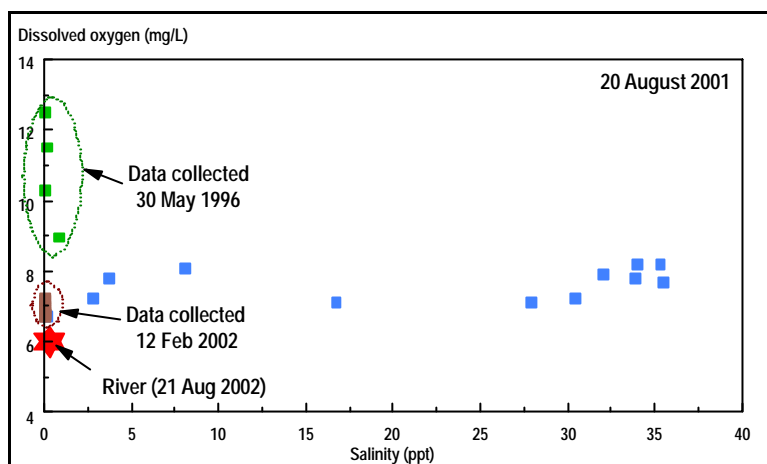


Although measured data on dissolved oxygen concentrations for the east coast could not be obtained, surface water in unpolluted and fairly turbulent areas, such as the surf zone adjacent to the Thukela River mouth, is usually well-oxygenated.

The relationship between salinity and dissolved oxygen concentrations measured in the Thukela Estuary during May 1996, August 2001 and February 2002 are given in Figure 6.7. On all occasions the estuary was well-oxygenated, as would be expected for a relatively unpolluted, small estuary with that is quite shallow and with good water exchange. Being quite a shallow system is likely that wind mixing will be able to maintain oxygenated conditions during the closed state, but this will have to be confirmed with field

measurements. Also, similar shallow systems along the Kwazulu-Natal coast have known to go anoxic during closure (Fiona MacKay, CRUZ, pers. comm.)

Fig 6.7 Relationship between salinity and dissolved oxygen measured in the Thukela Estuary in May 1996, August 2001 and February 2002



6.2 INORGANIC NUTRIENTS

6.2.1 Dissolved nitrite/nitrate

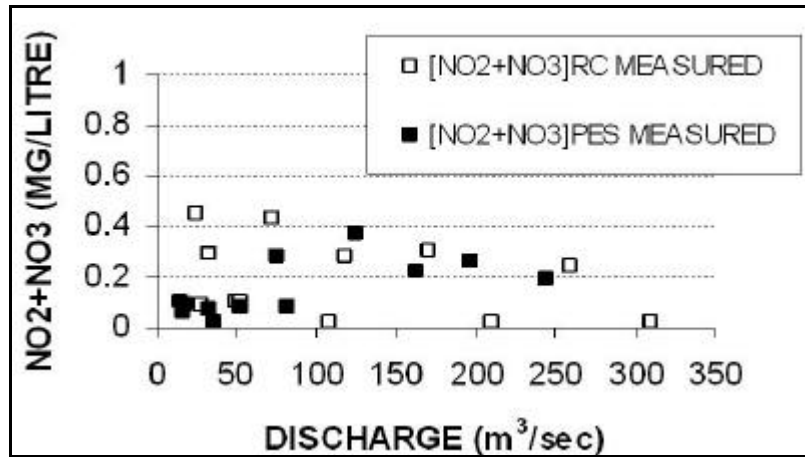
Variation in nitrite/nitrate concentrations in river inflow under Reference Conditions (1977-1985) and Present State (1995-2001), based on monthly data collected at the Mandini monitoring point (V5H002), are presented in Table 6.2. Results indicate no distinct difference between the Reference Condition and Present State and also no marked seasonal trends. A comparison between river inflow and discharge (river flow) for both the reference conditions and present state also showed no apparent trends (Figure 6.8).

Table 6.2 Nitrite/Nitrate-N concentrations ($\mu\text{g/L}$) in river inflow under Reference Condition (1977-1985) and Present State (1995-2001) based on monthly data collected at the Mandini monitoring point (V5H002)

Month	Reference Condition			Present State		
	Minimum	Median	Maximum	Minimum	Median	Maximum
January	20	240	1360	20	290	720
February	20	20	670	20	193	494
March	20	20	1000	20	208	606
April	20	20	300	49	282	418
May	20	100	420	20	73	736
June	20	290	970	20	89	515
July	20	450	650	43	101	534
August	20	85	540	20	58	416
September	20	100	850	20	20	119
October	20	430	1080	20	795	1007
November	20	280	1080	20	77	751
December	50	295	-	20	373	1379

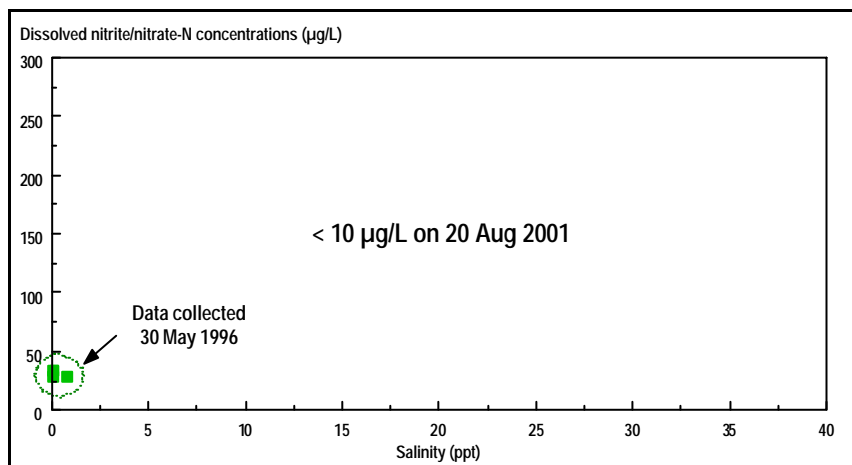
Average nitrite/nitrate-N concentrations, reported for the east Coast of South Africa near the Thukela River mouth is estimated at about 50 $\mu\text{g/L}$ (DWAF, 1995).

Fig 6.8 Relationship between river flow and nitrite/nitrate concentrations for the Reference Condition (RC) and Present State (PES) (Malan *et al.*, 2002)



The relationship between salinity and dissolved nitrite/nitrate-N concentrations measured in the Thukela Estuary during May 1996 and August 2001 are given in Figure 6.9. On both occasions the concentrations were very low. During the August 2001 survey, the concentrations measured in both the sea and river were also low (< 20 µg/L), similar to what was measured in the estuary at the time. Although such low concentrations are measured in river inflow (Table 6.2), concentrations can, at times, also be high, which may result in higher concentrations in the estuary, particularly at times of river dominance.

Fig 6.9 Relationship between salinity and dissolved nitrite/nitrate-N concentrations measured in the Thukela Estuary in May 1996 and August 2001



Based on the above, it is expected that nitrite/nitrate-N concentrations in the estuary will generally be low (i.e. < 50 µg/L). However, at times, particularly during periods of river dominance, concentrations may increase to as high as 1 400 µg/l (based on maximum present state concentrations in river inflow – Table 6.2), but probably only for short periods.

6.2.2 Total Ammonia

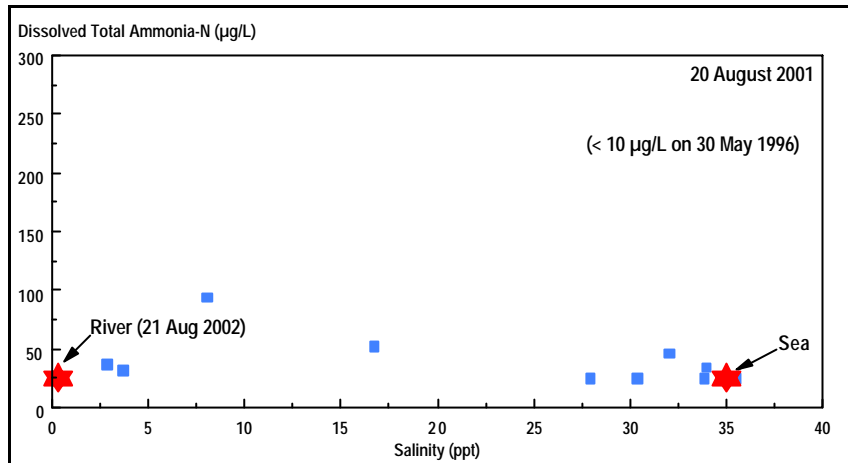
Total ammonia-N data are not collected at the Mandini monitoring station (V5H002). However, based on measurements collected from the estuary at low salinities (i.e. < 1 ppt, considered to be indicative concentrations in river inflow of river concentrations) indications are that river water concentrations are low, typically below 40 µg/L.

In unpolluted, well-oxygenated seawater total ammonia concentrations is expected to be low

(DWAF, 1995).

The relationship between salinity and dissolved total ammonia concentrations measured in the Thukela Estuary during August 2001 are given in Figure 6.10. During the survey in May 1996 throughout the estuary was less than 10 µg/L.

Fig 6.10 Relationship between salinity and dissolved nitrite/nitrate-N concentrations measured in the Thukela Estuary in May 1996 and August 2001



Based on the above, it can be expected that total ammonia-N concentrations in the Thukela Estuary will generally be low (i.e. < 50 µg/L).

6.2.3 Reactive phosphate

Variation in reactive phosphate-P concentrations in river inflow under Reference Conditions (1977-1985) and Present State (1995-2001), based on monthly data collected at the Mandini monitoring point (V5H002), are presented in Table 6.3. Results indicate no marked difference between the Reference Condition and Present State with median concentrations being low throughout, i.e. < 50 µg/L. Although the comparison between discharge (river flow) and reactive phosphate concentrations do indicate a slight increase in concentration with an increase in flow rate (Figure 6.11) (probably associated with wash-off from the agricultural areas in the catchment during period of higher rainfall), concentrations are still low.

Average reactive phosphate-P concentrations reported for the east Coast of South Africa near the Thukela River mouth is estimated at 19 µg/L (DWAF, 1995).

The relationship between salinity and dissolved reactive phosphate concentrations measured in the Thukela Estuary during May 1996 and August 2001 are given in Figure 6.12.

Table 6.3 Reactive phosphate-P ($\mu\text{g/L}$) in river inflow under Reference Condition (1977-1985) and Present State (1995-2001) based on monthly data collected at the Mandini monitoring point (V5H002)

Month	Reference Condition			Present State		
	Minimum	Median	Maximum	Minimum	Median	Maximum
January	12	29	50	8	22	47
February	14	34	61	12	28	87
March	3	23	61	10	31	53
April	7	32	74	6	21	54
May	3	15	73	10	17	79
June	3	46	140	6	12	26
July	3	7	325	16	27	110
August	3	17	115	12	19	217
September	3	11	43	10	26	33
October	3	13	68	3	22	64
November	3	14	50	3	19	59
December	3	14	47	3	19	145

Fig 6.11 Relationship between river flow and reactive phosphate concentrations for the Reference Condition (RC) and Present State (PES) (Malan *et al.*, 2002)

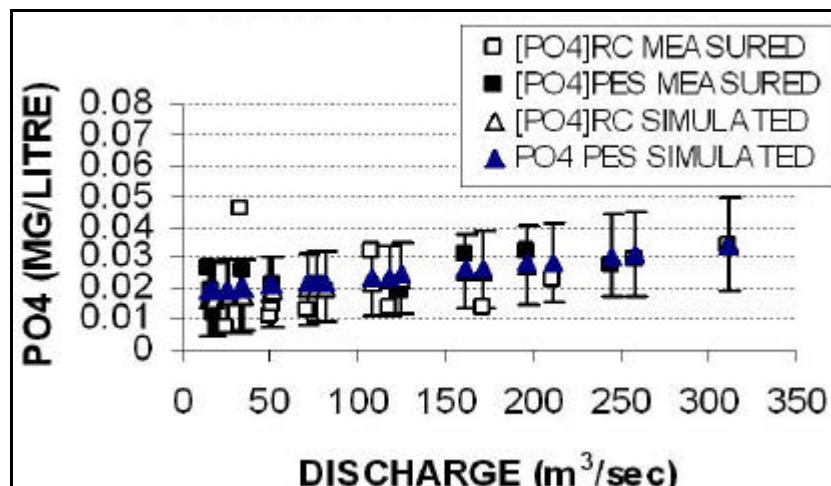
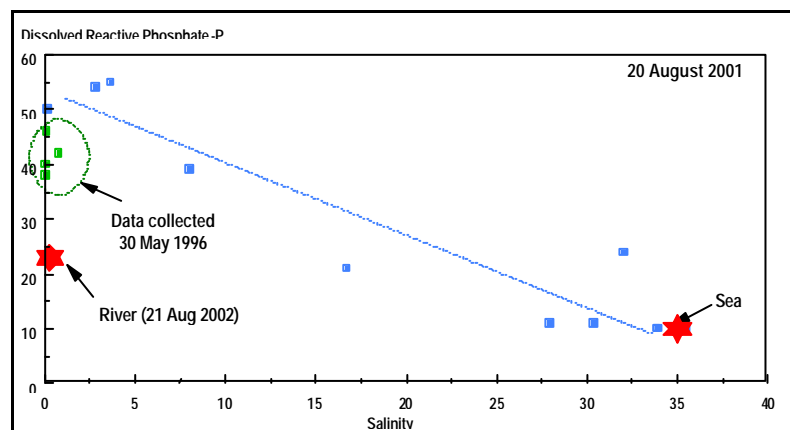


Fig 6.12 Relationship between salinity and dissolved reactive phosphate-P concentrations measured in the Thukela Estuary in May 1996 and August 2001



Data collected on 20 August 2001, when a well-defined salinity gradient existed in the estuary, showed a slight decrease in concentration with an increase in salinity, as a result of slightly lower concentrations of seawater compared with the inflowing river water at the time. Even so, concentrations throughout the estuary were still low, i.e. < 50 µg/L.

Based on the above, it is expected that reactive phosphate-P concentrations in the Thukela Estuary will generally be low, i.e. < 50 µg/L. However, at times, particularly during periods of river dominance, concentrations may increase to as high as 200 µg/l (based on maximum present state concentrations in river inflow – Table 6.3), but probably only for short periods.

6.2.4 Reactive silicate

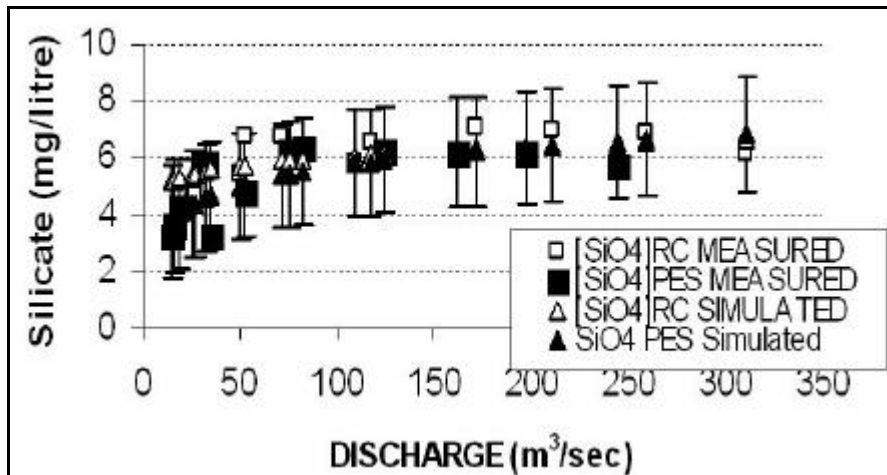
Variation in reactive silicate-Si concentrations in river inflow under Reference Conditions (1977-1985) and Present State (1995-2001), based on monthly data collected at the Mandini monitoring point (V5H002), are presented in Table 6.4. Results indicate no marked difference between the Reference Condition and Present State. The comparison between discharge (river flow) and reactive silicate-Si concentrations, however, do indicate a slight increase in concentration with an increase in flow rate (Figure 6.13), which is probably associated with wash-off from the catchment soils during periods of higher rainfall.

Average reactive silicate-Si concentrations reported for the east Coast of South Africa near the Thukela River mouth is estimated at 104 µg/L (DWAF, 1995).

Table 6.4 Reactive silicate-Si (µg/L) in river inflow under Reference Condition (1977-1985) and Present State (1995-2001) based on monthly data collected at the Mandini monitoring point (V5H002)

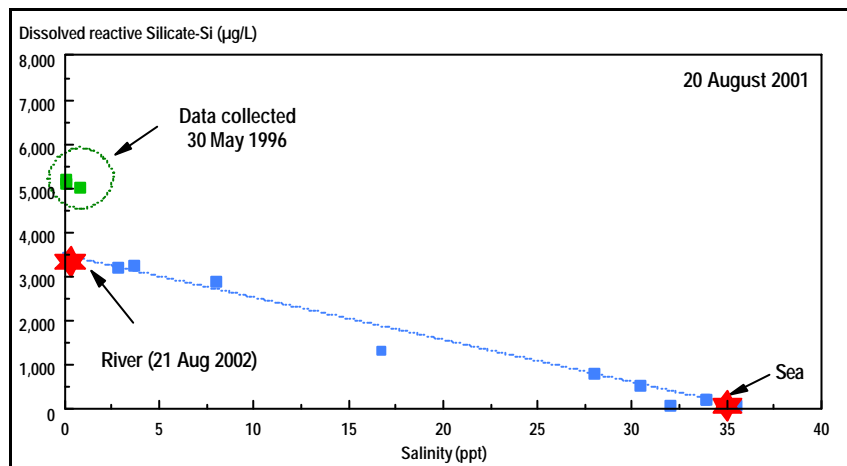
Month	Reference Condition			Present State		
	Minimum	Median	Maximum	Minimum	Median	Maximum
January	6060	6890	7700	5240	5930	9505
February	5410	6110	7340	4200	5776	6820
March	5990	6940	7400	4810	6290	7140
April	2390	5860	6880	5660	6290	7170
May	5860	6790	8290	4320	5860	6400
June	4780	5865	6940	3289	4295	5910
July	3690	4885	5340	2401	3260	6160
August	3980	4725	6090	2600	3680	5930
September	3770	5370	6780	2370	3260	5050
October	5850	7030	-	3290	4805	6700
November	5970	6675	-	4474	6330	7090
December	6000	7130	8890	5710	6240	7409

Fig 6.13 Relationship between river flow and reactive silicate-Si concentrations for the Reference Condition (RC) and Present State (PES) (Malan et al., 2002)



The relationship between salinity and dissolved reactive silicate concentrations measured in the Thukela Estuary during May 1996 and August 2001 are given in Figure 6.14. Data collected on 20 August 2001, when a well-defined salinity gradient existed in the estuary, showed a decrease concentration with an increase in salinity, as a result of slightly lower concentrations of seawater compared with the inflowing river water.

Fig 6.14 Relationship between salinity and dissolved reactive silicate-Si concentrations measured in the Thukela Estuary in May 1996 and August 2001



Based on the above, reactive silicate concentrations in the estuary largely depend on whether the system is marine dominated or freshwater (river) dominated. With strong marine influence silicate-Si concentrations will tend to be lower, i.e. below 1 000 µg/L, reflecting the influence of lower silicate seawater. With stronger river influence, associated with higher river inflows, concentrations will increase to between 5 000 - 7 000 µg/L.

6.3 TRACE METALS

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

Sediment trace metals data collected from the Thukela Estuary during May 1996 and August 2001 are given in Table 6.5. Sediment sampling stations are given in Figure 2.1.

Table 6.5 Total Trace Metal concentrations measured in sediments in the Thukela estuary during August 2001 and May 1996

Distance from mouth (km)	Sediment characteristics			Total trace metal ($\mu\text{g/g}$)							
	%Gravel	%Sand	%Mud	Al	Cd	Cr	Cu	Hg	Ni	Pb	Zn
<i>20 August 2001</i>											
0.50	0	100	0	4938	<0.25	14.1	5.6	<0.5	7.3	6.5	12.0
0.75	0	11	89	4411 7	<0.25	69.3	42.0	<0.5	49.4	18.0	71.2
1.40	0	99	0	6995	<0.25	25.3	8.8	<0.5	11.4	6.0	18.6
1.85	0	100	0	7246	<0.25	20.8	7.7	<0.5	10.8	6.4	21.2
2.30	0	96	0	6338	<0.25	24.8	9.3	<0.5	13.6	5.8	18.4
3.50	5	94	0	6918	<0.25	19.9	7.8	<0.5	10.9	6.1	12.0
<i>30 May 1996</i>											
0.30	-	-	-	2550	0.01	13.6	8.7	-	10.1	2.4	13.9
1.25	-	-	-	2890	0.05	14.1	9.0	-	10.1	2.5	14.6

In general the data from May 1996 were not markedly different from the August 2001 data set. Clearly evident from the August 2001 data set is the accumulation of trace metals in depositional areas, usually characterised by high mud content, i.e. the station at 0.75 km from the mouth.

In these assessments, it is also important to establish whether the accumulation of trace metal in sediments is actually as a result of anthropogenic inputs. It is possible for conditions to arise where total trace metal concentrations in sediment are high (particularly in depositional areas), but completely linked to the natural structure of clay minerals in which case the trace metals will not be bio-available. This type of condition would be characterised by geochemical ratios very similar to unpolluted sediments typical of the area (Monteiro and Scott, 2000). In this case geochemical ratios from the Maputo area (considered to be representative of catchment areas draining along the east coast) was compared with those of the Thukela Estuary sediments (Monteiro, 1998). The geochemical ratios of each trace metal relative to aluminium (TM [$\mu\text{g/g}$]: Al [%]) are presented in Table 6.6. Allowing a conservative 2 fold natural variation in the geochemical ratios, the trace metals in the sediments of the Thukela Estuary are largely within the bounds of natural variability, suggesting that anthropogenic inputs has had no marked effect. This is based on very limited data and should be viewed in that context.

Table 6.6 Geochemical ratios (Trace Metal:Aluminium) of sediments collected in the Thukela Estuary during August 2001 and from the Maputo area

Description	Cr:Al	Cu:Al	Ni:Al	Pb:Al	Zn:Al
0.50 km from mouth	29	11	15	13	24
0.75 km from mouth	16	10	11	4	16
1.40 km from mouth	36	13	16	9	27
1.85 km from mouth	29	11	15	9	29
2.30 km from mouth	39	15	21	9	29
3.50 km from mouth	29	11	16	9	17
Average ratio for 20 August 2001	30	12	16	9	24
Maputo Ratios (representative of catchments draining along east coast)	27	7	10	4	15

7 ABIOTIC STATES FOR THE THUKELA ESTUARY

7.1 DIFFERENT ABIOTIC STATES

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

State 1: Mouth closed, for weeks to a few months at a time	0 – 2 m³/s
State 2: Mouth open, occasional mouth closures of a few days	2 – 5 m³/s
State 3: Mouth open, saline intrusion	5 – 30 m³/s
State 4: Mouth open, river dominated	> 30 m³/s

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

7.1.1 State 1: Mouth closed, for weeks to a few months at a time

Typical flow patterns. Flow rates are between 0.0 and 2.0 m³/s (for this study only observed in Worst Case Scenarios)

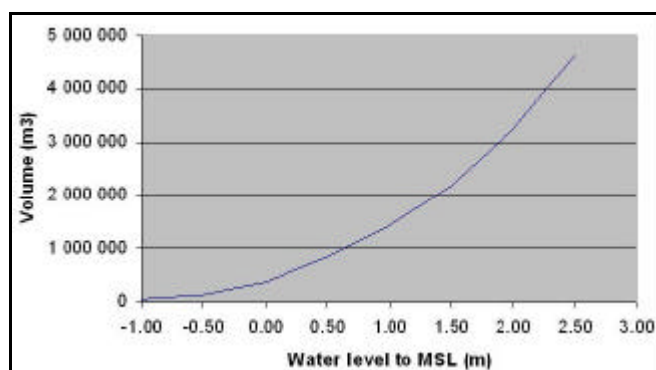
State of the mouth. Mouth closes for a weeks to a few months at a time in the lower flow range.

Flood plain inundation patterns. The berm at the mouth can build up to about 2.5 m MSL, causing extended back flooding of inter-tidal and flood plain areas.

Amplitude of tidal variation. During mouth closure there will be no tidal variation, indicating that intertidal areas will not be exposed during low tides or flooded during high tides.

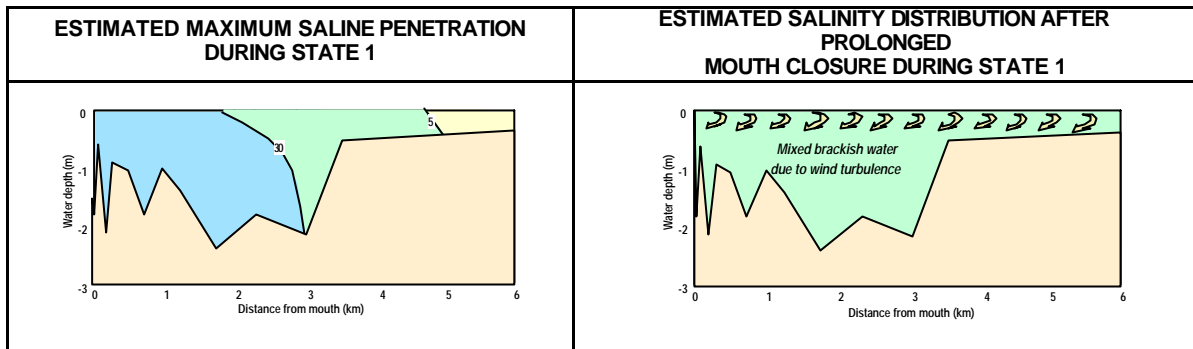
Retention times of water masses. Retention times for State 1 may range from a few weeks to months, particularly during the closed periods.

Total volume. For State 1 during its open phase volume will vary depending on the state of the tide. During the closed phase water levels can increase up to +2.5 m MSL correlating with a volume of approximately 4.6 x 10⁶ m³ (see below).



Salinity distributions in the estuary. Significant saline intrusion (about 6.0 km upstream) will normally occur before closure and at closure a horizontal salinity gradient will be present. The horizontal salinity gradient will gradually disappear after closure and vertical stratification will develop with higher salinity concentrations at the bottom and lower salinity concentrations at the surface. The vertical stratification in turn will be gradually eroded in the

shallower sections of the estuary through wind mixing. Overwash of the berm by waves will occasionally occur, causing a limited increase in salinities behind the berm. Otherwise, continuous low river flow and losses of more saline water through the berm, will result in a gradual freshening of the estuary. After a period of a few months almost the whole estuary could become fresh.



System variables. Measured data on system variables in the Thukela Estuary during the closed phase are not available. The data provided below, therefore are based on the available data sets on the open phase, system variable measurements of river inflow (where available) and expert opinion.

Variable	Estimated Concentration
Temperature (°C)	The flow range at which State 1 occurs (i.e. < 2m ³ /s) typically occurs during the spring/winter months when temperature throughout the estuary is expected to be in the low 20°C
pH	7 – 8
Suspended solids (mg/L)	During the closed phase it is expected that suspended solid concentrations in the estuary will largely reflect the concentrations in <u>river inflow</u> . Although suspended solid concentrations in river inflow are not being measured routinely, limited data seems indicate that concentrations during low flows, as those associated with State 1 (i.e. < 2 m ³ /s), are usually not very high. Concentrations throughout the estuary, therefore, are expected to remain below 20 mg/L .
Turbidity (NTU)	During the closed phase it is expected that turbidity levels in the estuary will largely reflect the concentrations in <u>river inflow</u> . Although turbidity levels in river inflow are not being measured routinely, limited data seems indicate that levels during low flows, as those associated with State 1 (i.e. < 2 m ³ /s), are usually not very high. Concentrations throughout the estuary, therefore, are expected to remain below 20 NTU .
Dissolved oxygen (mg/L)	The effect of mouth closure on dissolved oxygen concentrations in the estuary has not been documented. Being quite a shallow system is likely that wind mixing will be able to maintain well-oxygenated conditions during the closed state (above 6 mg/L), but this will have to be confirmed with field measurements. However, similar shallow systems along the Kwazulu-Natal coast have known to go anoxic during closure (Fiona MacKay, CRUZ, pers. comm.)

Inorganic Nutrients. Measured data on inorganic nutrients in the Thukela Estuary during the closed phase are not available. The data provided below, therefore are based on the available data sets on the open phase, nutrient measurements of river inflow and expert opinion.

Variable	Estimated Concentration
Nitrite/Nitrate-N (µg/L)	The system is marine-dominated and concentrations in the estuary will generally be low, i.e. < 50 µg/L (based on low concentrations measured in seawater, as well as median concentrations measured in river inflow). At times, concentrations in the upper reaches (lower salinities) may increase to as high as 1400 µg/l (based on maximum concentrations measured in river inflow), but probably only for short periods.
Total Ammonia-N (µg/L)	Generally be low, i.e. < 50 µg/L
Reactive Phosphate-P (µg/L)	The system is marine-dominated and concentrations in the estuary will generally be low, i.e. < 50 µg/L (based on low concentrations measured in seawater, as well as median concentrations measured in river inflow). At times, concentrations in the upper reaches (lower salinities) may increase to as high as 200 µg/l (based on maximum concentrations measured in river inflow), but probably only for short periods.
Reactive Silicate-Si (µg/L)	Initially, with the estuary is marine dominated, concentrations will tend to be lower, i.e. below 1 000 µg/L. As State 1 progresses and the system becomes more fresh, concentrations will increase to between 5 000 - 7 000 µg/L, as a result of higher concentrations in river inflow compared with that of seawater.

7.1.2 State 2: Mouth open, occasional mouth closures of a few days

Typical flow patterns. Flow rates between 2.0 and 5.0 m³/s (only observed in Present State and Worst Case Scenarios)

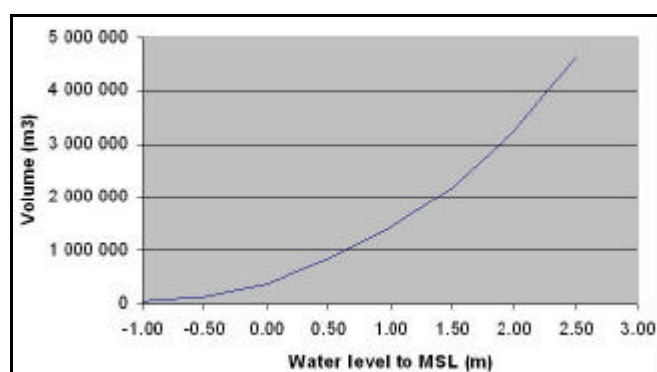
State of the mouth. Mouth normally open, but occasional mouth closures will occur at this flow range. Breaching will normally occur within a few days.

Flood plain inundation patterns. Not applicable.

Amplitude of tidal variation. Tidal variation could typically range between 0.3 m (neap tide) and 1.5 m (spring tide). During periods of mouth closure there will be no tidal variation.

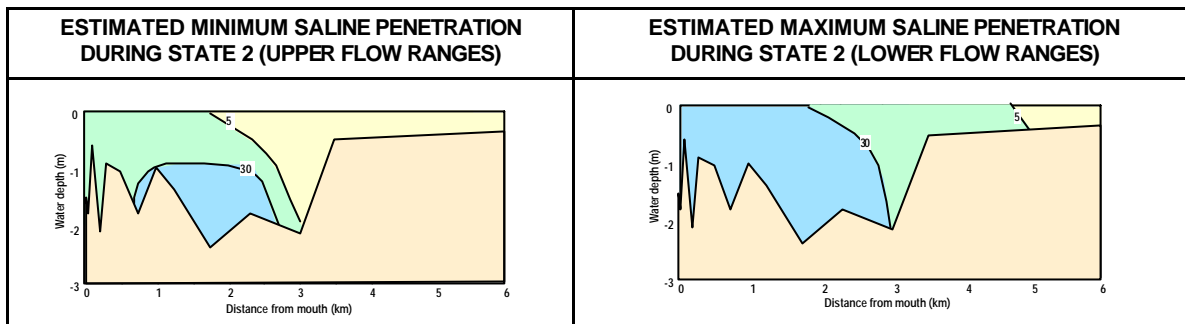
Retention times of water masses. Retention times for State 2 may range from a few days.

Total volume. For State 2 during its open phase volume will vary depending on the state of the tide. During the closed phase water levels can increase up to +2.5 m MSL correlating with a volume of approximately 4.6 x 10⁶ m³ (see below).



Salinity distributions patterns. As a result of strong tidal intrusion during the open phases, the system will largely be marine-dominated with a well-defined horizontal salinity gradient. Depending on the duration of State 2, saline water may penetrate up to about 6.0 km upstream. Although mouth closure is likely to occur, it will only be for short periods, i.e. a few days. It, therefore is unlikely that the system's salinity regime will be altered markedly through, for example wind mixing, as is the case with State 1, where mouth closure is likely

to occur for longer periods. Average salinity distributions along the length of the estuary during State 2 are shown below.



System variables:

Variable	Estimated Concentration
Temperature (°C)	The flow range at which State 2 occurs (i.e. 2 – 5 m ³ /s) typically occurs during the winter months when temperature throughout the estuary is expected to be in the low 20°C
pH	7 – 8
Suspended solids (mg/L)	As the system will be marine-dominated, suspended solid concentration is not expected to be high. At these flow ranges (i.e. 2 – 5 m ³ /s) indications are that river concentrations are also not be high. Concentrations throughout the estuary, therefore, are expected to remain below 20 mg/L .
Turbidity (NTU)	As the system will be marine-dominated, turbidity is not expected to be high. At these flow ranges (i.e. 2 – 5 m ³ /s) indications are that river concentrations are also not be high. Concentrations throughout the estuary, therefore, are expected to remain below 20 NTU .
Dissolved oxygen (mg/L)	As the estuary will only be closed for short periods, well-oxygenated conditions are likely to be maintained (above 6 mg/L) .

Inorganic Nutrients:

Variable	Estimated Concentration
Nitrite/Nitrate-N (µg/L)	The system is marine-dominated and concentrations in the estuary will generally be low, i.e. < 50 µg/L (based on low concentrations measured in seawater, as well as median concentrations measured in river inflow). At times, concentrations in the upper reaches (lower salinities) may increase to as high as 1400 µg/l (based on maximum concentrations measured in river inflow), but probably only for short periods.
Total Ammonia-N (µg/L)	Generally be low, i.e. < 50 µg/L
Reactive Phosphate-P (µg/L)	The system is marine-dominated and concentrations in the estuary will generally be low, i.e. < 50 µg/L (based on low concentrations measured in seawater, as well as median concentrations measured in river inflow). At times, concentrations in the upper reaches (lower salinities) may increase to as high as 200 µg/l (based on maximum concentrations measured in river inflow), but probably only for short periods.
Reactive Silicate-Si (µg/L)	As the system will be marine-dominated, concentrations in the estuary will be below 1000 µg/L . In the upper reaches (lower salinities) concentrations will increase to between 5000 - 7000 µg/L , as a result of higher concentrations in river inflow compared with that of seawater.

7.1.3 State 3: Mouth open, saline intrusion

Typical flow patterns. Flow rates between 5.0 and 30.0 m³/s and are at present common during autumn and winter (May to October).

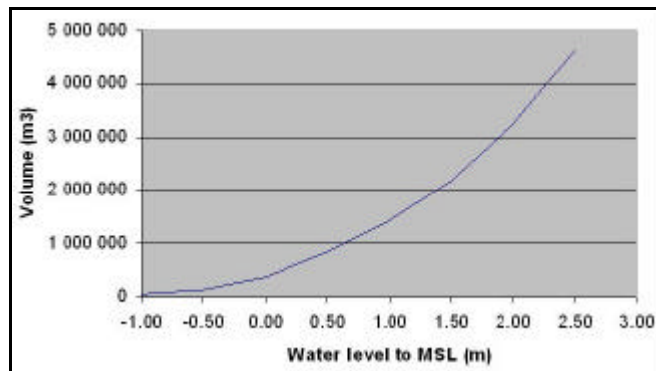
State of the mouth. The estuary mouth open, very rarely closed for up to 2 days.

Flood plain inundation patterns. Not applicable.

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

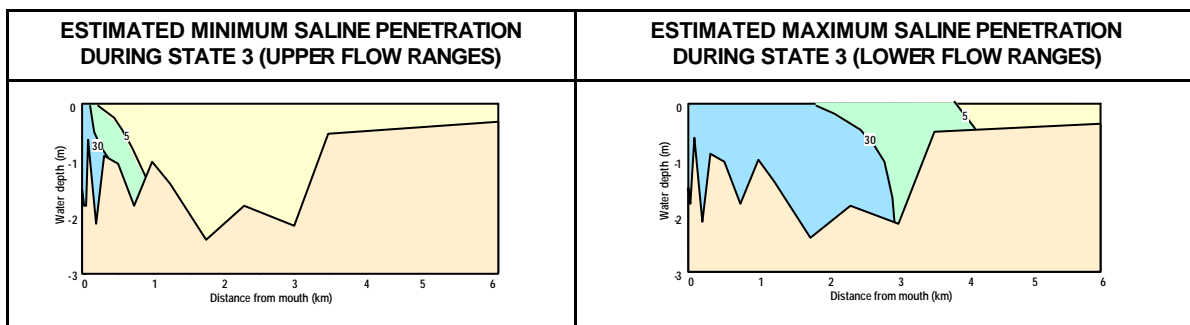
Retention times of water masses. In the upper flow ranges of State 3, retention time for a significant part of the water column will be less than a day. For the lower flow ranges retention time may increase to a few days.

Total volume. For State 3 during its open phase volume will vary depending on the state of the tide (see below).



Salinity distributions in the estuary. The extent of saline intrusion will depend on the river flow. Average salinity distributions along the length of the estuary during State 3 are shown below. Although there is still freshwater inflow, saline intrusion is significant and saline water remains in the estuary even during low tides. Depending on the duration of State 3, saline water may penetrate up to about 6.0 km upstream at river flows close to 5.0 m³/s.

The saline intrusion will not be as far upstream as during State 2, but otherwise similar conditions will exist in the estuary.



System variables:

Variable	Estimated Concentration
Temperature (°C)	The flow range at which State 2 occurs (i.e. 2 – 5 m ³ /s) typically occurs during the autumn and winter months when temperature throughout the estuary is expected to be in the low 20°C
pH	7 – 8
Suspended solids (mg/L)	The system is marine-dominated and therefore suspended solid concentration is not expected to be high. Although SS concentrations in river inflow is not expected to be high (below 20 mg/L) in the lower ranges of this flow band (i.e. ~5 m ³ /s), it is expected that SS concentration in river inflow towards the upper flow band (~30 m ³ /s) can increase dramatically. Concentration throughout the estuary, therefore, are expected to remain below 20 mg/L. , particularly in the more saline areas, but at higher river flows it is expected to be high , particularly in the fresher areas upstream.
Turbidity (NTU)	The system is marine-dominated and turbidity is not expected to be high. Although turbidity levels in river inflow is not expected to be high (below 20 NTU) in the lower ranges of this flow band (i.e. ~5 m ³ /s), it is expected that turbidity levels in river inflow towards the upper flow band (~30 m ³ /s) can increase dramatically. Concentration throughout the estuary, therefore, are expected to remain below 20 NTU , particularly in the more saline areas, but at higher river flows it is expected to be high , particularly in the fresher areas upstream.
Dissolved oxygen (mg/L)	Well-oxygenated conditions will be maintained (above 6 mg/L).

Inorganic Nutrients:

Variable	Estimated Concentration
Nitrite/Nitrate-N (µg/L)	The system is marine-dominated and concentrations in the estuary will generally be low, i.e. < 50 µg/L (based on low concentrations measured in seawater, as well as median concentrations measured in river inflow). At times, concentrations in the upper reaches (lower salinities) may increase to as high as 1400 µg/L (based on maximum concentrations measured in river inflow), but probably only for short periods.
Total Ammonia-N (µg/L)	Generally be low, i.e. < 50 µg/L
Reactive Phosphate-P (µg/L)	The system is marine-dominated and concentrations in the estuary will generally be low, i.e. < 50 µg/L (based on low concentrations measured in seawater, as well as median concentrations measured in river inflow). At times, concentrations in the upper reaches (lower salinities) may increase to as high as 200 µg/l (based on maximum concentrations measured in river inflow), but probably only for short periods.
Reactive Silicate-Si (µg/L)	The system will be marine-dominated with concentrations in the estuary below 1000 µg/L . In the upper reaches (lower salinities) concentrations will increase to between 5000 - 7000 µg/L , as a result of higher concentrations in river inflow compared with that of seawater.

7.1.4 State 4: Mouth open, river dominated

Typical flow patterns. Typical flow rates for State 4 are greater than 30.0 m³/s. These flows at present occur during the summer (November to April).

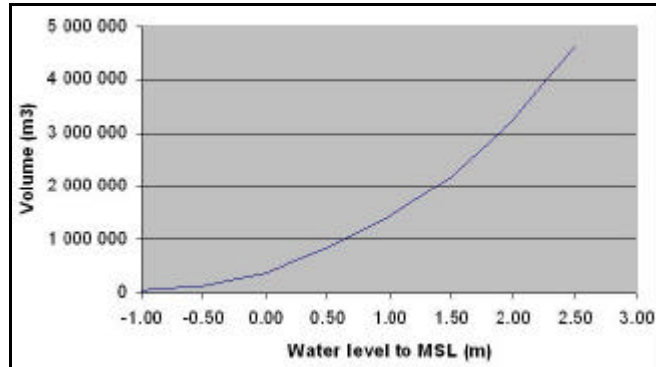
State of the mouth. The estuary mouth is wide open.

Flood plain inundation patterns. Extensive flood plain inundation during flooding events.

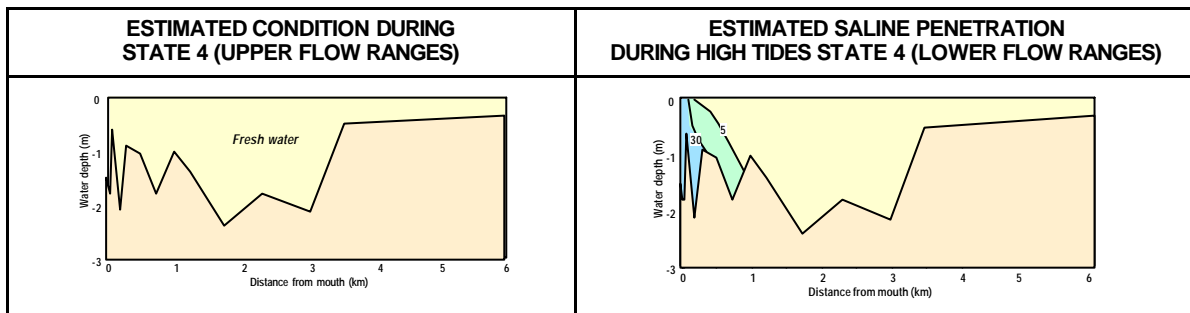
Amplitude of tidal variation (indicative of exposure of inter-tidal areas during low tide). Tidal variation could range between 0.3 m (neap tide) and 1.5 m (spring tide) depending on the flow, e.g. strong flows can reduce the amplitude of tidal variation.

Retention times of water masses. Due to high flow velocities retention time will be negligible.

Total volume. For State 4 during its open phase volume will vary depending on the state of the tide (see below).



Salinity distributions in the estuary. Average salinity distributions along the length of the estuary during State 4 are shown below. During State 4, the estuary will be freshwater dominated (low tides), but during high tides there might still be some saline intrusion into the lower 500 m of the system, even at relatively high flow (e.g. 50 m³/s).



System variables:

Variable	Estimated Concentration
Temperature (°C)	The flow range at which State 2 occurs (i.e. > 30 m ³ /s) typically occurs during summer temperature throughout the estuary is expected to be in the high 20°C
pH	7 – 8
Suspended solids (mg/L)	The system is fresh water dominated and at these high flows SS concentrations are expected to be high , showing a tendency to increase with river flow.
Turbidity (NTU)	The system is fresh water dominated and at these high flows turbidity levels are expected to be high , showing a tendency to increase with river flow.
Dissolved oxygen (mg/L)	Well-oxygenated conditions will be maintained (above 6 mg/L).

Inorganic Nutrients:

Variable	Estimated Concentration
Nitrite/Nitrate-N (µg/L)	The system is fresh water dominated and although it is expected for concentrations to be low, i.e. < 50 µg/L (based on median levels in river inflow) it may, at times, increase to as high as 1400 µg/L (based on maximum concentrations measured in river inflow), but probably only for short periods.
Total Ammonia-N (µg/L)	Generally be low, i.e. < 50 µg/L
Reactive	The system is fresh water dominated and although it is expected for

Variable	Estimated Concentration
Phosphate-P (µg/L)	concentrations to be low, i.e. < 50µg/L (based on median levels in river inflow) it may, at times, increase to as high as 200 µg/L (based on maximum concentrations measured in river inflow), but probably only for short periods. Concentrations measured in river inflow also showed a tendency to slightly increase with increase in flow.
Reactive Silicate-Si (µg/L)	The system is fresh water dominated with concentrations between 5000 - 7000 µg/L.

7.2 OCCURRENCE AND DURATION OF ABIOTIC STATES FOR DIFFERENT SCENARIOS

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 the each scenario to highlight the occurrences of the different States related to the different flow ranges. The median, average and 10%ile low flows for each month are summarized on the bottom of each table, as well as the occurrences of the four states for each month for the 70-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.

7.2.1 Reference condition

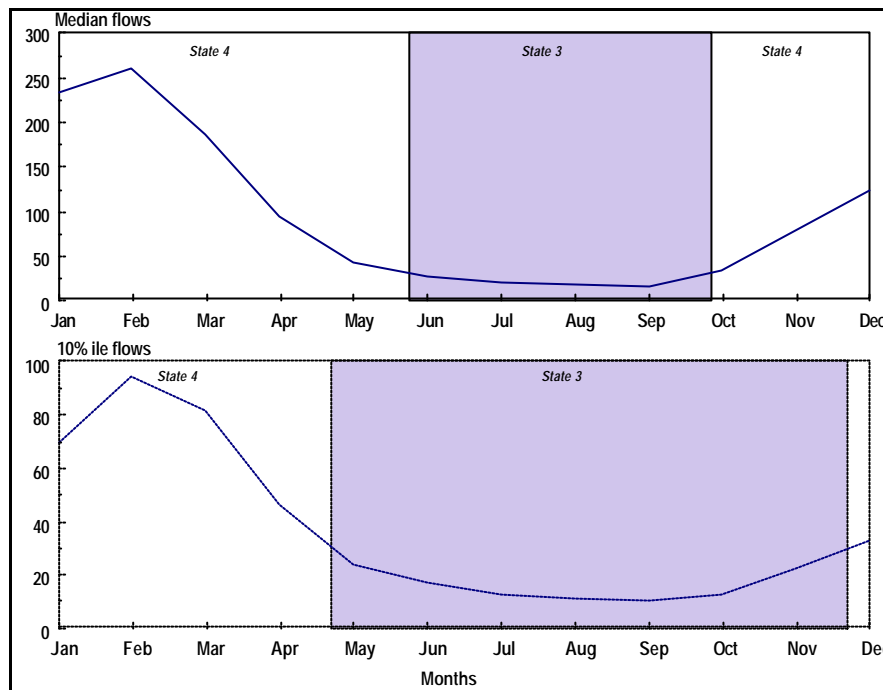
Monthly average simulated runoff data (in m³/s) for the Reference Condition is provided in Table 7.1.

Table 7.1 A summary of occurrences per month at intervals 10%, derived from the 70-year simulated data set, is provided below for the Reference Condition

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
90%ile	131.8	271.42	327.56	521.22	627.80	369.15	164.9	80.37	43.48	35.05	38.40	60.35
80%ile	91.35	206.37	262.41	385.30	474.65	305.85	141.4	59.95	37.31	29.02	29.10	35.16
70%ile	57.77	119.43	204.03	300.83	381.26	259.23	126.0	52.59	32.22	24.84	22.25	25.37
60%ile	43.34	90.28	173.14	263.73	279.65	217.66	109.5	46.35	29.36	22.17	18.24	20.64
50%ile	33.64	77.59	125.04	233.82	260.56	187.11	95.15	42.45	28.44	19.19	16.59	16.02
40%ile	24.94	66.11	105.90	186.82	229.60	156.49	78.77	37.13	25.88	18.17	14.80	14.50
30%ile	19.61	55.33	83.96	146.19	181.99	133.57	70.77	34.32	23.37	16.57	13.87	13.62
20%ile	16.69	46.14	66.29	117.36	145.89	114.90	56.72	29.43	19.25	14.84	12.72	11.94
10%ile	12.96	22.40	32.98	69.72	94.50	81.89	46.57	23.76	17.13	13.03	10.88	10.43
1%ile	8.04	13.57	19.40	40.71	46.43	39.68	28.43	19.64	14.31	10.81	9.25	8.13

To estimate the occurrence and duration of the different Abiotic States during the Reference Condition, median monthly flows and 10%ile flows, simulated for the 70-year period, were used to illustrate the situation for normal and drought periods, respectively (Figure 7.1).

Fig 7.1 Occurrence and duration of different Abiotic States during the Reference Condition, using median monthly flows and 10%ile flows (simulated for the 70-year period), to illustrate variations during normal and drought periods, respectively,



Occurrences of States

State 1, associated with prolonged mouth closure did not occur.

State 2, associated with occasional mouth closure of a few days and strong saline intrusion did not occur either.

State 3, associated with saline intrusion occurred for 279 months or 33 % of the time, mainly during the winter months from June till October. At median flows State 3 occurs for 4 months from June to September. At 10%ile low flows State 3 occurs for 7 months from May to November.

State 4, associated with a river dominated system occurred for 67 % of the time. At median flows State 4 occurs for 8 months from October to May. At 10%ile low flows State 4 occurs for 5 months from December till April, i.e. even in drought years under the Reference Condition, the system was river dominated for about 5 months of the year.

In summary, the mouth would have been almost permanently open and for most of the time the estuary would have been strongly dominated by river flow.

Highest monthly flows

The average highest monthly flows simulated for the 70-year period was 1132 m³/s in September 1987. The average of the ten highest monthly flows during the whole period was 812 m³/s. These flows are compared with the monthly flows in the same months for the other scenarios.

Table 7.2 Monthly runoff data (in m³/s) for Reference Condition, simulated over a 70-year period

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	AVE
1925	46.92	66.23	46.09	241.72	160.25	124.96	73.80	27.48	25.35	21.57	14.17	58.99	75.63
1926	114.32	126.30	128.75	146.41	261.57	266.29	122.29	34.32	19.89	16.63	17.92	15.36	105.84
1927	58.82	48.19	118.21	208.48	147.41	131.97	76.70	28.58	18.96	13.04	10.77	14.63	72.98
1928	28.23	28.86	89.19	151.08	148.55	313.53	181.65	46.05	40.58	51.83	38.90	113.70	102.68
1929	114.41	205.90	198.65	315.98	213.35	189.36	109.72	37.49	24.52	17.75	15.78	17.38	121.69
1930	19.73	20.14	70.02	356.45	274.74	105.18	56.78	29.47	17.15	16.41	14.53	10.00	82.55
1931	11.05	22.13	24.81	51.24	628.42	466.78	141.36	54.66	43.13	26.95	16.72	13.60	125.07
1932	13.10	46.49	98.98	70.20	94.69	82.10	45.21	23.24	14.76	14.64	13.93	9.69	43.92
1933	8.22	309.46	497.81	968.15	508.78	161.68	125.59	75.96	46.65	34.58	44.18	35.94	234.75
1934	35.70	208.25	563.00	272.95	169.73	147.05	81.78	40.29	31.62	22.96	15.18	11.35	133.32
1935	9.74	22.43	26.87	288.36	457.00	285.26	109.51	130.21	93.64	31.86	17.12	13.21	123.77
1936	21.04	380.37	228.16	314.24	446.88	180.54	51.15	24.65	16.34	11.86	9.15	8.40	141.06
1937	15.26	16.59	204.31	233.85	185.68	84.41	88.32	55.70	32.89	39.32	36.54	25.12	84.83
1938	87.28	81.93	287.09	275.46	803.19	454.55	113.04	47.81	34.69	28.84	26.39	26.79	188.92
1939	40.07	342.83	285.96	129.07	106.93	83.88	53.04	220.41	180.05	63.45	28.95	26.47	130.09
1940	26.95	65.69	323.03	305.35	314.14	189.35	131.24	69.36	30.73	18.13	13.33	11.18	124.87
1941	14.04	17.23	30.22	277.76	401.69	305.54	150.49	53.32	32.03	22.54	19.46	23.69	112.33
1942	41.73	381.93	514.67	520.84	256.45	158.74	593.40	323.88	86.50	106.23	439.14	234.85	304.86
1943	416.22	481.11	289.65	197.52	472.93	252.22	70.57	29.49	38.39	33.84	20.89	72.59	197.95
1944	97.39	65.93	33.11	33.88	80.39	419.54	230.99	44.09	25.08	16.73	12.00	9.03	89.01
1945	7.63	6.86	7.34	120.06	173.37	219.31	110.68	29.98	18.23	12.60	9.35	7.55	60.25
1946	37.07	137.45	85.23	43.78	229.74	229.55	104.05	37.65	30.73	26.92	18.22	14.75	82.93
1947	30.40	249.97	275.85	313.52	212.76	247.29	141.59	50.96	29.33	18.97	13.48	11.87	133.00
1948	21.48	32.01	44.01	233.79	266.76	187.18	127.02	58.69	28.67	17.37	12.48	12.32	86.81
1949	25.65	99.75	203.91	145.68	103.70	281.77	164.84	57.04	36.62	22.97	22.01	20.15	98.67
1950	19.32	28.63	189.72	142.26	96.31	85.31	57.79	29.20	19.28	13.88	40.56	43.75	63.83
1951	50.60	33.27	54.29	495.64	413.61	147.21	72.89	38.24	25.92	25.31	23.27	16.01	116.35
1952	17.99	79.81	153.02	160.89	627.73	301.51	71.46	36.33	22.83	15.63	18.29	18.30	126.98
1953	17.98	66.39	97.57	85.14	378.55	228.74	79.04	47.07	37.21	23.11	14.86	21.36	91.42
1954	130.97	352.19	195.36	536.07	723.55	290.12	91.78	44.53	28.48	19.26	13.44	10.48	203.02
1955	20.68	51.24	108.71	64.14	329.42	405.78	162.96	41.57	28.33	18.81	13.45	13.96	104.92
1956	22.92	162.44	757.92	567.44	234.73	187.04	130.40	60.39	32.29	47.14	51.28	535.34	232.44
1957	578.78	229.80	81.99	298.90	261.29	119.77	143.08	79.74	32.17	18.19	12.74	13.74	155.85
1958	20.00	70.30	170.80	162.14	258.03	127.88	46.73	99.36	61.88	29.74	20.33	16.64	90.32
1959	46.11	128.78	121.34	78.90	139.82	167.44	119.61	59.84	29.39	17.42	13.72	14.32	78.06
1960	25.02	90.15	468.55	265.69	88.32	136.32	136.88	70.45	36.12	22.38	14.73	15.97	114.21
1961	19.08	55.63	83.29	262.72	271.23	134.26	77.82	42.78	23.61	15.35	14.00	14.28	84.50
1962	14.54	90.02	176.64	389.74	197.25	153.11	95.93	37.06	28.89	169.10	110.80	24.57	123.97
1963	24.84	102.05	69.29	250.01	158.82	78.20	56.47	29.67	22.59	18.34	14.52	25.95	70.90
1964	271.97	217.48	113.95	174.52	128.98	42.08	26.38	19.19	32.20	32.88	34.01	38.24	94.32
1965	32.29	50.86	42.93	360.15	259.83	60.33	29.35	23.34	18.78	13.03	11.85	13.35	76.34
1966	16.13	54.63	165.14	597.50	627.09	368.97	225.20	86.01	40.19	26.58	19.30	13.75	186.71
1967	16.09	54.52	72.04	58.65	41.82	52.73	41.11	20.34	13.31	9.74	11.87	13.63	33.82
1968	11.70	27.07	83.96	88.41	101.32	342.64	211.25	66.01	40.00	24.80	17.14	16.30	85.88
1969	77.27	63.23	112.78	118.66	149.91	80.01	30.12	19.84	16.58	12.88	27.60	49.78	63.22
1970	91.07	75.18	38.98	261.13	197.07	79.92	63.38	106.38	69.96	30.13	29.72	24.51	88.95
1971	45.22	57.86	140.64	208.33	286.20	361.16	165.71	46.00	32.87	23.11	16.70	11.96	116.31
1972	16.84	53.81	45.44	45.91	370.75	203.90	104.17	54.60	26.45	15.32	31.89	77.52	87.22
1973	61.52	100.53	116.35	384.19	481.53	267.97	143.75	63.01	37.72	27.79	20.86	14.78	143.33
1974	11.02	99.49	268.13	394.19	671.80	307.06	96.11	47.48	29.24	18.62	13.61	98.88	171.30
1975	75.26	116.49	303.92	524.63	483.65	673.67	314.18	91.82	57.46	33.80	22.81	19.33	226.42
1976	75.94	90.47	117.53	255.79	226.86	137.65	94.36	42.41	21.88	14.41	11.29	38.54	93.93
1977	98.70	86.66	95.06	535.35	387.58	177.36	112.26	52.27	28.41	18.50	16.79	26.28	136.27
1978	169.05	128.64	227.14	150.61	233.31	130.18	52.06	34.41	25.83	21.70	44.31	48.85	105.51
1979	42.10	56.16	71.17	192.07	253.49	146.00	54.82	23.81	16.33	11.75	9.30	34.57	75.96
1980	35.00	67.28	216.81	401.46	729.17	256.21	56.94	35.25	28.47	22.02	24.66	34.96	159.02
1981	28.44	78.34	83.95	112.16	77.37	91.28	70.80	29.28	17.70	13.02	10.29	12.45	52.09
1982	92.44	72.29	31.86	65.36	48.50	34.35	32.15	20.73	16.90	15.43	16.47	14.06	38.38
1983	37.49	267.20	368.74	733.67	438.26	216.56	127.70	46.81	27.00	24.94	31.52	29.15	195.75
1984	49.06	44.72	30.78	203.79	877.73	370.74	54.78	25.65	17.94	13.42	10.36	8.91	142.32
1985	130.59	190.25	185.00	389.94	275.28	164.32	103.76	45.45	26.50	19.13	16.04	14.88	130.09
1986	57.33	76.84	217.06	226.34	371.03	348.59	132.06	35.48	24.75	19.46	38.34	1132.36	223.30
1987	613.39	220.00	152.50	178.94	495.16	412.86	149.70	51.72	40.32	39.98	30.59	24.72	200.82
1988	52.62	83.00	260.98	265.25	725.83	319.84	68.20	35.50	27.98	21.33	15.29	11.41	157.27
1989	14.55	369.40	368.39	139.69	92.84	117.34	84.96	42.48	23.60	14.89	16.11	16.04	108.36
1990	16.84	17.05	101.69	487.58	588.03	252.63	82.80	31.01	22.39	17.42	12.62	12.25	136.86
1991	139.31	113.68	217.39	142.62	229.41	131.04	44.44	23.32	15.70	11.29	9.98	9.01	90.60
1992	8.98	60.83	181.53	107.49	265.42	196.43	78.36	30.96	19.17	13.25	10.90	11.79	82.09
1993	297.54	209.93	135.78	239.16	296.83	197.39	97.64	37.17	21.57	15.98	27.05	21.67	133.14
1994	17.73	16.80	27.31	108.91	85.47	94.00	70.69	34.33	29.14	21.01	14.35	10.72	44.20
Median	33.64	77.59	125.04	233.82	260.56	187.11	95.15	42.45	28.44	19.19	16.59	16.02	94.63
Average	72.21	117.51	171.40	258.97	311.36	210.94	108.81	52.42	32.74	25.42	27.15	50.11	119.92
10%ile	12.96	22.40	32.98	69.72	94.50	81.89	46.57	23.76	17.13	13.03	10.88	10.43	63.77

1: Closed < 2.0 2: Open (closed for) 2.0-5.0 3: Open (Saline) 5.0-30 4: Open (Riverine) > 30.0

< 2.0	0	0	0	0	0	0	0	0	0	0	0	0	0.00%
2.0-5.0	0	0	0	0	0	0	0	0	0	0	0	0	0.00%
5.0-30	33	11	4	0	0	0	2	18	43	57	57	54	33.21%
> 30.0	37	59	66	70	70	70	68	52	27	13	13	16	66.79%

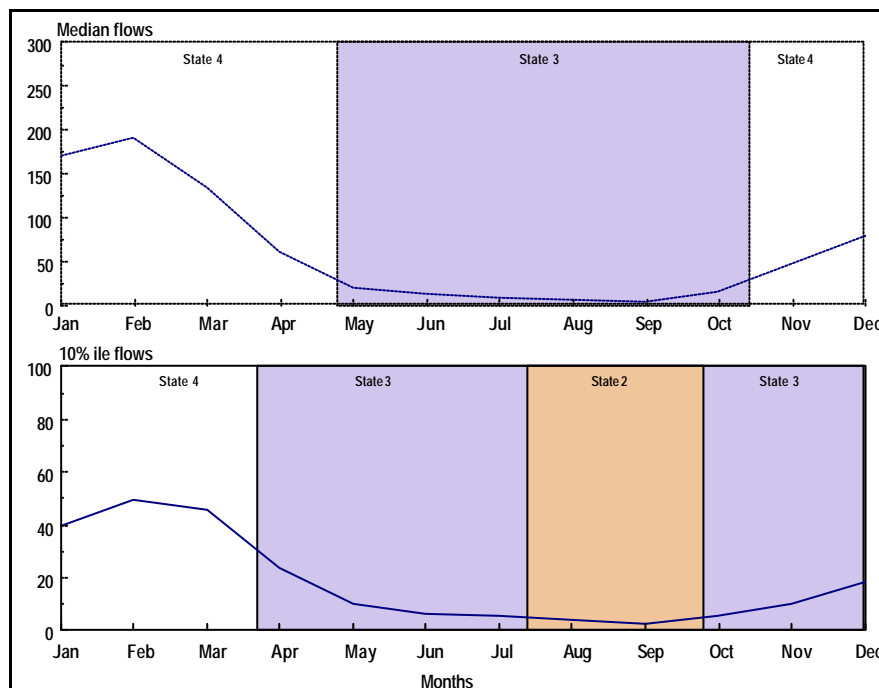
7.2.2 Present state

Monthly average simulated runoff data (in m³/s) for the Present State is provided in Table 7.2. A summary of occurrences per month at intervals 10%, derived from the 70-year simulated data set, is provided below for the Present State:

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
90%ile	93.31	206.62	275.84	429.28	501.41	297.52	115.48	51.72	24.85	20.19	21.87	38.07
80%ile	55.92	143.69	186.38	278.42	412.98	246.48	101.13	35.98	20.55	15.13	17.20	18.25
70%ile	32.17	77.99	152.97	234.30	295.88	205.85	91.77	30.56	17.78	12.31	9.68	12.36
60%ile	21.62	54.62	112.74	191.99	220.23	158.29	73.01	25.70	15.82	10.78	8.22	9.22
50%ile	16.20	48.84	79.81	170.32	192.02	136.09	61.94	22.31	14.09	8.85	7.19	6.17
40%ile	13.01	40.09	61.03	124.83	158.46	115.31	46.62	18.78	12.02	7.73	6.50	5.45
30%ile	10.08	33.32	45.34	94.48	117.42	88.51	39.12	14.62	10.43	7.00	5.86	5.07
20%ile	7.43	18.46	32.51	66.40	85.55	75.88	29.76	13.14	8.77	6.36	4.49	3.55
10%ile	5.36	10.09	18.44	39.58	49.76	45.59	23.56	9.55	6.60	5.32	3.97	2.69
1%ile	2.07	3.54	6.92	18.84	23.01	18.25	11.24	8.03	5.57	4.25	3.25	1.69

To estimate the occurrence and duration of the different Abiotic States during the Present State, median monthly flows and 10%ile flows, simulated for the 70-year period, were used to illustrate the situation for normal and drought periods, respectively (Figure 7.2).

Fig 7.2 Occurrence and duration of different Abiotic States during the Present State, using median monthly flows and 10%ile flows (simulated for the 70-year period), to illustrate variations during normal and drought periods, respectively



Occurrences of States

State 1, associated with prolonged mouth closure, only occurred for 0.6 % of the time and are therefore negligible. At median flows and at 10 %ile low flows State 1 does not occur at this scenario.

State 2, associated with occasional mouth closure for up a few days and strong saline intrusion, occurs for 6.2 % of the time, which is a significant increase compared to Reference Condition Scenario. At median flows State 2 does not occur. At 10%ile low flows State 2 occurs for 2 months during August and September.

State 3, associated with saline intrusion, occurs for 42.1 % of the time and has increased from 33.2 % compared to Reference Condition Scenario. At median flows, State 3 occurs for 6 months from May to October. At 10%ile low flows State 3 occurs for 7 months from April to July and from October to December.

State 4, associated with a river dominated system and no significant saline intrusion occurs 51.1 % of the time, compared to 66.8 % of the Reference Condition Scenario. At median flows, State 4 occurs for 6 months from November to April. At 10%ile low flows, State 4 occurs for 3 months from January to March.

Highest monthly flows

The average monthly flow in September 1987, which had the highest monthly flow at the Reference Condition, was 1010 m³/s, which is a reduction to 89 % compared to Reference Condition. The average of the ten monthly flows during those months, which were the highest the Reference Condition for the whole period was 715 m³/s, which is a reduction to 88 % compared to the Reference Condition Scenario.

Table 7.3 Monthly runoff data (in m³/s) for Present State, simulated over a 70-year period

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	AVE
1925	29.48	40.24	23.22	177.80	107.49	92.26	41.10	13.82	15.90	11.41	6.05	37.39	49.68
1926	85.62	87.05	85.46	81.87	171.61	203.13	82.53	15.53	7.32	8.15	9.52	5.48	70.27
1927	23.41	17.41	57.47	147.95	97.96	79.49	39.71	12.97	7.19	4.79	4.63	8.38	41.78
1928	14.18	11.50	41.43	79.91	81.10	235.63	131.15	23.46	24.10	33.20	18.45	72.86	63.91
1929	76.11	155.41	152.08	247.41	158.12	137.99	73.01	17.57	10.15	6.86	6.51	8.81	87.50
1930	9.50	10.27	42.87	236.24	205.01	66.27	29.56	11.55	6.50	8.35	4.40	1.73	52.69
1931	4.59	6.99	12.07	21.99	499.89	374.51	93.43	37.32	27.32	14.34	6.77	5.10	92.02
1932	4.24	20.48	65.78	35.93	52.91	48.91	24.16	9.56	6.31	8.75	5.92	2.72	23.80
1933	2.99	207.95	381.16	826.00	460.76	130.41	95.63	51.30	24.37	18.53	24.82	14.03	186.50
1934	14.85	140.76	482.34	226.23	139.17	115.98	50.92	22.12	20.07	12.04	6.50	3.09	102.84
1935	2.62	4.31	8.76	231.20	371.72	219.46	73.01	112.36	67.40	17.67	6.94	5.01	93.37
1936	10.32	282.32	179.87	272.44	407.71	141.48	25.27	8.71	5.88	4.40	3.32	2.90	112.05
1937	5.45	7.08	145.91	159.21	129.00	57.88	55.40	30.30	20.67	26.63	20.13	10.33	55.66
1938	48.18	49.40	220.22	203.83	706.74	416.88	74.37	26.47	15.84	16.11	12.20	12.65	150.24
1939	16.57	254.36	241.86	92.07	64.48	49.31	30.40	200.06	160.99	44.76	14.34	14.01	98.60
1940	12.67	42.69	273.68	242.40	260.99	149.81	115.22	44.60	15.28	7.90	4.49	3.58	97.78
1941	5.47	6.78	16.16	204.88	330.92	250.59	111.65	31.17	16.31	10.44	9.28	11.61	83.77
1942	20.43	281.77	448.82	470.77	208.74	113.66	545.85	311.06	59.11	95.25	413.26	194.60	263.61
1943	410.36	470.08	275.70	179.36	466.08	230.34	37.74	11.29	19.70	15.90	8.10	44.27	180.74
1944	53.71	34.95	12.31	13.36	29.92	334.54	170.66	22.50	10.54	6.44	3.82	1.58	57.86
1945	1.66	1.82	2.83	60.32	83.13	138.47	62.37	12.57	6.61	4.55	3.11	1.96	31.62
1946	20.09	81.38	46.87	21.31	151.29	158.01	65.58	18.55	19.76	14.98	8.39	6.22	51.03
1947	11.96	190.16	203.89	232.19	155.23	163.38	96.70	26.58	11.61	6.34	3.83	3.44	92.11
1948	12.22	18.50	24.48	167.63	209.05	134.19	91.06	35.70	14.74	7.97	4.75	4.52	60.40
1949	15.83	64.64	142.17	86.85	40.55	183.36	109.23	34.02	16.56	8.99	9.37	5.37	59.74
1950	7.65	14.98	115.44	98.78	54.41	48.54	33.39	13.25	8.57	5.77	32.11	29.21	38.51
1951	29.01	14.83	34.03	395.70	295.64	88.21	41.48	18.93	11.43	15.16	10.62	4.73	79.98
1952	5.73	46.04	93.69	90.66	493.42	237.28	43.10	15.69	9.21	5.76	10.06	7.19	88.15
1953	6.52	39.86	55.05	42.45	286.63	170.10	44.60	31.37	21.65	11.42	5.93	12.23	60.65
1954	109.35	289.15	146.69	445.58	633.70	271.72	59.84	23.77	12.07	6.72	3.98	2.29	167.07
1955	12.90	34.42	59.43	26.62	231.47	318.81	110.34	20.02	11.94	7.29	4.71	6.06	70.33
1956	13.08	112.43	660.79	511.60	185.46	158.71	97.68	36.14	16.38	33.15	32.41	478.16	194.66
1957	562.17	206.47	66.51	286.87	226.08	85.00	117.77	50.67	15.80	6.97	4.04	5.39	136.14
1958	10.56	35.01	93.07	112.36	202.82	89.51	25.17	67.75	37.08	15.12	8.59	5.59	58.55
1959	25.00	72.27	74.15	39.98	86.45	114.31	83.95	35.94	14.23	7.31	5.70	6.12	47.12
1960	13.89	59.22	380.01	205.51	58.70	85.78	98.94	45.88	20.52	10.79	6.01	8.14	82.78
1961	9.71	29.78	39.75	184.10	192.04	90.60	53.76	24.56	9.63	5.60	6.69	5.68	54.32
1962	7.48	52.88	132.14	270.61	120.78	116.37	67.57	19.26	17.51	151.26	93.64	12.02	88.46
1963	14.30	61.66	38.00	180.91	109.58	40.17	29.80	13.54	12.96	8.52	6.23	11.69	43.95
1964	189.54	164.37	66.24	117.27	86.15	16.51	10.11	7.20	20.74	18.54	20.51	19.46	61.39
1965	17.65	30.31	22.85	259.85	187.11	25.21	12.89	11.82	9.57	6.36	6.53	6.21	49.70
1966	8.55	29.26	86.61	476.63	515.12	335.16	215.04	55.51	19.88	11.19	6.40	3.07	146.87
1967	7.75	34.36	44.84	35.35	21.34	30.84	22.10	9.47	5.99	4.60	7.13	6.71	19.21
1968	5.68	12.33	45.55	45.48	46.29	248.28	158.61	45.33	22.54	12.09	6.55	6.04	54.56
1969	47.58	35.88	59.76	67.05	97.93	44.27	11.74	8.91	8.83	7.01	17.01	29.97	36.33
1970	66.20	53.28	22.17	157.60	98.20	34.62	32.82	86.12	52.90	19.67	17.96	11.92	54.46
1971	31.32	34.77	98.01	141.63	192.00	246.03	108.59	25.63	16.60	10.78	7.24	3.41	76.33
1972	7.06	30.92	26.44	25.90	271.78	155.93	81.81	33.72	14.06	7.47	21.20	56.38	61.05
1973	39.74	65.47	67.00	276.30	364.12	228.26	113.51	34.76	20.47	12.58	7.43	3.09	102.73
1974	2.25	47.46	189.85	317.17	616.11	270.59	65.14	22.86	12.44	6.41	4.15	74.23	135.72
1975	49.46	77.78	223.62	465.22	468.70	666.12	295.51	80.91	30.64	14.16	7.48	6.14	198.81
1976	45.78	51.99	71.89	233.47	200.28	108.16	64.06	21.88	9.09	5.46	4.19	28.90	70.43
1977	64.78	56.64	49.12	427.47	341.22	162.74	99.27	29.35	12.75	7.28	7.77	14.38	106.06
1978	120.82	94.37	160.80	102.57	178.14	84.36	26.33	19.87	11.73	12.19	25.75	26.95	71.99
1979	19.14	18.28	25.67	112.68	148.56	78.28	20.30	8.41	5.41	4.19	3.47	23.30	38.97
1980	18.41	43.82	157.37	320.07	609.82	212.21	23.72	13.18	14.20	8.96	12.51	17.94	121.02
1981	14.13	48.27	41.73	63.78	40.15	62.56	43.26	13.92	8.21	6.19	3.91	3.84	29.16
1982	71.52	49.98	18.69	41.98	23.76	19.03	18.24	12.02	9.57	9.40	8.85	5.16	24.02
1983	18.03	186.05	277.09	635.71	384.91	129.92	75.91	24.79	14.12	14.90	21.54	14.85	149.82
1984	29.99	23.99	15.48	134.66	726.44	295.15	24.44	8.77	6.43	4.98	3.32	2.47	106.34
1985	91.52	137.63	124.09	316.92	221.24	128.09	72.55	25.82	15.81	9.43	7.66	4.40	96.26
1986	33.16	40.67	158.07	176.59	296.44	293.42	95.51	17.89	13.74	10.57	25.99	1010.90	181.08
1987	539.61	161.83	110.93	129.86	434.04	383.27	112.87	26.63	24.58	24.91	13.65	9.83	164.34
1988	31.75	52.11	185.51	183.57	679.96	281.77	32.13	13.99	11.50	7.98	4.55	2.24	123.92
1989	7.24	301.06	311.43	95.52	50.14	82.90	60.75	26.39	12.70	7.17	8.93	5.20	80.79
1990	8.77	8.54	61.88	381.26	490.35	189.54	46.29	13.45	10.95	7.45	4.76	5.18	102.37
1991	88.46	78.49	172.52	109.48	181.40	88.65	21.27	8.72	5.65	4.28	4.22	2.18	63.78
1992	3.22	51.09	155.04	77.83	158.69	130.84	46.84	14.88	7.96	5.36	4.48	5.13	55.11
1993	229.31	165.37	90.73	173.01	219.56	142.75	61.52	16.20	7.62	6.95	18.53	12.68	95.35
1994	10.24	7.37	14.03	52.80	37.81	45.73	36.06	19.41	18.42	12.99	7.54	3.85	22.19
Median	16.20	48.84	79.81	170.32	192.02	136.09	61.94	22.31	14.09	8.85	7.19	6.17	63.65
Average	52.26	82.16	124.73	196.65	245.06	162.32	76.32	33.08	18.35	14.39	16.73	35.74	88.15
10%ile	5.36	10.09	18.44	39.58	49.76	45.59	23.56	9.55	6.60	5.32	3.97	2.69	38.29

1: Closed < 2.0 2: Open (closed for) 2.0-5.0 3: Open (Saline) 5.0-30 4: Open (Riverine) > 30.0

< 2.0	1	1	0	0	0	0	0	0	0	0	0	3	0.60%
2.0-5.0	6	1	0	0	0	0	0	0	0	7	20	17	6.19%
5.0-30	40	17	13	5	3	3	15	48	64	58	46	42	42.14%
> 30.0	23	51	56	65	67	67	55	22	6	5	4	8	51.07%

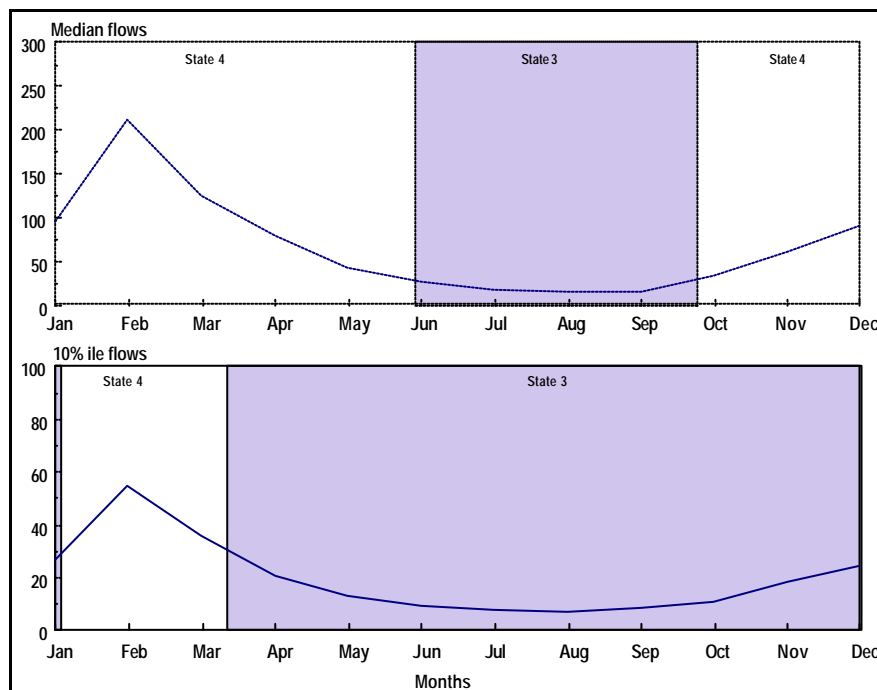
7.2.3 River scenario: Category A

Monthly average simulated runoff data (in m³/s) for the Scenario: River Category A is provided in Table 7.3. A summary of occurrences per month at intervals 10%, derived from the 70-year simulated data set, is provided below for the Scenario: River Category A:

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
90%ile	48.18	70.09	139.58	277.28	466.55	249.27	98.23	56.57	39.72	30.55	26.88	36.48
80%ile	47.81	69.62	122.41	123.56	352.85	175.17	92.21	56.13	37.31	29.02	26.64	35.16
70%ile	46.86	68.48	112.79	111.13	258.83	134.71	90.34	52.59	32.22	24.84	22.25	25.37
60%ile	42.66	66.77	104.74	102.23	228.82	132.42	86.80	46.35	29.36	22.17	18.24	20.64
50%ile	33.64	62.94	91.48	96.46	211.82	124.51	79.66	42.45	28.44	19.19	16.54	16.02
40%ile	24.94	57.11	77.02	86.09	170.87	110.53	68.77	37.13	25.88	18.17	14.80	14.43
30%ile	19.61	47.06	64.71	69.88	139.49	89.78	53.56	33.00	22.90	16.57	13.87	13.62
20%ile	16.69	33.84	44.62	48.03	100.14	67.98	35.55	22.15	15.87	12.37	10.99	11.94
10%ile	10.75	18.91	24.69	27.06	55.16	35.86	20.33	13.01	9.50	7.60	6.80	8.61
1%ile	7.20	8.67	10.33	13.94	26.31	17.69	13.27	8.79	6.60	5.35	4.85	5.94

To estimate the occurrence and duration of the different Abiotic States during the Scenario: River Category A, median monthly flows and 10%ile flows, simulated for the 70-year period, were used to illustrate the situation for normal and drought periods, respectively (Figure 7.3).

Fig 7.3 Occurrence and duration of different Abiotic States during the Scenario: River Category A, using median monthly flows and 10%ile flows (simulated for the 70-year period), to illustrate variations during normal and drought periods, respectively



Occurrences of States

State 1, associated with prolonged mouth closure, will not occur.

State 2, associated with occasional mouth closure for up to a few days and strong saline intrusion, occurs only for 0.36 of the time, which is negligible. Therefore under this scenario

mouth closure is unlikely to occur.

State 3, associated with saline intrusion, occurs for 38 % of the time and has increased from 33 % at the Reference Condition. At median flows, State 3 occurs for 4 months from June to September. At 10%ile low flows, State 3 occurs for 10 months from April to January.

State 4, associated with a river dominated system and no significant saline intrusion, occurs 61.7 % of the time, compared to 66.8 % of the Reference Condition. At median flows, State 4 occurs for 8 months from October to May. At 10%ile low flows, State 4 occurs for 2 months from February to March.

Highest monthly flows

The average monthly flow during September 1987, which had the highest monthly flow at the Reference Condition, is 929 m³/s, which is a reduction to 82 % compared to the Reference Condition. The average of the ten monthly flows during those months, which were highest at the Reference Condition, has been reduced to 646 m³/s, which is a reduction to 79 % compared to the Reference Condition.

Table 7.4 Monthly runoff data (in m³/s) for River Scenario: Category A, simulated over a 70-year period

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	AVE
1925	45.57	57.21	36.13	95.49	123.01	75.02	61.88	17.24	25.35	21.57	14.17	36.47	50.76
1926	48.07	68.69	94.48	67.52	211.88	132.01	89.94	32.99	16.83	16.63	17.92	15.36	67.69
1927	46.94	36.55	85.95	86.10	105.13	86.71	65.90	20.02	14.89	7.67	6.64	14.50	48.08
1928	27.96	26.38	68.23	69.95	101.21	133.93	92.95	46.05	39.67	30.61	26.88	36.53	58.36
1929	48.07	69.62	111.18	109.31	158.59	122.10	86.86	37.49	24.52	17.75	15.78	17.38	68.22
1930	19.73	16.26	48.53	110.74	220.88	59.45	35.69	22.25	9.57	16.41	14.53	8.05	48.51
1931	9.30	18.58	11.67	18.37	300.64	140.36	98.01	54.66	39.72	26.95	16.72	13.60	62.38
1932	10.86	33.99	73.93	27.29	55.41	35.97	19.87	12.51	6.60	12.00	13.93	7.65	25.84
1933	7.20	70.09	134.27	925.98	462.89	119.60	90.30	56.52	39.79	30.54	26.88	35.94	166.67
1934	35.70	69.63	412.86	230.87	130.19	102.12	70.94	40.29	31.62	22.96	15.18	11.34	97.81
1935	8.30	18.94	15.29	105.12	268.83	181.06	86.76	70.78	51.67	30.47	17.12	13.21	72.30
1936	21.04	172.71	187.32	273.90	400.32	138.82	25.26	14.01	7.52	6.03	4.85	5.94	104.81
1937	15.26	9.48	112.88	93.67	142.29	46.31	75.21	55.70	32.89	30.61	26.85	25.12	55.52
1938	47.72	64.36	126.94	103.94	639.64	411.81	88.96	47.81	34.69	28.84	26.39	26.79	137.32
1939	40.07	70.09	207.45	87.97	78.85	43.96	27.34	147.59	135.39	30.61	26.63	26.47	76.87
1940	26.95	56.77	129.27	258.00	269.39	148.70	91.48	56.45	30.73	18.13	13.13	10.84	92.48
1941	13.19	12.84	20.48	104.15	261.50	184.71	107.49	53.32	32.03	22.54	19.46	23.69	71.28
1942	41.73	88.21	474.97	479.71	211.75	118.89	552.44	283.04	44.87	65.01	398.50	192.44	245.96
1943	374.13	438.41	248.71	156.94	427.69	209.06	53.33	22.45	38.39	30.53	20.89	36.53	171.42
1944	47.89	56.97	24.88	13.94	36.16	134.71	170.49	44.09	25.08	16.73	9.10	6.79	48.90
1945	7.20	6.86	7.34	49.16	132.95	128.40	87.47	27.65	12.47	7.03	4.89	5.94	39.78
1946	37.07	69.24	65.57	13.94	169.48	129.17	84.11	37.65	30.73	26.92	18.22	14.74	58.07
1947	30.29	69.96	124.02	108.71	157.62	130.50	92.18	50.96	29.33	18.97	13.48	11.87	69.82
1948	21.48	27.74	35.25	93.65	215.43	121.65	90.45	56.02	28.67	17.37	10.36	12.32	60.86
1949	25.65	67.82	112.76	66.55	78.02	132.88	92.93	55.87	36.62	22.97	22.01	20.15	61.19
1950	19.32	26.12	108.50	62.01	59.48	50.32	37.07	21.57	15.94	10.64	26.88	36.41	39.52
1951	46.29	28.28	39.57	116.70	257.69	102.23	59.36	38.24	25.92	25.31	23.27	16.01	64.91
1952	17.99	63.75	99.34	75.07	308.94	133.64	55.43	36.33	21.73	15.63	18.29	18.30	72.04
1953	17.98	57.29	73.30	35.88	256.39	129.11	69.15	47.07	37.21	23.11	14.86	21.36	65.23
1954	48.18	70.09	110.19	356.95	678.20	247.44	77.46	44.53	28.48	19.26	13.44	8.67	141.91
1955	20.68	41.16	78.27	24.44	238.57	134.71	92.90	41.57	28.33	18.81	13.45	13.96	62.24
1956	22.92	69.38	508.07	526.25	188.83	145.23	91.28	56.17	32.29	30.61	26.88	366.55	172.04
1957	535.81	187.24	63.25	236.00	216.03	78.80	100.17	56.56	32.17	18.19	11.05	13.74	129.09
1958	20.00	59.26	102.91	75.31	206.87	78.86	20.39	56.63	39.79	29.74	20.33	16.64	60.56
1959	45.34	68.81	88.48	32.29	95.85	113.46	89.66	56.12	29.39	17.42	13.72	14.32	55.41
1960	25.02	66.73	132.21	101.08	46.83	92.91	91.86	56.46	36.12	22.38	14.73	15.97	58.52
1961	19.08	47.50	64.22	100.37	218.48	91.09	67.46	42.78	23.42	14.91	14.00	14.28	59.80
1962	14.42	66.69	104.08	111.92	149.11	106.13	80.17	37.06	28.89	30.61	26.88	24.57	65.04
1963	24.84	67.95	45.88	97.42	121.87	33.79	35.00	24.42	21.21	18.34	14.52	25.95	44.27
1964	48.23	69.85	82.50	77.75	91.09	17.69	13.27	8.79	32.20	30.52	26.83	36.29	44.58
1965	32.29	40.58	34.22	110.88	209.42	23.76	13.27	12.61	14.29	7.60	8.72	13.35	43.41
1966	16.13	46.06	101.77	117.35	434.51	328.11	184.13	56.63	39.66	26.58	19.30	13.75	115.33
1967	16.09	45.89	55.87	21.86	25.68	21.23	18.47	9.51	6.60	5.35	8.75	13.63	20.74
1968	9.80	24.30	64.71	37.76	72.05	134.35	92.95	56.34	39.65	24.80	17.14	16.30	49.18
1969	47.50	54.79	81.56	48.49	103.74	34.80	13.86	8.79	8.12	7.40	26.55	36.44	39.34
1970	47.80	61.73	30.46	100.00	149.00	34.75	44.68	56.63	39.79	30.13	26.67	24.47	53.84
1971	43.52	49.80	96.86	86.06	227.57	134.59	92.95	46.00	32.87	23.11	16.70	11.96	71.83
1972	16.84	44.87	35.85	15.21	254.45	125.16	84.17	54.60	26.45	14.73	26.80	36.53	61.30
1973	47.02	67.91	84.44	111.73	280.86	132.10	92.31	56.25	37.72	27.79	20.86	14.78	81.15
1974	9.28	67.79	122.01	112.93	576.49	265.72	80.26	47.48	29.24	18.62	13.61	36.53	115.00
1975	47.45	68.39	128.03	441.64	441.28	635.23	271.26	56.63	39.79	30.53	22.81	19.33	183.53
1976	47.47	66.82	85.40	98.76	167.57	94.08	79.15	42.41	19.69	11.59	7.61	36.29	63.07
1977	47.90	65.72	72.18	187.19	342.40	134.59	88.47	52.27	28.41	18.50	16.79	26.28	90.06
1978	48.23	68.81	118.24	69.71	171.86	86.49	26.26	33.36	25.83	21.70	26.88	36.43	61.15
1979	42.10	48.05	52.71	81.21	205.22	101.43	31.32	13.06	7.50	5.89	4.85	34.57	52.32
1980	35.00	57.74	117.15	114.58	499.43	214.93	35.90	35.25	28.47	22.02	24.66	34.96	101.67
1981	28.44	63.32	64.70	46.19	35.25	53.06	53.60	21.76	11.04	7.59	5.91	12.45	33.61
1982	47.83	60.27	22.98	25.01	26.60	17.69	15.41	10.07	8.94	15.31	16.38	13.94	23.37
1983	37.36	70.00	132.21	420.03	394.66	173.69	90.61	46.81	27.00	24.94	26.78	29.15	122.77
1984	46.17	33.23	21.33	84.70	581.66	328.95	31.22	15.16	11.69	9.81	6.02	6.63	98.05
1985	48.17	69.53	106.90	307.73	230.71	123.85	83.97	45.45	26.50	19.13	16.04	14.88	91.07
1986	46.82	62.57	117.23	91.43	254.52	240.02	91.54	35.48	24.75	19.46	26.88	929.21	161.66
1987	566.90	177.52	112.08	138.60	451.01	371.29	107.56	51.72	39.66	30.61	26.72	24.72	174.87
1988	46.45	64.67	121.35	100.96	654.79	278.79	50.47	35.50	27.98	21.33	15.29	11.41	119.08
1989	14.45	70.09	310.63	99.20	52.92	70.12	73.01	42.48	23.40	12.46	16.11	16.04	66.74
1990	16.84	12.62	75.14	119.81	537.33	207.67	71.60	28.91	20.79	17.42	10.73	12.25	94.26
1991	48.23	68.31	117.35	62.49	171.80	84.92	19.61	12.58	7.14	5.35	5.45	6.76	50.83
1992	7.75	52.85	105.73	44.53	214.51	123.59	68.20	28.85	15.58	8.88	6.82	11.79	57.42
1993	48.23	69.67	95.89	94.90	235.80	144.41	81.00	37.17	19.25	15.98	26.52	21.67	74.21
1994	17.73	10.95	16.06	45.03	43.00	54.31	53.47	33.00	29.14	21.01	14.35	9.42	28.96
Median	33.64	62.94	91.48	96.46	211.82	124.51	79.66	42.45	28.44	19.19	16.54	16.02	68.60
Average	50.85	63.60	105.32	131.66	236.29	137.10	79.42	43.86	28.14	20.38	22.69	39.98	79.94
10%ile	10.75	18.91	24.69	27.06	55.16	35.86	20.33	13.01	9.50	7.60	6.80	8.61	39.75

1: Closed < 2.0 2: Open (closed for) 2.0-5.0 3 Open (Saline) 5.0-30 4 Open (Riverine) > 30.0

< 2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00%
2.0-5.0	0	0	0	0	0	0	0	0	0	0	3	0	0	0.36%
5.0-30	33	13	8	8	2	4	11	20	43	57	66	54	54	37.98%
> 30.0	37	57	62	62	68	66	59	50	27	13	1	16	16	61.67%

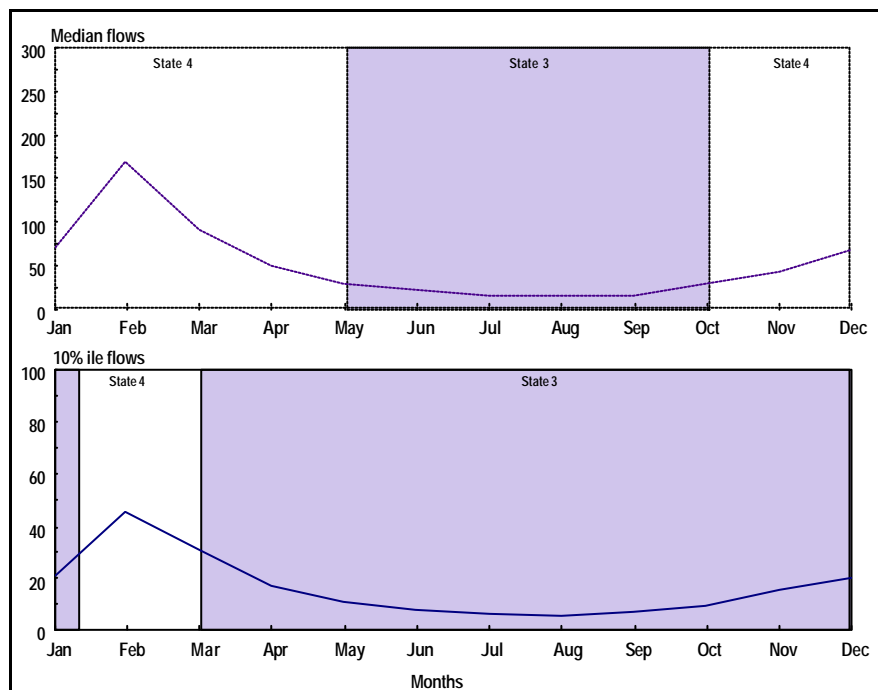
7.2.4 River scenario: Category B

Monthly average simulated runoff data (in m³/s) for the Scenario: River Category B is provided in Table 7.4. A summary of occurrences per month at intervals 10%, derived from the 70-year simulated data set, is provided below for the Scenario: River Category B:

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
90%ile	33.39	65.47	151.76	302.51	534.73	275.35	96.11	33.97	24.35	19.04	16.93	24.54
80%ile	33.15	49.04	96.90	205.43	378.13	210.88	81.59	33.74	24.19	18.91	16.80	24.38
70%ile	32.54	48.28	87.28	129.35	238.21	148.53	60.92	33.14	23.79	18.63	16.50	23.84
60%ile	30.99	47.14	78.04	80.55	195.40	115.05	55.88	31.84	22.96	17.94	15.98	20.64
50%ile	28.68	44.60	68.19	71.02	169.96	90.94	50.57	29.91	21.49	16.74	14.88	16.02
40%ile	24.94	40.73	55.40	61.48	157.05	86.90	44.40	26.37	18.99	14.91	13.19	14.50
30%ile	19.61	34.06	47.05	49.00	110.62	76.23	35.78	21.48	15.29	12.17	10.76	13.62
20%ile	14.24	25.27	33.42	33.81	77.72	51.42	25.57	15.73	11.50	9.11	8.17	11.03
10%ile	9.25	15.35	19.90	21.32	45.23	30.98	16.95	10.89	8.07	6.51	5.87	7.44
1%ile	6.96	8.40	9.91	13.51	24.77	17.00	12.94	8.64	6.51	5.27	4.79	5.80

To estimate the occurrence and duration of the different Abiotic States during the Scenario: River Category B, median monthly flows and 10%ile flows, simulated for the 70-year period, were used to illustrate the situation for normal and drought periods, respectively (Figure 7.4).

Fig 7.4 Occurrence and duration of different Abiotic States during the Scenario: River Category B, using median monthly flows and 10%ile flows (simulated for the 70-year period), to illustrate variations during normal and drought periods, respectively



Occurrences of States

State 1, associated with prolonged mouth closure, does not occur.

State 2, associated with occasional mouth closure for up a few days and strong saline intrusion, occurs for 0.36 % of the time, which is a negligible.

State 3, associated with saline intrusion, occurs for 48.8 % of the time and has increased from 33 % at the Reference Condition. At median flows, State 3 occurs for 6 months from May to October. At 10%ile low flows, State 3 occurs for 10 months from April to January.

State 4, associated with a river dominated system, and no significant saline intrusion occurs 50.8 % of the time, compared to 66.8 % at Reference Condition. At median flows, State 4 occurs for 6 months from November to April. At 10%ile low flows, State 4 occurs for 2 months, namely February and November.

Highest monthly flows

The average monthly flow during September 1987 is 930 m³/s which is a reduction to 82 % of the Reference Condition. The average of the ten monthly flows during those months, which were highest at the Reference Condition, was 684 m³/s, which is a reduction to 84 % compared to the Reference Condition.

Table 7.5 Monthly runoff data (in m³/s) for River Scenario: Category B, simulated over a 70-year period

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	AVE
1925	31.71	40.80	27.65	63.36	93.20	53.40	40.50	13.12	18.26	17.71	11.65	24.54	36.32
1926	33.32	48.42	68.83	45.42	159.84	89.59	56.41	21.47	12.02	12.26	15.77	15.36	48.22
1927	32.59	27.07	62.21	56.92	80.34	60.82	42.78	14.60	10.97	6.54	5.77	14.63	34.60
1928	26.70	20.31	49.44	46.87	77.79	90.80	58.11	31.69	24.32	19.07	16.93	24.57	40.55
1929	33.33	49.04	82.15	200.62	161.13	142.53	61.63	26.64	17.05	14.22	14.15	17.38	68.32
1930	19.73	13.59	36.07	74.70	167.08	43.51	25.65	15.78	8.10	11.98	12.60	7.09	36.32
1931	8.32	15.14	11.06	16.14	235.75	373.09	91.59	33.39	24.35	18.82	15.00	13.60	71.35
1932	9.32	25.37	53.31	21.45	45.41	28.61	16.68	10.62	6.51	8.91	10.94	6.84	20.33
1933	6.96	49.35	140.76	919.78	456.03	113.34	76.86	33.94	24.39	19.03	16.93	24.39	156.81
1934	29.33	49.05	466.24	224.67	117.93	99.99	45.63	28.49	23.49	18.37	13.60	9.11	93.83
1935	7.67	15.38	13.52	70.23	230.43	236.30	60.61	83.67	45.27	18.99	15.25	13.21	67.54
1936	21.04	154.24	181.12	267.70	393.46	132.56	19.74	11.41	7.00	5.65	4.79	5.80	100.38
1937	12.50	9.09	83.56	62.10	106.84	35.17	48.05	33.53	23.88	19.07	16.92	23.78	39.54
1938	33.10	45.54	95.65	119.97	751.62	405.55	63.93	32.73	24.06	18.90	16.71	24.23	136.00
1939	30.28	64.80	238.02	81.77	61.76	33.68	20.92	155.20	128.98	19.07	16.79	24.14	72.95
1940	26.23	40.50	125.84	257.92	262.52	142.44	83.00	33.91	23.30	14.84	9.35	8.80	85.72
1941	10.83	11.32	17.04	69.48	200.75	253.82	101.06	33.21	23.69	18.12	16.19	23.51	64.92
1942	30.64	91.86	468.78	473.51	204.89	112.64	546.02	276.84	38.47	58.81	392.24	185.96	240.06
1943	367.85	431.98	242.51	150.75	421.06	202.80	35.65	15.89	24.24	19.03	16.38	24.57	162.73
1944	33.21	40.63	20.03	13.51	31.79	148.18	181.15	30.73	17.88	12.44	7.13	6.32	45.25
1945	6.96	6.86	7.34	34.48	100.23	87.30	55.00	18.64	9.67	6.19	4.81	5.80	28.61
1946	29.63	48.79	47.63	13.51	126.06	87.78	53.10	26.75	23.30	18.82	15.96	14.75	42.17
1947	27.49	49.27	93.11	73.04	117.46	179.70	92.25	33.00	22.92	16.34	9.68	10.81	60.42
1948	21.48	21.22	27.06	62.09	162.69	83.01	56.69	33.68	21.85	13.60	7.82	12.32	43.62
1949	25.65	47.84	83.46	44.84	61.39	90.14	74.38	33.60	24.16	18.38	16.48	20.15	45.04
1950	19.32	20.14	79.91	42.13	48.28	37.72	26.43	15.42	11.54	8.17	16.93	24.50	29.21
1951	32.18	21.58	29.99	79.73	294.12	100.22	39.07	27.14	19.05	18.67	16.57	16.01	57.86
1952	17.41	45.14	72.63	49.91	375.65	253.96	36.84	25.28	14.66	10.97	16.00	18.30	78.06
1953	17.39	40.85	52.88	26.57	196.39	87.75	44.62	32.24	24.19	18.40	13.31	21.36	47.99
1954	33.39	58.51	148.49	489.73	671.34	241.19	49.33	30.94	21.54	16.86	9.57	7.47	148.20
1955	20.68	30.13	56.25	19.76	182.00	164.22	114.69	29.33	21.38	16.05	9.58	13.96	56.50
1956	22.92	48.88	517.44	520.05	181.97	138.97	81.24	33.76	23.83	19.07	16.93	391.84	166.41
1957	529.54	180.81	46.06	240.80	209.17	72.55	93.75	33.97	23.76	14.95	8.21	13.74	122.28
1958	20.00	42.16	75.41	50.06	155.82	55.84	16.98	34.00	24.39	18.94	16.32	16.64	43.88
1959	31.56	48.50	64.18	24.43	73.78	77.81	56.24	33.73	23.02	13.69	10.35	14.32	39.30
1960	25.02	47.12	100.26	186.26	39.34	86.30	89.10	33.91	24.13	18.02	13.02	15.97	56.54
1961	19.08	34.34	46.72	66.72	165.15	63.61	43.66	30.08	15.57	10.50	11.14	14.28	43.40
1962	11.62	47.09	76.32	84.69	145.62	105.29	50.86	26.28	22.20	43.68	63.70	23.65	58.42
1963	24.84	47.93	34.27	103.71	108.39	31.25	25.26	16.93	14.38	15.22	12.57	23.98	38.23
1964	33.42	134.93	67.54	128.04	77.46	17.00	12.94	8.64	23.78	19.02	16.90	24.43	47.01
1965	28.19	29.75	26.36	74.81	157.87	20.85	12.94	10.67	10.65	6.51	6.92	13.35	33.24
1966	13.55	33.39	74.52	239.54	573.14	321.86	177.71	39.81	24.32	18.79	16.16	13.75	128.88
1967	13.51	33.28	41.05	18.22	24.17	19.25	15.89	9.03	6.51	5.27	6.94	13.63	17.23
1968	8.64	18.94	47.05	27.69	57.17	91.08	58.11	33.85	24.31	18.62	15.26	16.30	34.75
1969	32.96	39.18	58.81	34.08	79.58	27.86	13.28	8.64	7.33	6.40	16.75	24.52	29.11
1970	33.15	43.79	23.81	66.46	111.58	27.83	30.75	34.00	24.39	18.95	16.82	23.63	37.93
1971	31.40	35.87	70.69	56.89	172.83	91.22	58.11	31.66	23.88	18.40	14.99	11.08	51.42
1972	14.41	32.60	27.47	14.26	194.74	85.24	53.13	33.38	14.26	10.40	16.89	24.57	43.89
1973	32.65	47.90	61.04	75.51	258.48	219.72	95.56	33.80	24.22	18.86	16.37	14.78	74.91
1974	8.30	47.82	91.36	258.40	619.66	259.47	50.91	32.51	22.78	15.72	10.02	24.57	120.13
1975	32.92	48.22	130.90	478.28	434.66	628.98	264.84	44.83	24.39	19.03	16.55	19.33	178.58
1976	32.94	47.18	61.79	71.81	173.93	88.85	50.28	29.89	13.56	8.68	6.31	24.43	50.80
1977	33.21	46.45	52.12	300.02	335.54	128.33	62.17	33.12	21.47	15.49	15.04	24.08	88.92
1978	33.42	48.50	96.06	104.13	181.82	83.25	20.31	21.67	18.91	17.76	16.93	24.52	55.61
1979	30.72	34.71	38.91	53.57	154.84	70.17	23.17	10.91	6.99	5.57	4.79	24.37	38.23
1980	29.18	41.15	87.18	77.97	676.32	208.68	25.77	23.58	21.52	17.88	16.63	24.38	104.19
1981	26.78	44.85	47.05	32.71	31.15	39.46	35.80	15.52	8.90	6.50	5.37	12.45	25.55
1982	33.17	42.83	18.73	20.10	25.03	17.00	14.15	9.33	7.76	10.71	14.77	13.94	18.96
1983	29.72	49.29	100.26	454.99	388.04	167.44	78.92	32.06	20.09	18.64	16.87	24.27	115.05
1984	32.10	24.86	17.62	55.96	625.81	322.70	23.12	12.02	9.25	7.71	5.43	6.22	95.23
1985	33.39	48.98	78.62	324.89	223.85	117.60	55.64	31.40	19.61	16.62	14.39	14.88	81.65
1986	32.52	44.35	87.26	60.57	265.28	300.71	83.34	24.11	17.41	16.93	16.93	930.79	156.68
1987	560.63	171.10	105.88	132.40	444.39	365.03	101.13	33.07	24.32	19.07	16.84	23.69	166.46
1988	32.28	45.75	90.80	139.40	675.06	272.54	34.03	24.14	21.04	17.63	13.70	9.32	114.64
1989	11.64	49.35	318.79	93.00	43.64	66.04	46.81	29.93	15.56	9.16	14.44	16.04	59.53
1990	14.41	11.18	54.13	132.88	530.47	201.41	46.01	19.31	14.15	13.70	8.03	12.25	88.16
1991	33.42	48.16	87.35	45.17	179.66	84.08	16.53	10.66	6.79	5.27	5.12	6.30	44.04
1992	7.32	37.90	77.66	31.72	161.95	84.24	44.08	19.28	11.35	7.20	5.88	10.53	41.59
1993	33.42	71.50	89.04	190.21	243.96	149.36	51.33	26.43	13.32	11.42	16.73	21.67	76.53
1994	16.75	10.07	14.04	32.02	36.63	40.25	35.73	21.48	22.61	17.51	12.20	7.93	22.27
Median	28.68	44.60	68.19	71.02	169.96	90.94	50.57	29.91	21.49	16.74	14.88	16.02	51.92
Average	44.01	51.35	91.24	132.50	226.19	135.16	63.83	31.92	20.61	15.54	19.01	37.62	72.41
10%ile	9.25	15.35	19.90	21.32	45.23	30.98	16.95	10.89	8.07	6.51	5.87	7.44	29.20

1: Closed < 2.0 2: Open (closed for) 2.0-5.0 3: Open (Saline) 5.0-30 4: Open (Riverine) > 30.0

< 2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00%
2.0-5.0	0	0	0	0	0	0	0	0	0	0	3	0	0	0.36%
5.0-30	39	17	14	11	2	7	17	36	67	68	65	67	3	48.81%
> 30.0	31	53	56	59	68	63	53	34	3	2	2	3	3	50.83%

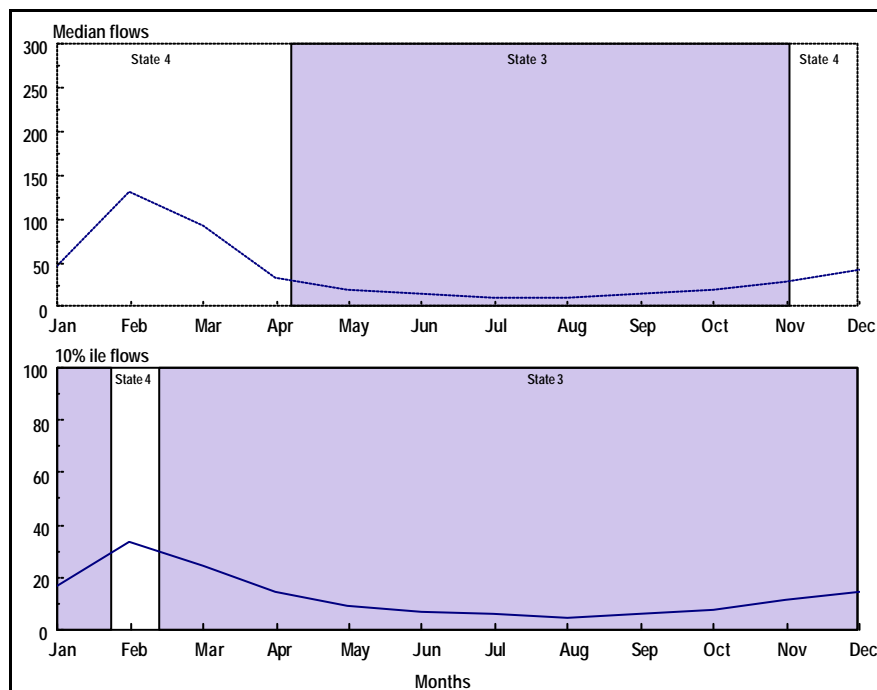
7.2.5 River scenario: Category C

Monthly average simulated runoff data (in m³/s) for the Scenario: River Category C is provided in Table 7.5. A summary of occurrences per month at intervals 10%, derived from the 70-year simulated data set, is provided below for the Scenario: River Category C:

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
90%ile	21.39	128.60	175.42	321.73	527.87	269.10	96.07	23.46	15.33	12.21	10.99	15.86
80%ile	21.26	31.94	102.34	223.76	392.17	216.78	83.08	20.73	15.25	12.15	10.92	15.77
70%ile	20.91	31.46	56.05	168.05	238.99	157.37	67.87	20.44	15.05	12.00	10.77	15.47
60%ile	20.04	30.78	48.93	105.56	173.80	115.64	45.15	19.81	14.63	11.65	10.50	14.97
50%ile	18.73	29.28	43.37	46.67	132.57	92.67	33.44	18.88	13.90	11.05	9.94	14.20
40%ile	16.92	26.98	34.91	39.21	104.17	76.01	28.51	17.16	12.66	10.12	9.07	12.61
30%ile	13.91	23.02	30.14	32.11	76.00	57.36	24.12	14.79	10.82	8.73	7.82	10.76
20%ile	10.56	17.81	22.36	23.49	51.74	39.70	18.91	12.00	8.93	7.18	6.49	8.41
10%ile	7.75	11.93	14.63	16.85	34.02	24.71	14.51	9.65	7.23	5.86	5.31	6.44
1%ile	6.45	7.79	8.89	12.70	20.77	15.52	12.47	8.56	6.45	5.23	4.75	5.53

To estimate the occurrence and duration of the different Abiotic States during the Scenario: River Category C, median monthly flows and 10%ile flows, simulated for the 70-year period, were used to illustrate the situation for normal and drought periods, respectively (Figure 7.5).

Fig 7.5 Occurrence and duration of different Abiotic States during Scenario: Reserve Category C, using median monthly flows and 10%ile flows (simulated for the 70-year period), to illustrate variations during normal and drought periods, respectively



Occurrences of States

State 1, associated with prolonged mouth closure, does not occur.

State 2, associated with occasional mouth closure for up a few days and strong saline intrusion, occurs for 0.48 % of the time, which is negligible.

State 3, associated with saline intrusion, occurs for 62.6 % of the time and has increased from 33 % at Reference Condition Scenario. At median flows, State 3 occurs for 7 months from May to November. At 10%ile low flows, State 3 occurs for 11 months from March to January.

State 4, associated with a river dominated system and no significant saline intrusion, occurs 36.9 % of the time, compared to 66.8 % at Reference Condition Scenario. At median flows, State 4 occurs for 5 months from December to April. At 10%ile low flows, State 4 occurs for 1 month, namely February.

Highest monthly flows

The average monthly flow during September 1987 (highest flow at the Reference Condition) is 924 m³/s which is a reduction of to 81.6 % compared to natural conditions. The average of the ten monthly flows during those months, which were highest at the Reference Condition, was 686 m³/s, which is a reduction to 84 % compared to the Reference Condition.

Table 7.6 Monthly runoff data (in m³/s) for River Scenario: Category C, simulated over a 70-year period

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	AVE
1925	20.44	27.02	19.06	39.50	59.67	36.31	26.52	10.73	12.29	11.54	8.28	15.86	23.93
1926	21.35	31.54	42.82	29.66	98.22	105.76	66.78	14.78	9.19	8.77	10.39	13.53	37.73
1927	20.94	18.88	38.92	35.88	52.14	40.55	27.69	11.45	8.67	5.87	5.26	12.79	23.25
1928	17.61	14.87	31.51	30.43	50.92	57.67	84.71	19.74	15.31	12.23	10.99	15.88	30.16
1929	21.35	135.65	145.84	262.37	154.27	136.28	55.20	17.29	11.69	9.77	9.56	14.44	81.14
1930	14.02	10.88	23.87	46.05	155.43	51.84	18.95	12.02	7.24	8.63	8.77	6.25	30.33
1931	7.22	11.80	9.59	14.10	157.47	407.91	85.16	20.56	15.32	12.10	10.00	10.74	63.50
1932	7.79	17.87	33.72	16.92	32.56	22.15	14.38	9.52	6.45	7.08	7.91	6.11	15.20
1933	6.45	32.09	129.47	913.59	449.17	107.09	70.43	23.44	15.34	12.21	10.99	15.78	148.84
1934	19.10	31.91	483.61	218.47	111.07	93.74	29.14	18.18	14.90	11.87	9.28	7.36	87.39
1935	6.85	11.94	10.99	43.41	243.43	230.05	54.19	77.47	38.86	12.19	10.13	10.35	62.49
1936	15.58	142.82	174.92	261.50	386.60	126.31	15.94	9.91	6.70	5.42	4.75	5.53	96.33
1937	9.59	8.21	51.58	38.79	67.40	25.90	30.37	20.63	15.09	12.23	10.99	15.44	25.52
1938	21.22	29.83	58.88	216.23	744.76	399.30	57.50	20.24	15.18	12.14	10.88	15.69	133.49
1939	19.63	74.08	231.82	75.57	50.66	30.74	16.54	147.90	122.58	12.23	10.92	15.64	67.36
1940	17.34	26.84	131.47	251.73	255.66	136.19	76.58	20.81	14.80	10.08	7.10	7.19	79.65
1941	8.64	9.54	13.00	42.98	200.02	250.37	94.64	20.47	15.00	11.75	10.61	15.29	57.69
1942	19.84	100.38	462.58	467.32	198.03	106.38	539.59	270.64	32.07	52.61	385.99	179.48	234.58
1943	361.58	425.56	236.31	144.55	414.44	196.55	24.05	12.07	15.27	12.21	10.71	15.88	155.76
1944	21.29	26.92	14.71	12.70	24.83	155.73	174.72	19.27	12.10	8.86	5.96	5.82	40.24
1945	6.45	6.86	7.34	23.85	63.66	55.67	33.92	13.41	8.02	5.70	4.77	5.53	19.60
1946	19.27	31.76	30.47	12.70	78.31	55.94	32.95	17.34	14.80	12.10	10.49	12.91	27.42
1947	18.06	32.04	57.34	165.97	155.77	191.98	85.83	20.37	14.61	10.84	7.27	8.29	64.03
1948	15.73	15.41	18.73	38.78	99.91	59.55	72.54	20.70	14.08	9.46	6.31	9.29	31.71
1949	17.07	31.20	51.52	29.35	41.62	165.23	108.94	20.66	15.23	11.88	10.76	14.89	43.20
1950	13.63	14.77	49.40	27.92	34.19	27.35	19.35	11.85	8.95	6.70	10.99	15.84	20.08
1951	20.70	15.62	20.40	57.69	356.46	93.96	25.79	17.53	12.69	12.03	10.81	14.19	54.82
1952	12.36	29.59	45.07	32.05	419.79	247.70	24.66	16.63	10.50	8.12	10.52	14.59	72.63
1953	12.35	27.05	33.47	19.64	119.96	89.50	28.62	20.00	15.24	11.89	9.13	15.09	33.50
1954	21.39	150.51	142.30	483.54	664.48	234.93	36.03	19.37	13.93	11.11	7.21	6.46	149.27
1955	15.15	20.69	35.40	16.02	111.25	235.90	108.27	18.60	13.85	10.70	7.21	11.84	50.41
1956	16.22	31.81	518.64	513.86	175.10	132.72	74.81	20.74	15.06	12.23	10.99	395.11	159.77
1957	523.27	174.39	29.58	244.88	202.31	66.29	87.33	26.36	15.03	10.14	6.51	11.14	116.44
1958	14.35	27.83	46.71	32.13	97.75	74.54	14.53	23.64	15.34	12.16	10.68	14.32	32.00
1959	20.36	31.59	40.08	18.51	48.42	56.65	63.50	20.73	14.66	9.50	7.61	12.35	28.66
1960	16.94	30.77	179.93	211.63	29.11	83.08	82.67	20.82	15.22	11.70	8.98	14.15	58.75
1961	13.41	23.19	29.95	41.39	126.37	81.01	28.14	18.96	10.96	7.88	8.02	12.30	33.46
1962	9.09	30.75	47.25	149.72	138.76	99.04	40.54	17.12	14.26	45.72	57.45	15.37	55.42
1963	16.88	31.25	22.84	116.09	101.77	24.99	18.75	12.58	10.36	10.28	8.75	15.55	32.51
1964	21.41	128.36	61.34	121.84	70.60	15.52	12.47	8.56	15.04	12.20	10.98	15.80	41.18
1965	18.45	20.47	18.33	46.12	121.72	17.72	12.47	9.54	8.51	5.86	5.85	10.49	24.63
1966	10.18	22.63	46.19	269.44	566.28	315.60	171.29	33.61	15.31	12.09	10.60	11.15	123.70
1967	10.15	22.56	26.72	15.20	20.27	16.80	13.97	8.75	6.45	5.23	5.86	10.77	13.56
1968	7.40	14.05	30.14	20.24	39.23	57.82	35.50	20.79	15.30	12.00	10.14	14.26	23.07
1969	21.14	26.06	36.91	23.64	51.94	21.72	12.64	8.56	6.86	5.80	10.90	15.85	20.17
1970	21.25	28.80	16.87	41.25	70.09	21.71	21.55	20.86	15.34	12.17	10.93	15.36	24.68
1971	20.27	24.10	43.92	35.86	105.78	91.59	110.77	19.73	15.09	11.89	9.99	8.44	41.45
1972	10.66	22.16	18.96	13.10	118.97	54.49	32.96	20.56	12.94	7.83	10.97	15.88	28.29
1973	20.97	31.23	38.23	194.13	420.14	213.47	89.14	20.76	15.26	12.12	10.71	12.95	89.92
1974	7.21	31.19	56.29	290.55	612.80	253.22	41.42	20.14	14.54	10.53	7.44	15.88	113.43
1975	21.13	31.42	148.65	472.08	428.03	622.73	258.41	38.63	15.34	12.21	10.80	14.76	172.85
1976	21.13	30.80	38.67	98.53	167.07	82.60	39.03	18.87	9.96	6.96	5.53	15.80	44.58
1977	21.29	30.37	33.04	320.62	328.68	122.08	55.75	20.43	13.89	10.41	10.02	15.61	81.85
1978	21.41	31.59	112.95	97.93	174.96	76.99	16.23	14.88	12.62	11.57	10.99	15.85	49.83
1979	19.88	23.41	25.49	34.00	95.14	58.76	17.69	9.66	6.69	5.38	4.75	15.77	26.38
1980	19.01	27.23	53.76	172.90	669.46	202.42	19.01	15.80	13.92	11.63	10.84	15.77	102.65
1981	17.65	29.43	30.14	22.91	24.47	28.34	24.13	11.90	7.64	5.85	5.05	9.61	18.09
1982	21.27	28.22	13.97	16.20	21.00	15.52	13.09	8.89	7.08	7.99	9.88	11.98	14.59
1983	19.32	32.06	61.67	493.21	381.41	161.19	72.50	19.92	13.20	12.01	10.96	15.71	107.76
1984	20.66	17.57	13.33	35.34	648.87	316.45	17.66	10.20	7.81	6.47	5.08	5.76	92.10
1985	21.39	31.87	48.62	331.75	216.99	111.34	49.22	19.60	12.97	10.99	9.68	13.05	73.12
1986	20.90	29.13	53.81	47.22	310.99	294.46	76.92	16.06	11.87	11.14	10.99	924.61	150.68
1987	554.35	164.67	99.69	126.20	437.76	358.78	94.71	20.41	15.31	12.23	10.95	15.39	159.20
1988	20.76	29.96	55.95	187.20	668.20	266.28	23.23	16.08	13.68	11.50	9.33	7.48	109.14
1989	9.10	37.33	314.87	86.80	34.42	61.92	29.74	18.89	10.95	7.20	9.71	14.22	52.93
1990	10.66	9.45	34.18	136.48	523.61	195.16	29.33	13.74	10.25	9.50	6.42	9.14	82.33
1991	21.41	31.39	53.87	78.99	173.04	77.82	14.30	9.54	6.59	5.23	4.92	5.81	40.24
1992	6.65	25.30	48.05	22.38	99.47	53.92	28.35	13.72	8.86	6.21	5.31	8.14	27.20
1993	21.41	130.72	82.85	184.01	237.09	143.11	42.44	17.19	9.84	8.35	10.89	15.11	75.25
1994	11.99	8.79	11.29	22.54	27.58	28.80	24.09	14.79	14.46	11.44	8.56	6.71	15.92
Median	18.73	29.28	43.37	46.67	132.57	92.67	33.44	18.88	13.90	11.05	9.94	14.20	38.72
Average	36.16	44.26	78.28	135.09	211.97	130.73	57.86	23.65	14.58	11.03	14.99	33.25	65.99
10%ile	7.75	11.93	14.63	16.85	34.02	24.71	14.51	9.65	7.23	5.86	5.31	6.44	22.49

1: Closed < 2.0 2: Open (closed for) 2.0-5.0 3: Open (Saline) 5.0-30 4: Open (Riverine) > 30.0

< 2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00%
2.0-5.0	0	0	0	0	0	0	0	0	0	0	4	0	0	0.48%
5.0-30	67	39	20	19	6	12	32	65	67	68	64	67	67	62.62%
> 30.0	3	31	50	51	64	58	38	5	3	2	2	3	3	36.90%

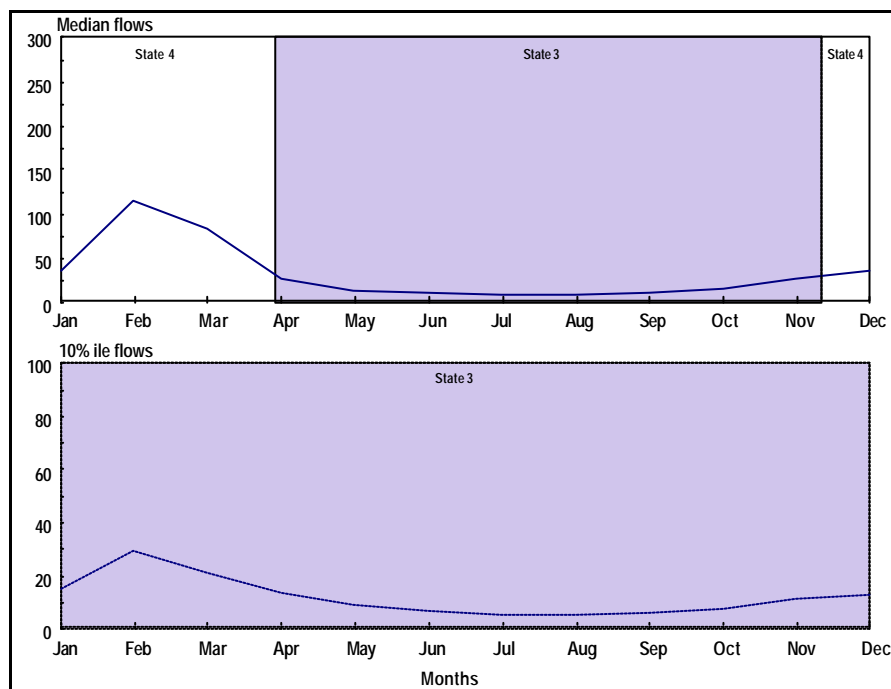
7.2.6 River scenario: Category D

Monthly average simulated runoff data (in m³/s) for the Scenario: River Category D is provided in Table 7.6. A summary of occurrences per month at intervals 10%, derived from the 70-year simulated data set, is provided below for the Scenario: River Category D:

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
90%ile	18.59	87.24	161.02	299.21	522.73	264.41	91.25	15.84	11.68	9.48	8.62	13.36
80%ile	18.48	29.25	81.57	217.58	385.57	211.86	73.25	15.44	11.64	9.44	8.58	13.30
70%ile	18.19	28.82	46.35	141.42	222.50	141.63	56.81	15.28	11.52	9.35	8.48	13.07
60%ile	17.48	28.22	40.32	97.13	168.77	110.95	40.33	14.92	11.27	9.14	8.32	12.68
50%ile	16.41	26.87	35.73	36.83	114.65	83.52	26.44	14.39	10.84	8.76	7.97	12.10
40%ile	14.92	24.82	28.81	31.33	88.54	67.70	23.13	13.41	10.10	8.20	7.43	10.88
30%ile	12.45	21.28	25.12	26.02	65.25	49.32	20.18	12.06	9.01	7.35	6.65	9.47
20%ile	9.71	16.61	19.11	20.02	44.25	35.85	16.68	10.48	7.90	6.40	5.82	7.67
10%ile	7.41	11.35	13.15	15.39	29.26	20.83	13.72	9.15	6.89	5.60	5.08	6.16
1%ile	6.34	7.67	8.66	12.50	19.89	15.20	12.35	8.53	6.43	5.21	4.74	5.47

To estimate the occurrence and duration of the different Abiotic States during the Scenario: River Category D, median monthly flows and 10%ile flows, simulated for the 70-year period, were used to illustrate the situation for normal and drought periods, respectively (Figure 7.6).

Fig 7.6 Occurrence and duration of different Abiotic States during Scenario: Reserve Category D, using median monthly flows and 10%ile flows (simulated for the 70-year period), to illustrate variations during normal and drought periods, respectively



Occurrences of States

State 1, associated with prolonged mouth closure, does not occur.

State 2, associated with occasional mouth closure for up a few days and strong saline intrusion, occurs for 0.71 % of the time, which is negligible.

State 3, associated with saline intrusion, occurs for 68.0 % of the time and has increased from 33 % at Reference Condition Scenario. At median flows, State 3 occurs for 8 months from April to November. At 10%ile low flows, State 3 occurs for 11 months from March to January.

State 4, associated with a river dominated system and no significant saline intrusion, occurs 31.3 % of the time, compared to 66.8 % at Reference Condition Scenario. At median flows, State 4 occurs for 4 months from December to March. At 10%ile low flows, State 4 occurs for 1 month, during February.

Highest monthly flows

The average monthly flow during September 1987 is 910 m³/s which is a reduction to 80.4 % compared with the Reference Condition. The average of the ten monthly flows during those months which was highest at the Reference Condition was 677 m³/s, which is a reduction to 83 % compared with the Reference Condition.

Table 7.7 Monthly runoff data (in m³/s) for River Scenario: Category D, simulated over a 70-year period

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	AVE
1925	17.81	24.85	16.57	31.55	50.25	32.95	21.79	9.76	9.89	9.07	6.93	13.36	20.40
1926	18.56	28.90	35.28	24.31	81.23	97.67	61.96	12.06	8.05	7.38	8.25	11.59	32.94
1927	18.22	17.57	32.07	28.78	44.25	36.57	22.57	10.17	7.74	5.61	5.05	11.02	19.97
1928	15.49	13.98	26.18	24.85	43.43	51.19	46.47	14.88	11.67	9.49	8.62	13.38	23.30
1929	18.56	121.18	141.19	257.72	149.12	131.59	50.38	13.49	9.53	7.99	7.73	12.28	76.73
1930	12.55	10.42	20.28	36.80	132.97	47.15	16.71	10.50	6.90	7.29	7.24	6.02	26.23
1931	6.97	11.24	9.26	13.48	119.81	396.01	80.35	15.35	11.68	9.41	8.00	9.45	57.58
1932	7.44	16.67	27.88	15.44	29.11	20.86	13.63	9.07	6.43	6.34	6.71	5.91	13.79
1933	6.34	29.39	70.07	908.94	444.02	102.40	65.62	18.79	11.69	9.48	8.62	13.30	140.72
1934	16.71	29.23	466.92	213.83	105.92	89.05	23.55	14.00	11.43	9.27	7.56	6.87	82.86
1935	6.67	11.37	10.34	34.62	218.45	225.36	49.37	72.82	34.06	9.46	8.09	9.16	57.48
1936	13.82	126.57	170.27	256.85	381.45	121.62	14.68	9.29	6.57	5.33	4.74	5.47	93.06
1937	8.91	8.03	42.56	31.00	56.28	24.06	24.38	15.39	11.55	9.49	8.62	13.04	21.11
1938	18.45	27.37	48.77	182.40	739.61	394.61	52.68	15.17	11.60	9.43	8.55	13.23	126.82
1939	17.15	59.34	227.18	70.92	45.69	26.05	15.09	140.00	117.77	9.49	8.58	13.19	62.54
1940	15.27	24.70	115.01	247.08	250.52	131.50	71.76	15.49	11.37	8.18	6.20	6.74	75.32
1941	8.13	9.21	11.89	34.27	173.31	245.68	89.82	15.30	11.49	9.19	8.38	12.93	52.47
1942	17.31	85.35	457.93	462.67	192.88	101.69	534.77	265.99	27.26	47.97	381.30	174.62	229.15
1943	356.88	420.74	231.66	139.90	409.47	191.86	20.13	10.52	11.65	9.47	8.45	13.38	152.01
1944	18.50	24.77	13.21	12.50	23.09	124.13	169.91	14.61	9.78	7.43	5.49	5.69	35.76
1945	6.34	6.86	7.34	20.27	53.36	49.48	26.76	11.28	7.36	5.50	4.75	5.47	17.06
1946	16.85	29.09	25.38	12.50	64.78	49.72	26.11	13.52	11.37	9.41	8.31	11.11	23.18
1947	15.86	29.35	47.46	113.87	150.80	187.29	81.01	15.24	11.26	8.64	6.30	7.58	56.22
1948	13.94	14.46	16.31	31.00	82.63	48.94	67.73	15.43	10.94	7.79	5.71	8.35	26.94
1949	15.05	28.59	42.50	24.10	36.18	149.12	104.12	15.40	11.63	9.27	8.48	12.62	38.09
1950	12.23	13.89	40.71	23.10	30.38	25.30	16.97	10.40	7.91	6.11	8.62	13.35	17.41
1951	18.02	14.66	17.60	39.35	323.63	89.27	21.30	13.62	10.12	9.36	8.51	12.09	48.13
1952	11.18	27.16	37.12	25.98	402.05	243.01	20.54	13.11	8.83	6.98	8.33	12.39	68.06
1953	11.18	24.88	27.70	17.34	99.41	77.99	23.20	15.03	11.63	9.28	7.46	12.77	28.16
1954	18.59	135.70	137.65	478.89	659.33	230.24	31.21	14.67	10.86	8.80	6.27	6.18	144.86
1955	13.47	19.19	29.18	14.81	92.12	224.20	103.45	14.23	10.81	8.55	6.27	10.29	45.55
1956	14.35	29.14	497.64	509.21	169.96	128.03	70.00	15.45	11.53	9.49	8.62	385.28	154.06
1957	518.56	169.57	24.69	240.48	197.16	61.60	82.51	21.71	11.51	8.21	5.83	9.76	112.63
1958	12.81	25.58	38.47	26.03	79.37	69.85	13.73	15.52	11.69	9.45	8.43	12.18	26.93
1959	17.74	28.94	33.02	16.55	41.35	44.85	54.61	15.44	11.29	7.82	6.52	10.68	24.07
1960	14.94	28.21	159.99	206.98	26.43	76.17	77.86	15.49	11.62	9.16	7.37	12.06	53.86
1961	12.04	21.43	24.98	33.01	109.49	76.32	22.88	14.44	9.10	6.83	6.77	10.64	28.99
1962	8.50	28.19	38.92	129.76	133.61	94.35	35.72	13.39	11.05	38.60	52.76	12.99	49.82
1963	14.89	28.64	19.49	102.90	96.80	20.34	16.57	10.81	8.75	8.29	7.23	13.13	28.99
1964	18.60	104.28	56.69	117.19	65.45	15.20	12.35	8.53	11.51	9.47	8.61	13.31	36.77
1965	16.18	18.99	16.00	36.86	89.23	17.08	12.35	9.09	7.65	5.60	5.42	9.26	20.31
1966	9.39	20.92	38.04	232.59	561.13	310.91	166.47	28.96	11.67	9.40	8.38	9.77	117.30
1967	9.38	20.86	22.48	14.25	19.41	16.30	13.36	8.63	6.43	5.21	5.43	9.47	12.60
1968	7.12	13.25	25.13	17.75	34.31	51.32	27.83	15.47	11.67	9.35	8.09	12.14	19.45
1969	18.39	24.00	30.42	20.12	44.23	20.50	12.47	8.53	6.67	5.56	8.56	13.35	17.73
1970	18.48	26.44	14.88	32.89	58.38	20.49	18.45	15.52	11.69	9.45	8.59	12.98	20.69
1971	17.67	22.24	36.18	28.76	87.51	64.47	105.95	14.87	11.54	9.28	8.00	7.70	34.51
1972	9.79	20.50	16.49	12.78	98.58	48.48	26.12	15.35	10.27	6.80	8.61	13.38	23.93
1973	18.24	28.62	31.50	171.63	414.99	208.78	84.32	15.46	11.64	9.42	8.44	11.14	84.52
1974	6.96	28.58	46.55	276.56	607.65	248.53	36.60	15.11	11.22	8.45	6.41	13.38	108.83
1975	18.37	28.79	130.38	467.43	423.06	618.04	253.60	33.98	11.69	9.47	8.50	12.52	167.99
1976	18.38	28.24	31.87	83.94	161.93	77.91	34.21	14.38	8.50	6.27	5.22	13.32	40.35
1977	18.50	27.85	27.36	298.81	323.53	117.39	50.93	15.27	10.83	8.38	8.02	13.17	76.67
1978	18.60	28.94	95.47	93.28	169.81	72.30	14.88	12.12	10.08	9.08	8.62	13.35	45.55
1979	17.35	21.62	21.53	27.33	78.68	46.83	15.86	9.15	6.57	5.31	4.74	13.29	22.36
1980	16.64	25.04	44.41	144.97	664.31	197.73	16.75	12.64	10.85	9.12	8.53	13.29	97.02
1981	15.52	27.01	25.12	19.61	22.81	26.15	20.18	10.42	7.13	5.59	4.93	8.59	16.09
1982	18.48	25.93	12.64	14.94	20.10	15.20	12.77	8.72	6.80	6.90	7.93	10.39	13.40
1983	16.89	29.36	51.16	493.55	376.45	156.50	67.68	14.98	10.43	9.35	8.60	13.25	104.02
1984	17.99	16.40	12.15	28.36	627.11	311.76	15.84	9.46	7.23	5.97	4.95	5.65	88.57
1985	18.59	29.20	40.06	302.85	211.84	106.65	44.10	14.80	10.29	8.73	7.81	11.21	67.20
1986	18.18	26.74	44.44	32.91	305.84	289.77	72.40	12.79	9.64	8.82	8.62	910.95	145.07
1987	549.65	159.85	95.04	121.55	432.79	354.09	89.89	15.26	11.67	9.49	8.60	13.00	155.07
1988	18.07	27.48	46.26	176.04	663.05	261.59	19.58	12.80	10.71	9.04	7.59	6.96	104.93
1989	8.51	29.39	295.51	82.15	29.28	57.23	24.19	14.40	9.09	6.42	7.83	12.11	48.01
1990	9.79	9.14	28.25	113.31	518.46	190.47	23.68	11.47	8.68	7.82	5.78	8.23	77.92
1991	18.60	28.76	44.49	59.51	168.07	73.13	13.58	9.08	6.51	5.21	4.84	5.68	36.46
1992	6.51	23.32	39.59	19.24	82.27	47.99	23.02	11.46	7.85	5.81	5.09	7.47	23.30
1993	18.60	84.94	78.20	179.37	231.95	138.42	37.62	13.43	8.43	7.12	8.56	12.79	68.29
1994	10.88	8.55	10.57	19.36	25.23	26.54	20.16	12.07	11.17	9.00	7.11	6.37	13.92
Median	16.41	26.87	35.73	36.83	114.65	83.52	26.44	14.39	10.84	8.76	7.97	12.10	32.88
Average	34.15	40.28	70.71	126.20	202.24	124.94	53.27	20.01	12.05	9.07	13.31	31.24	61.46
10%ile	7.41	11.35	13.15	15.39	29.26	20.83	13.72	9.15	6.89	5.60	5.08	6.16	17.70

1: Closed < 2.0 2: Open (closed for) 2.0-5.0 3: Open (Saline) 5.0-30 4: Open (Riverine) > 30.0

< 2.0	0	0	0	0	0	0	0	0	0	0	0	0	0.00%
2.0-5.0	0	0	0	0	0	0	0	0	0	0	6	0	0.71%
5.0-30	67	60	29	26	8	13	37	66	68	68	62	67	67.98%
> 30.0	3	10	41	44	62	57	33	4	2	2	2	3	31.31%

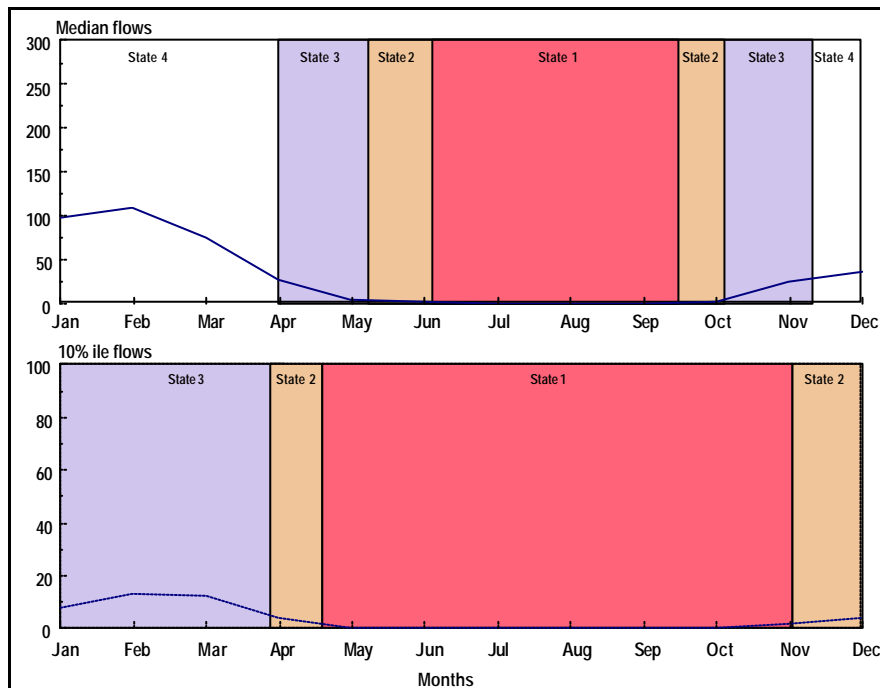
7.2.7 Scenario: Worst case 1

Monthly average simulated runoff data (in m³/s) for the Scenario: Worst Case 1 is provided in Table 7.7. A summary of occurrences per month at intervals 10%, derived from the 70-year simulated data set, is provided below for the Scenario: Worst Case 1:

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
90%ile	65.29	154.43	207.07	260.35	422.27	230.27	81.95	26.65	8.21	7.13	6.73	16.67
80%ile	27.67	86.55	130.81	199.27	328.23	174.60	64.01	16.89	6.21	3.43	2.41	5.26
70%ile	18.90	41.51	89.22	147.62	196.30	134.71	50.13	10.41	4.59	1.86	0.41	1.49
60%ile	6.48	30.92	53.44	122.36	144.13	106.79	40.53	7.39	3.42	0.45	0.22	0.39
50%ile	3.22	25.65	37.53	104.17	116.55	84.77	28.66	5.96	2.25	0.16	0.19	0.26
40%ile	1.23	18.71	23.41	69.58	83.46	67.33	21.89	3.28	0.98	0.14	0.17	0.23
30%ile	0.73	15.28	17.95	44.43	71.30	48.19	13.20	1.74	0.20	0.11	0.13	0.19
20%ile	0.31	3.97	9.71	21.39	26.63	26.78	7.24	0.71	0.11	0.09	0.11	0.15
10%ile	0.21	1.82	4.44	8.05	13.20	12.22	4.10	0.13	0.08	0.08	0.09	0.11
1%ile	0.12	0.21	0.17	0.96	0.42	0.14	0.09	0.08	0.06	0.06	0.06	0.07

To estimate the occurrence and duration of the different Abiotic States during the Scenario: Worst Case 1, median monthly flows and 10%ile flows, simulated for the 70-year period, were used to illustrate the situation for normal and drought periods, respectively (Figure 7.7).

Fig 7.7 Occurrence and duration of different Abiotic States during Scenario: Worst Case 1, using median monthly flows and 10%ile flows (simulated for the 70-year period), to illustrate variations during normal and drought periods, respectively



Occurrences of States

State 1, associated with prolonged mouth closure, occurs 31.6 % of the time, while this state did not occur at Reference Condition Scenario. At median flows, State 1 occurs for 3 months from July to September. At 10%ile low flows, State 1 occurs for 7 months from May to November.

State 2, associated with occasional mouth closure for up to a few days and strong saline intrusion, occurs for 8.9 % of the time, compared to 0 % at Reference Condition Scenario. At median flows, State 2 occurs for 2 months namely June and October. At 10%ile low flows, State 2 occurs for 2 months, April and December.

State 3, associated with saline intrusion, occurs for 24.4 % of the time compared to 33.2 % at Reference Condition Scenario. At median flows, State 3 occurs for 3 months, namely April, May and November. At 10%ile low flows, State 3 occurs for 3 months from January till March.

State 4, associated with a river dominated system and no significant saline intrusion, occurs 35.1 % of the time, compared to 66.8 % at Reference Condition Scenario. At median flows, State 4 occurs for 4 months from December to March. At 10%ile low flows, State 4 does not occur.

Highest monthly flows

The average monthly flow during September 1987 is 907 m³/s, which is a reduction to 80.1 % compared with the Reference Condition. The average of the ten monthly flows during those months which, were highest at the Reference Condition, was 606 m³/s, which is a reduction to 74 % of that at Reference Condition.

Table 7.8 Monthly runoff data (in m³/s) for Worst Case 1 Scenario, simulated over a 70-year period

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	AVE
1925	10.06	17.83	7.87	121.98	84.24	66.47	23.29	2.27	4.38	1.24	0.17	15.11	29.58
1926	55.88	49.75	22.87	8.23	114.26	206.70	58.50	2.45	0.10	0.10	0.22	0.26	43.28
1927	4.25	2.19	24.23	78.51	51.68	27.04	11.42	0.23	0.12	0.07	0.11	0.30	16.68
1928	0.83	0.34	4.43	14.79	5.90	118.85	76.75	5.84	6.20	9.32	1.94	27.07	22.69
1929	45.30	99.48	83.52	247.61	127.17	133.52	49.64	1.90	0.06	0.05	0.14	0.45	65.74
1930	1.01	1.99	19.94	158.95	133.96	22.01	5.84	0.13	0.08	0.08	0.09	0.10	28.68
1931	0.16	0.29	1.84	1.30	327.75	232.15	56.38	20.25	13.71	3.87	0.18	0.15	54.83
1932	0.22	2.45	23.77	8.17	17.53	15.33	4.10	0.12	0.07	0.10	0.13	0.11	6.01
1933	0.13	117.72	252.36	608.02	405.25	104.53	69.89	22.16	6.92	4.14	6.22	0.45	133.15
1934	1.94	52.52	454.26	196.71	110.90	87.36	25.52	7.09	7.44	2.98	0.40	0.18	78.94
1935	0.17	0.21	0.18	198.28	273.13	160.22	47.06	74.95	44.69	5.11	0.17	0.20	67.03
1936	0.39	191.33	114.72	145.86	330.13	105.97	7.06	0.11	0.07	0.09	0.10	0.13	74.66
1937	0.21	0.27	122.45	102.59	78.58	32.11	20.08	6.29	6.08	10.64	6.54	0.36	32.18
1938	22.50	18.86	164.10	137.79	495.25	365.90	41.21	7.85	2.75	2.88	0.46	1.47	105.08
1939	2.66	167.38	167.89	52.65	42.79	21.00	8.19	173.01	133.33	27.22	3.71	2.48	66.86
1940	1.29	25.48	204.14	131.09	197.75	114.15	81.65	26.71	3.32	0.10	0.10	0.17	65.50
1941	0.24	0.30	3.86	158.85	223.32	143.73	65.89	9.33	2.98	0.16	0.22	1.13	50.83
1942	7.03	154.14	360.45	454.59	183.53	102.54	547.75	267.70	34.89	62.57	378.43	156.20	225.82
1943	366.81	426.22	233.43	133.96	421.94	183.14	19.71	0.25	5.26	3.40	0.26	18.14	151.04
1944	27.30	15.83	2.45	0.23	3.77	186.43	139.76	7.84	0.15	0.10	0.07	0.07	32.00
1945	0.20	0.21	0.14	20.24	19.40	49.24	22.99	0.14	0.09	0.07	0.06	0.07	9.40
1946	6.53	40.15	19.82	5.68	76.03	72.09	24.69	4.17	6.29	3.08	0.26	0.20	21.58
1947	0.32	138.94	132.34	114.39	73.48	108.03	76.38	6.37	0.34	0.10	0.08	0.08	54.24
1948	1.16	6.60	9.00	120.42	144.05	76.01	51.30	17.67	2.91	0.18	0.13	0.15	35.80
1949	4.84	42.92	113.83	57.07	9.24	45.58	44.41	13.53	1.33	0.10	0.13	0.18	27.76
1950	0.25	3.78	54.40	44.00	21.76	14.98	7.28	1.07	0.09	0.08	19.34	15.36	15.20
1951	15.84	4.01	15.83	220.59	144.26	32.56	11.20	4.75	1.04	2.48	0.20	0.14	37.74
1952	0.14	27.94	41.01	43.05	339.70	172.47	20.24	1.99	0.10	0.08	0.13	0.24	53.93
1953	0.33	22.03	17.97	8.27	124.98	111.80	19.45	12.30	7.90	1.14	0.19	1.51	27.32
1954	88.32	201.85	81.49	394.54	626.16	210.25	28.61	5.96	0.90	0.16	0.10	0.14	136.54
1955	3.77	23.03	30.72	3.62	126.82	193.61	79.95	5.96	0.47	0.14	0.16	0.26	39.04
1956	2.61	83.32	487.26	484.04	168.03	131.42	72.75	16.70	4.54	20.26	16.99	372.84	155.06
1957	521.99	157.04	22.51	243.21	195.68	57.92	94.00	26.65	3.57	0.13	0.10	0.19	110.25
1958	0.27	13.97	46.61	52.01	117.52	47.54	6.64	38.34	13.90	3.11	0.20	0.28	28.37
1959	10.12	46.47	40.89	6.96	20.40	24.62	31.81	12.15	1.89	0.15	0.14	0.23	16.32
1960	2.08	40.91	292.20	155.49	26.12	28.85	60.10	24.05	7.69	0.51	0.23	0.28	53.21
1961	0.86	14.44	12.73	65.19	82.30	48.47	26.65	3.40	0.14	0.08	0.19	0.27	21.23
1962	0.45	30.04	81.04	105.76	67.48	90.53	35.82	6.54	5.02	135.24	80.05	1.94	53.33
1963	1.03	27.53	12.39	122.92	74.18	6.80	5.93	0.80	1.26	0.12	0.13	0.20	21.11
1964	135.24	113.78	34.18	74.74	53.40	0.12	0.10	0.13	4.44	5.17	4.84	3.32	35.79
1965	6.39	16.79	9.89	120.72	86.93	2.91	1.89	0.72	0.24	0.18	0.17	0.23	20.59
1966	0.31	4.30	28.08	255.98	319.71	301.21	174.09	24.20	4.60	0.41	0.18	0.14	92.77
1967	0.30	20.13	18.03	8.85	0.55	8.40	6.32	0.20	0.11	0.08	0.24	1.05	5.35
1968	1.12	2.08	26.43	24.43	13.60	144.48	88.34	19.29	6.69	1.33	0.19	0.28	27.35
1969	25.41	17.90	17.90	17.93	46.32	12.49	0.63	0.22	0.37	0.24	2.09	9.10	12.55
1970	40.43	32.23	8.94	38.02	23.39	3.73	13.97	69.72	39.97	7.76	5.29	2.26	23.81
1971	17.98	18.49	72.10	92.94	118.11	156.41	55.76	8.79	5.54	1.73	0.52	0.23	45.72
1972	0.25	6.50	5.23	5.24	198.86	103.92	37.74	12.07	2.75	0.11	6.40	35.79	34.57
1973	21.95	32.30	17.16	151.74	182.51	77.00	38.41	10.55	3.76	0.74	0.17	0.12	44.70
1974	0.08	17.68	140.00	203.21	465.24	230.06	42.91	6.93	1.44	0.14	0.12	47.18	96.25
1975	26.02	33.86	103.93	417.51	425.20	623.97	251.54	37.68	11.00	2.18	0.17	0.23	161.11
1976	19.03	20.94	41.54	125.75	115.58	82.19	32.73	3.11	0.13	0.09	0.13	16.50	38.14
1977	38.47	27.64	19.46	299.75	300.93	115.60	53.02	8.65	1.61	0.15	0.21	1.48	72.25
1978	85.21	57.19	52.80	44.61	173.64	66.58	4.55	1.25	0.14	0.35	4.95	9.12	41.70
1979	4.58	2.44	4.44	68.35	81.12	78.98	0.06	0.07	0.07	0.06	0.09	9.91	20.85
1980	6.45	23.97	58.16	175.40	611.15	171.75	4.05	0.67	2.49	0.34	0.96	4.93	88.36
1981	2.34	25.83	12.05	21.68	9.65	25.76	19.61	2.64	0.21	0.12	0.09	0.12	10.01
1982	54.19	32.79	5.82	3.73	0.14	0.14	2.07	1.14	0.09	0.14	0.37	0.33	8.41
1983	0.79	138.72	190.56	585.31	352.90	78.03	40.08	9.29	3.09	4.58	8.41	2.36	117.84
1984	20.18	15.64	4.86	70.40	472.09	201.06	9.33	0.08	0.06	0.07	0.07	0.09	66.16
1985	63.08	61.99	51.45	221.84	160.42	95.47	48.60	11.25	4.59	0.14	0.13	0.16	59.93
1986	5.48	6.54	90.07	129.94	110.50	270.44	63.55	5.97	4.14	1.63	9.23	907.39	133.74
1987	497.42	160.36	94.75	111.24	404.35	323.86	84.67	6.25	5.81	7.06	1.86	0.59	141.52
1988	18.85	28.02	136.89	119.04	647.59	246.84	9.76	0.16	0.17	0.14	0.11	0.13	100.64
1989	0.32	248.16	259.55	66.67	26.76	61.46	42.20	10.35	2.00	0.14	0.20	0.26	59.84
1990	1.61	2.10	31.98	212.09	335.62	137.49	26.51	1.75	0.44	0.15	0.14	0.24	62.51
1991	29.14	25.81	88.86	71.97	106.00	42.36	3.85	0.13	0.08	0.06	0.06	0.09	30.70
1992	0.14	40.02	130.43	37.80	51.58	51.30	17.72	1.07	0.09	0.06	0.08	0.22	27.54
1993	186.13	122.44	41.57	79.51	72.94	67.83	28.70	1.70	0.07	0.11	10.40	6.58	51.50
1994	0.59	0.30	3.54	23.72	7.45	9.81	9.21	5.80	7.68	3.54	0.64	0.22	6.04
Median	3.22	25.65	37.53	104.17	116.55	84.77	28.66	5.96	2.25	0.16	0.19	0.26	34.11
Average	35.98	51.81	79.74	130.11	172.29	110.62	47.03	15.73	6.37	4.86	8.24	24.00	57.23
10%ile	0.21	1.82	4.44	8.05	13.20	12.22	4.10	0.13	0.08	0.08	0.09	0.11	14.93

1: Closed < 2.0 2: Open (closed for) 2.0-5.0 3: Open (Saline) 5.0-30 4: Open (Riverine) > 30.0

< 2.0	31	8	3	2	2	2	4	24	34	49	55	51	31.55%
2.0-5.0	8	8	6	2	1	2	5	7	16	11	4	5	8.93%
5.0-30	18	25	23	13	12	12	27	33	16	8	9	9	24.40%
> 30.0	13	29	38	53	55	54	34	6	4	2	2	5	35.12%

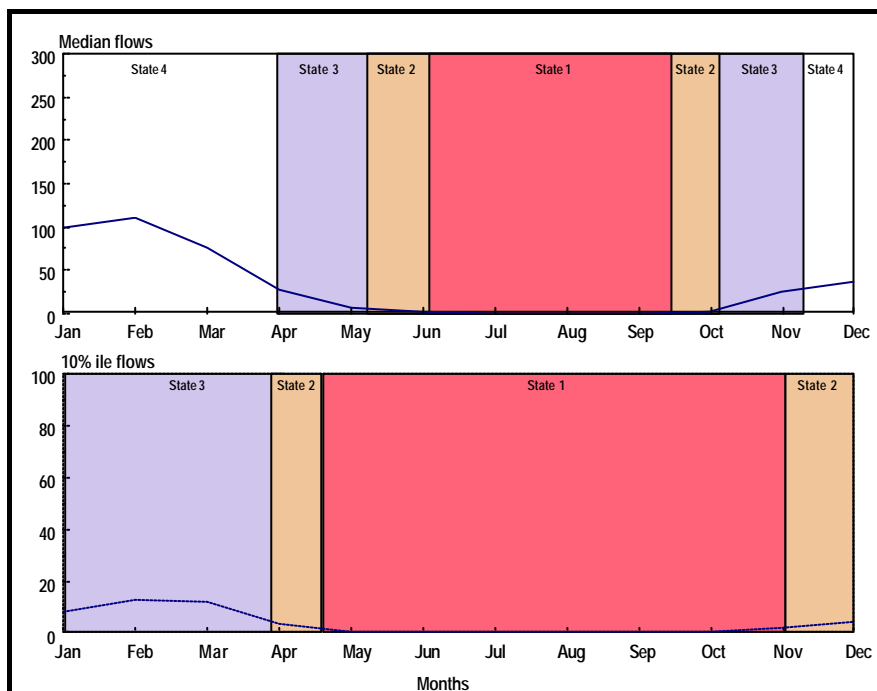
7.2.8 Scenario: Worst case 2

Monthly average simulated runoff data (in m³/s) for the Scenario: Worst Case 2 is provided in Table 7.8. A summary of occurrences per month at intervals 10%, derived from the 70-year simulated data set, is provided below for the Scenario: Worst Case 2:

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
90%ile	65.29	143.66	206.35	256.42	389.90	189.39	77.89	26.65	8.21	7.13	6.73	16.67
80%ile	27.67	86.55	130.81	191.27	315.57	152.61	55.86	16.89	6.21	3.43	2.41	5.26
70%ile	18.90	41.51	86.04	140.09	184.28	124.76	46.19	10.41	4.59	1.86	0.41	1.49
60%ile	6.48	30.92	53.44	121.60	133.43	96.21	36.59	7.39	3.42	0.45	0.22	0.39
50%ile	3.22	25.65	37.53	99.16	109.76	76.50	27.23	5.96	2.25	0.16	0.19	0.26
40%ile	1.23	18.71	23.41	69.58	80.81	55.38	21.89	3.28	0.98	0.14	0.17	0.23
30%ile	0.73	15.28	17.95	43.72	62.28	46.95	13.20	1.74	0.20	0.11	0.13	0.19
20%ile	0.31	3.97	9.71	21.39	26.63	25.53	7.24	0.71	0.11	0.09	0.11	0.15
10%ile	0.21	1.82	4.44	8.05	13.20	12.22	4.10	0.13	0.08	0.08	0.09	0.11
1%ile	0.12	0.21	0.17	0.96	0.42	0.14	0.09	0.08	0.06	0.06	0.06	0.07

To estimate the occurrence and duration of the different Abiotic States during the Scenario: Worst Case 2, median monthly flows and 10%ile flows, simulated for the 70-year period, were used to illustrate the situation for normal and drought periods, respectively (Figure 7.8).

Fig 7.8 Occurrence and duration of different Abiotic States during the Scenario: Worst Case 2, using median monthly flows and 10%ile flows (simulated for the 70-year period), to illustrate variations during normal and drought periods, respectively



Occurrences of States

State 1, associated with prolonged mouth closure, occurs for 31.6 % of the time, while under the Reference Condition Scenario this state never occurred. At median flows, State 1 occurs for 3 months from July to September. At 10%ile low flows, State 1 occurs for 7 months from May to November.

State 2, associated with occasional mouth closure for up to a few days and strong saline intrusion, occurs for 8.9% of the time, while this State did not occur at Reference Condition Scenario. At median flows, State 2 occurs for 2 months, June and October. At 10%ile low flows, State 2 occurs for 2 months, April and December.

State 3, associated with saline intrusion, occurs for 24.9 % of the time and has decreased from 33.2 % at Reference Condition Scenario. At median flows, State 3 occurs for 3 months, April, May and November. At 10%ile low flows, State 3 occurs for 3 months from January to March.

State 4, associated with a river dominated system and no significant saline intrusion, occurs 34.6 % of the time, compared to 66.8 % at Reference Condition Scenario. At median flows, State 4 occurs for 4 months from December to March. At 10%ile low flows, State 4 does not occur.

Highest monthly flows

The average monthly flow during September 1987 is 872 m³/s, which is a reduction to 77 % compared with the Reference Condition. The average of the ten monthly flows during those months, which were the highest at the Reference Condition, was 553 m³/s, which is a reduction to 68 % of that at Reference Condition Scenario.

Table 7.9 Monthly runoff data (in m³/s) for Worst Case 2 Scenario, simulated over a 70-year period

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	AVE
1925	10.06	17.83	7.87	104.31	66.09	59.27	23.29	2.27	4.38	1.24	0.17	15.11	25.99
1926	55.88	49.75	22.87	8.23	85.72	151.66	51.31	2.45	0.10	0.10	0.22	0.26	35.71
1927	4.25	2.19	24.23	78.51	51.68	27.04	11.42	0.23	0.12	0.07	0.11	0.30	16.68
1928	0.83	0.34	4.43	14.79	5.90	118.85	76.75	5.84	6.20	9.32	1.94	27.07	22.69
1929	45.30	99.48	73.62	135.02	108.27	105.10	39.29	1.90	0.06	0.05	0.14	0.45	50.72
1930	1.01	1.99	19.94	158.95	133.96	22.01	5.84	0.13	0.08	0.08	0.09	0.10	28.68
1931	0.16	0.29	1.84	1.30	327.75	232.15	55.52	20.25	13.71	3.87	0.18	0.15	54.76
1932	0.22	2.45	23.77	8.17	17.53	15.33	4.10	0.12	0.07	0.10	0.13	0.11	6.01
1933	0.13	117.72	252.36	578.81	389.78	97.33	62.69	19.98	6.92	4.14	6.22	0.45	128.04
1934	1.94	52.52	401.65	189.51	103.64	80.16	25.52	7.09	7.44	2.98	0.40	0.18	72.75
1935	0.17	0.21	0.18	198.28	273.13	160.22	47.06	74.95	44.69	5.11	0.17	0.20	67.03
1936	0.39	191.33	114.72	145.86	247.15	86.24	7.06	0.11	0.07	0.09	0.10	0.13	66.10
1937	0.21	0.27	122.45	102.59	78.58	32.11	20.08	6.29	6.08	10.64	6.54	0.36	32.18
1938	22.50	18.86	164.10	137.79	441.85	307.63	34.01	7.85	2.75	2.88	0.46	1.47	95.18
1939	2.66	167.38	142.26	48.26	28.20	13.29	8.19	173.01	133.33	27.22	3.71	2.48	62.50
1940	1.29	25.48	204.14	131.09	147.16	103.42	81.65	26.71	3.32	0.10	0.10	0.17	60.38
1941	0.24	0.30	3.86	158.85	223.32	143.73	65.89	9.33	2.98	0.16	0.22	1.13	50.83
1942	7.03	154.14	345.40	432.88	172.58	78.55	512.65	260.50	34.89	62.57	361.05	156.20	214.87
1943	349.08	419.03	226.23	126.77	414.93	175.94	19.71	0.25	5.26	3.40	0.26	18.14	146.58
1944	27.30	15.83	2.45	0.23	3.77	186.43	112.88	7.84	0.15	0.10	0.07	0.07	29.76
1945	0.20	0.21	0.14	20.24	19.40	49.24	22.99	0.14	0.09	0.07	0.06	0.07	9.40
1946	6.53	40.15	19.82	5.68	76.03	72.09	24.69	4.17	6.29	3.08	0.26	0.20	21.58
1947	0.32	138.94	132.34	114.39	73.48	50.36	31.49	6.37	0.34	0.10	0.08	0.08	45.69
1948	1.16	6.60	9.00	120.42	144.05	76.01	51.30	17.67	2.91	0.18	0.13	0.15	35.80
1949	4.84	42.92	113.83	57.07	9.24	45.58	44.41	13.53	1.33	0.10	0.13	0.18	27.76
1950	0.25	3.78	54.40	44.00	21.76	14.98	7.28	1.07	0.09	0.08	19.34	15.36	15.20
1951	15.84	4.01	15.83	220.59	144.26	32.56	11.20	4.75	1.04	2.48	0.20	0.14	37.74
1952	0.14	27.94	41.01	43.05	339.70	164.17	20.24	1.99	0.10	0.08	0.13	0.24	53.23
1953	0.33	22.03	17.97	8.27	124.98	81.53	19.45	12.30	7.90	1.14	0.19	1.51	24.80
1954	88.32	201.85	81.49	260.37	391.00	203.05	28.61	5.96	0.90	0.16	0.10	0.14	105.16
1955	3.77	23.03	30.72	3.62	126.82	148.96	55.58	5.96	0.47	0.14	0.16	0.26	33.29
1956	2.61	83.32	481.58	435.09	133.07	124.22	65.56	16.70	4.54	20.26	16.99	348.78	144.39
1957	504.39	149.84	22.51	228.81	188.42	50.72	86.80	26.65	3.57	0.13	0.10	0.19	105.18
1958	0.27	13.97	46.61	52.01	117.52	47.54	6.64	38.34	13.90	3.11	0.20	0.28	28.37
1959	10.12	46.47	40.89	6.96	20.40	24.62	31.81	12.15	1.89	0.15	0.14	0.23	16.32
1960	2.08	40.91	292.20	155.49	26.12	28.85	60.10	24.05	7.69	0.51	0.23	0.28	53.21
1961	0.86	14.44	12.73	65.19	82.30	48.47	26.65	3.40	0.14	0.08	0.19	0.27	21.23
1962	0.45	30.04	81.04	105.76	41.25	66.31	35.82	6.54	5.02	135.24	80.05	1.94	49.12
1963	1.03	27.53	12.39	122.92	74.18	6.80	5.93	0.80	1.26	0.12	0.13	0.20	21.11
1964	135.24	113.78	34.18	74.74	53.40	0.12	0.10	0.13	4.44	5.17	4.84	3.32	35.79
1965	6.39	16.79	9.89	120.72	86.93	2.91	1.89	0.72	0.24	0.18	0.17	0.23	20.59
1966	0.31	4.30	28.08	255.98	312.52	188.09	111.64	23.24	4.60	0.41	0.18	0.14	77.46
1967	0.30	20.13	18.03	8.85	0.55	8.40	6.32	0.20	0.11	0.08	0.24	1.05	5.35
1968	1.12	2.08	26.43	24.43	13.60	144.48	88.34	19.29	6.69	1.33	0.19	0.28	27.35
1969	25.41	17.90	17.90	17.93	46.32	12.49	0.63	0.22	0.37	0.24	2.09	9.10	12.55
1970	40.43	32.23	8.94	38.02	23.39	3.73	13.97	69.72	39.97	7.76	5.29	2.26	23.81
1971	17.98	18.49	72.10	92.94	118.11	156.41	55.76	8.79	5.54	1.73	0.52	0.23	45.72
1972	0.25	6.50	5.23	5.24	198.86	103.92	37.74	12.07	2.75	0.11	6.40	35.79	34.57
1973	21.95	32.30	17.16	151.74	182.51	77.00	38.41	10.55	3.76	0.74	0.17	0.12	44.70
1974	0.08	17.68	140.00	203.21	347.07	126.00	27.81	6.93	1.44	0.14	0.12	47.18	76.47
1975	26.02	33.86	103.93	295.98	416.36	616.77	244.35	31.31	11.00	2.18	0.17	0.23	148.51
1976	19.03	20.94	41.54	125.75	109.03	58.10	26.01	3.11	0.13	0.09	0.13	16.50	35.03
1977	38.47	27.64	19.46	274.28	210.25	108.40	45.82	8.65	1.61	0.15	0.21	1.48	61.37
1978	85.21	57.19	52.80	42.99	121.56	49.11	4.55	1.25	0.14	0.35	4.95	9.12	35.77
1979	4.58	2.44	4.44	68.35	76.14	23.32	0.06	0.07	0.07	0.06	0.09	9.91	15.79
1980	6.45	23.97	58.16	145.47	530.19	164.55	4.05	0.67	2.49	0.34	0.96	4.93	78.52
1981	2.34	25.83	12.05	21.68	9.65	25.76	19.61	2.64	0.21	0.12	0.09	0.12	10.01
1982	54.19	32.79	5.82	3.73	0.14	0.14	2.07	1.14	0.09	0.14	0.37	0.33	8.41
1983	0.79	138.72	190.56	585.31	352.90	78.03	40.08	9.29	3.09	4.58	8.41	2.36	117.84
1984	20.18	15.64	4.86	70.40	472.09	201.06	9.33	0.08	0.06	0.07	0.07	0.09	66.16
1985	63.08	61.99	51.45	221.84	160.42	95.47	48.60	11.25	4.59	0.14	0.13	0.16	59.93
1986	5.48	6.54	90.07	129.94	110.50	130.24	56.28	5.97	4.14	1.63	9.23	872.04	118.50
1987	468.77	142.98	84.83	95.73	361.69	316.67	77.47	6.25	5.81	7.06	1.86	0.59	130.81
1988	18.85	28.02	136.89	119.04	571.77	239.64	9.76	0.16	0.17	0.14	0.11	0.13	93.72
1989	0.32	248.16	259.55	66.67	26.76	61.46	42.20	10.35	2.00	0.14	0.20	0.26	59.84
1990	1.61	2.10	31.98	212.09	335.62	137.49	26.51	1.75	0.44	0.15	0.14	0.24	62.51
1991	29.14	25.81	88.86	71.97	106.00	42.36	3.85	0.13	0.08	0.06	0.06	0.09	30.70
1992	0.14	40.42	130.43	37.80	51.58	51.30	17.72	1.07	0.09	0.06	0.08	0.22	27.54
1993	186.13	122.44	41.57	79.51	72.94	67.83	28.70	1.70	0.07	0.11	10.40	6.58	51.50
1994	0.59	0.30	3.54	23.72	7.45	9.81	9.21	5.80	7.68	3.54	0.64	0.22	6.04
Median	3.22	25.65	37.53	99.16	109.76	76.50	27.23	5.96	2.25	0.16	0.19	0.26	32.32
Average	35.07	51.36	77.94	121.66	156.59	97.62	42.86	15.49	6.37	4.86	7.99	23.15	53.41
10%ile	0.21	1.82	4.44	8.05	13.20	12.22	4.10	0.13	0.08	0.08	0.09	0.11	14.93

1: Closed < 2.0 2: Open (closed for) 2.0-5.0 3: Open (Saline) 5.0-30 4: Open (Riverine) > 30.0

< 2.0	31	8	3	2	2	2	4	24	34	49	55	51	31.55%
2.0-5.0	8	8	6	2	1	2	5	7	16	11	4	5	8.93%
5.0-30	18	25	23	13	13	13	29	33	16	8	9	9	24.88%
> 30.0	13	29	38	53	54	53	32	6	4	2	2	5	34.64%

7.3 COMPARISON OF ABIOTIC STATES AMONG DIFFERENT SCENARIOS

Table 7.10 is included summarising the occurrences of the different states for each scenario in terms of percentages.

Table 7.10 Percentage occurrence of States per scenario

Scenario	State 1 (%)	State 2 (%)	State 3 (%)	State 4 (%)
Reference Condition	0	0	33.2	66.8
Present State	0.6	6.2	42.0	51.0
River Category A	0	0.4	38.0	61.6
River Category B	0	0.4	48.8	50.8
River Category C	0	0.5	62.6	36.9
River Category D	0	0.7	68.0	31.3
Worst Case 1	31.6	8.9	24.4	35.1
Worst Case 2	31.6	8.9	24.9	34.6

Tables 7.11 and 7.12 summarise the occurrence of the different abiotic states for the different flow scenarios under normal and drought conditions, respectively.

Table 7.11 Comparison of the distribution and occurrence of abiotic states at the different runoff scenarios, for normal (median) flow conditions states (flows of < 30 m³/s are shaded)

MEDIAN	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Reference	4	4	4	4	4	4	4	4	3	3	3	3
Present	3	4	4	4	4	4	4	3	3	3	3	3
River Category A	4	4	4	4	4	4	4	4	3	3	3	3
River Category B	3	4	4	4	4	4	4	3	3	3	3	3
River Category C	3	3	4	4	4	4	4	3	3	3	3	3
River Category D	3	3	4	4	4	4	3	3	3	3	3	3
Worst 1	2	3	4	4	4	4	3	3	2	1	1	1
Worst 2	2	3	4	4	4	4	3	3	2	1	1	1

Table 7.12 Comparison of the distribution and occurrence of abiotic states at the different runoff scenarios, for drought (10%ile) low conditions states (flows of < 30 m³/s are shaded)

10%ILE	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Reference	3	3	4	4	4	4	4	3	3	3	3	3
Present	3	3	3	4	4	4	3	3	3	3	2	2
River Category A	3	3	3	3	4	4	3	3	3	3	3	3
River Category B	3	3	3	3	4	4	3	3	3	3	3	3
River Category C	3	3	3	3	4	3	3	3	3	3	3	3
River Category D	3	3	3	3	3	3	3	3	3	3	3	3
Worst 1	1	1	2	3	3	3	2	1	1	1	1	1
Worst 2	1	1	2	3	3	3	2	1	1	1	1	1

In Table 7.13 the 10 highest average monthly flows for Reference Condition Scenario have been selected.

Table 7.13 Reduction of highest average monthly flows (m³/s) for different scenarios compared to Scenario 1 (Natural conditions)

Year/month	Reference Condition	Present State	River Category A	River Category B	River Category C	River Category D	Worst Case 1	Worst Case 2
1934/01	968	826	925	918	913	908	608	578
1939/02	803	706	639	751	744	739	495	441
1955/02	723	633	678	671	664	659	626	391
1956/12	757	660	508	517	518	497	487	481
1976/03	673	666	635	628	622	618	623	616
1981/02	729	609	499	676	669	664	611	530
1984/01	733	635	420	454	493	493	585	585
1985/02	877	726	581	625	648	627	472	472
1987/09	1132	1010	929	930	924	910	907	872
1989/02	725	679	654	675	668	663	647	571
Average	812	715	646	684	686	677	606	553
Average %	100	88	79	84	84	83	74	68

8 ASSESSMENT OF SEDIMENT DYNAMICS

8.1 INTRODUCTION

The catchment area of the Thukela River at the estuary is 29000 km². The Thukela River is relatively steep and has a high sediment transport capacity with a mean annual sediment yield (present day) of about 9.3 million ton (based on simulations done during this study).

At the estuary the main channel is relatively wide (about 500 m). The sediment consists mostly of fine sand ($d_{50} = 0.22\text{mm}$ at the N2-bridge) (Basson and Rooseboom, 1990). The alluvial bed is deep with bedrock 55 m below sea level at the N2-bridge (Basson and Rooseboom, 1990). At flow gauging station V5H002 upstream of John Ross Bridge, the river is steep (1:130) with bedrock conditions, but downstream of the N2-bridge at the estuary the general slope is much flatter at 1:1500.

The estuary is dominated by floods in the river and is relatively shallow and short (5 km in length). During low flow conditions ($<10\text{ m}^3/\text{s}$) the river meanders through several sand banks in the main channel. The Thukela River flood peaks are high and therefore the system is very dynamic with rapid changes in the river morphology from time to time. During falling stages of flood hydrographs sediment deposition has been observed in the river mouth (see Figure 8.1), but this sediment is later scoured by the south to north long-shore currents. A typical morphology of the estuary is shown in Figure 8.2.

Fig 8.1 Sediment deposition (May 1976)

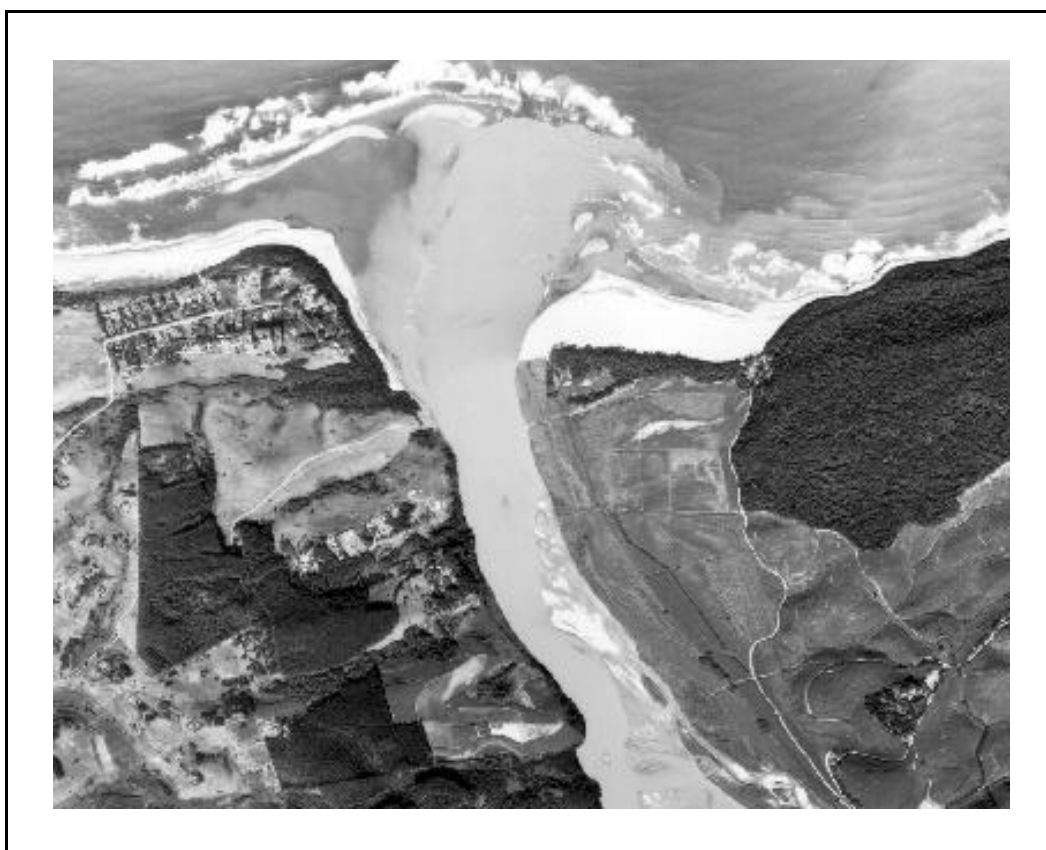


Fig 8.2 **Aerial view of Thukela Estuary**



Several large dams have been constructed in the catchment such as Woodstock, Spioenkop, Chelmsford, Zaaihoek and Wagendrift. These dams would trap most of the sediment yield in their respective catchments and would also attenuate floods. The impact of these dams on the estuary would however be minimal, since they are located high up in the catchment. The ratio of the catchment area presently under dam development to the total catchment area at the estuary is only 0.2 (as set out in Table 8.1). In contrast, with the proposed Jana and Mielietuin Dams that ratio increases to 0.47, which suggest that these dams will have a somewhat greater effect than the existing dams on the estuary. Also the fact that the ratio of total reservoir capacity to mean annual runoff is about 30% lower without the two proposed dams means that more spilling takes place without these dams. All of this indicates that any change between the reference and present day condition of the fluvial morphology of the estuary because of water resources development to date, would be small, with an estimated reduction in flood peaks of about 8%.

However, significant land use changes and overgrazing to date could have led to an increase in the sediment yield, meaning that under natural conditions the sediment yield could have been around 200 ton/km².a. This would mean that the estuary was a lot longer (around 8.5km) and also deeper compared to the present day. Further catchment developments, again causing the sediment yield to increase, could have a significant effect on the Thukela Estuary fluvial morphology.

Table 8.1 Changes in dam development from present day to post-dam

	$\frac{\sum \text{Catchment area(Dams)}}{\text{Total catchment area}}$	$\frac{\sum \text{Re servoir capacity}}{\sum \text{MAR}^1}$
Existing dams	0.2	0.63
Existing & proposed dams	0.47	0.84

1 Mean annual runoff at dam site

8.2 FLUVIAL MORPHOLOGICAL SIMULATION SCENARIOS

In order to assess how the sediment dynamics of the Thukela Estuary might change with further catchment development, mathematical modelling of the hydraulics and morphology of the Thukela Estuary was carried out. Six scenarios were selected:

- **Scenario 0:** “natural” conditions (sediment yield of 200 ton/km².a).
- **Scenario 1:** present day (corresponding to the ‘Present Day’ scenario of the Reserve Determination).
- **Scenario 2:** full demand placed on proposed dams, with environmental flow releases (worst case in terms of floods).
- **Scenario 3:** scenario 1 including a resetting flood.
- **Scenario 4:** scenario 2 including a resetting flood.
- **Scenario 5:** scenario 2 with a higher sediment yield of 600 ton/km².a.

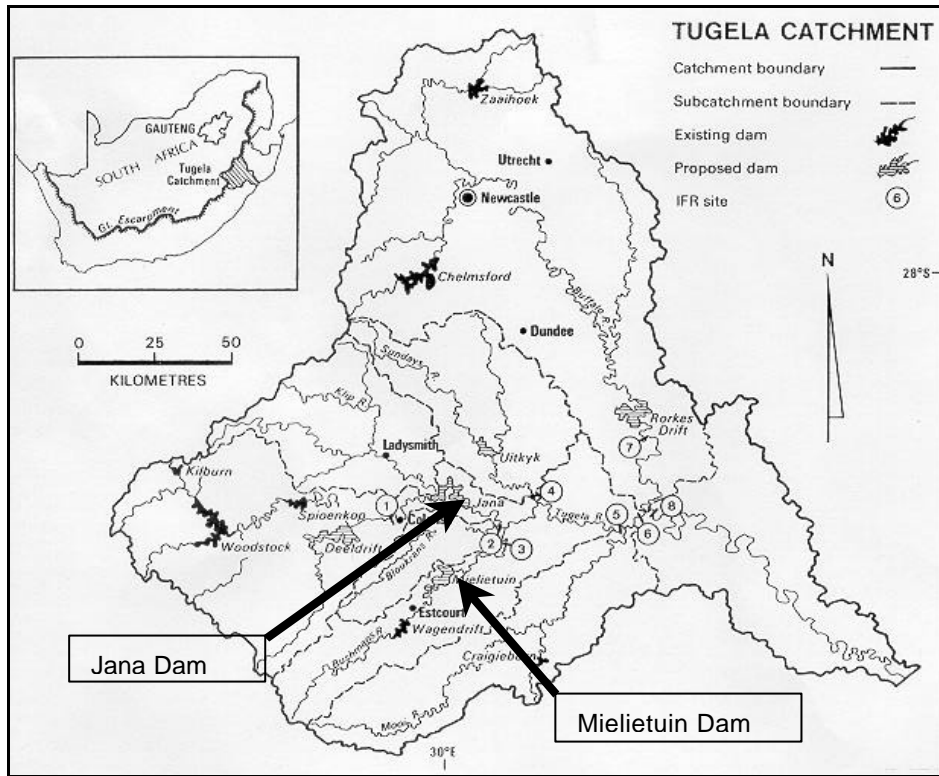
Different scenarios than for the reserve determination were selected since most of those described in the hydrological report (Hughes, 2002), except Natural and Present Day, are basically the same in terms of floods and therefore will not yield different results in terms of sediment dynamics.

The 15-year period used for the simulations was a combination of flows from 1962 to 1967, and 1990 to 2000. This was done since it yielded the longest continuous and representative flow series from observed flow records (primary, break point data of DWAF).

8.3 FLOOD ROUTING

Before any estuary simulations could be done the flows from the proposed dam sites had to be routed to the estuary, since both the proposed Jana Dam (Thukela River) and the Mielietuin Dam (Bushmans River) are situated relatively high in the catchment, with Jana Dam approximately 270km from the estuary as set out in Figure 8.3.

Fig 8.3 Thukela catchment layout (Rowntree & Wadeson, 1999)



The one-dimensional mathematical model MIKE 11 (Danish Hydraulics Institute) was set up for a 270 km reach of the Thukela River with cross-sections taken from 1:10 000 orthophotos at 3km intervals. Only the hydrodynamic module was set up because this exercise was intended solely for the purpose of routing the flows from the dam sites to the estuary and not for morphological investigations. Tributary flows were included for all major sub-catchments, with gauging stations on the Mooi, Buffels, Bushmans and Sundays River. A schematic layout is shown in Figure 8.4. The observed flows were scaled up to account for the whole sub-catchment, based on a function of the mean annual runoff (MAR) ratio (Table 8.2). Ungauged catchments close to the estuary were considered by scaling the flows from the Buffels River, since the MAR's are very similar.

Fig 8.4 Schematic layout of Thukela and major tributaries

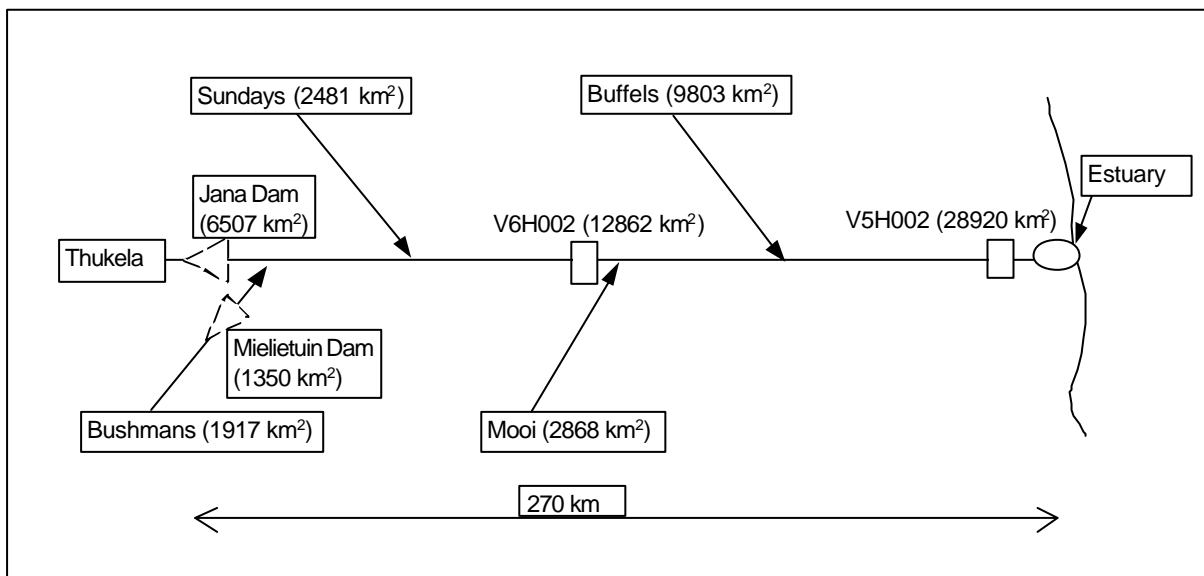
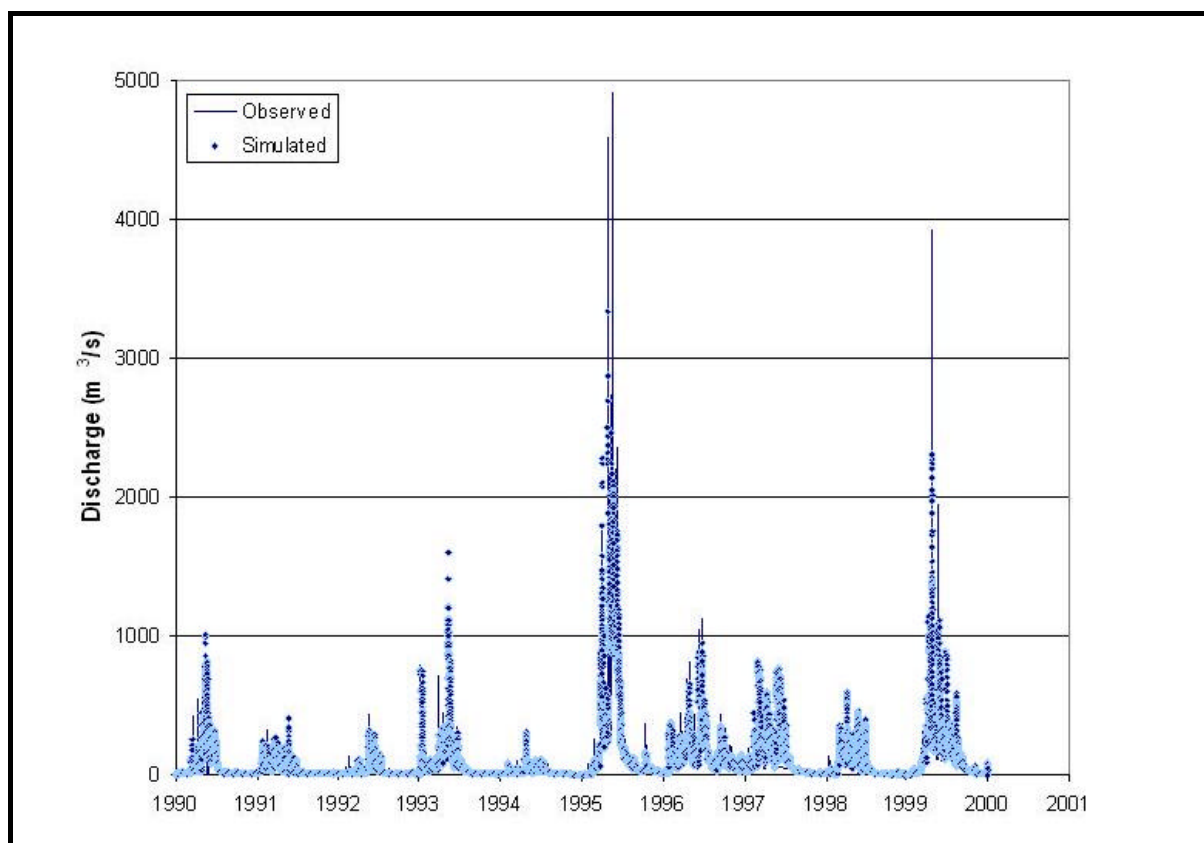


Table 8.2 Scaling factors

Tributary	Catchment area at gauging station (km²)	Total catchment area (km²)	MAR at gauging station (Mm³)	Total MAR (Mm³)	Scaling factor
Mooi (V2H004)	1546	2868	292.3	402.5	1.37
Bushmans (V7H020)	744	1917	222.1	312.7	1.4
Buffels (V3H010)	5887	9803	701.9	1016.8	2
Sundays (V6H004)	658	2481	86.5	224.3	2.6

The hydrodynamic model was calibrated based on observed flows at two gauging stations on the Thukela River (V6H002 at Thukela Ferry and V5H002 at Mandini). The discharge table limit had to be extended for V5H002 from 1990 onwards to include medium and large floods. This made the calibration process somewhat difficult since extending the discharge table introduces a certain amount of inaccuracy. However, the simulated flows could be predicted to within 30% of the observed floods, which is similar to the accuracy of the gauging stations. The observed and simulated flows at Mandini are shown in Figure 8.5.

Fig 8.5 Observed and simulated flows at Mandini (V5H002)



The present day flows (without Jana and Mielietuin Dam) could thus be obtained at the estuary. In order to generate flows for the second scenario (including both Jana and Mielietuin Dams), hydrological reservoir routing was carried out with the proposed dam characteristics taken from the DWAF website (Table 8.3).

Table 8.3 Reservoir characteristics

	FSC ¹ (million m ³)	FSL ² (masl)	Spillway length (m)	HFY ³ (million m ³ /a)	MAR at dam site (million m ³)
Jana Dam	1500	RL 860	165	507.7	1446
Mielietuin Dam	350	RL1025	69	192.8	288

¹ Full Supply Capacity

² Full Supply Level

³ Historical Firm Yield

Observed flows at gauging stations V1H001 for Jana Dam and V7H020 for Mielietuin Dam were used as inflows. The historical firm yield (WRP, 2001) was taken as the net demand (including environmental releases of 13% of the MAR as set out in the hydrological report (Hughes, 2001) for Reserve B). The pre-dam flows at the proposed Jana Dam and Mielietuin Dam sites, as well as the post-dam flows are shown in Figures 8.6 to 8.9.

Similar to the present day scenario the flows thus obtained were routed to the estuary. The pre-dam and post-dam flows at the estuary are shown in Figures 8.10 and 8.11.

Fig 8.6 Pre-dam flows at proposed Jana Dam site

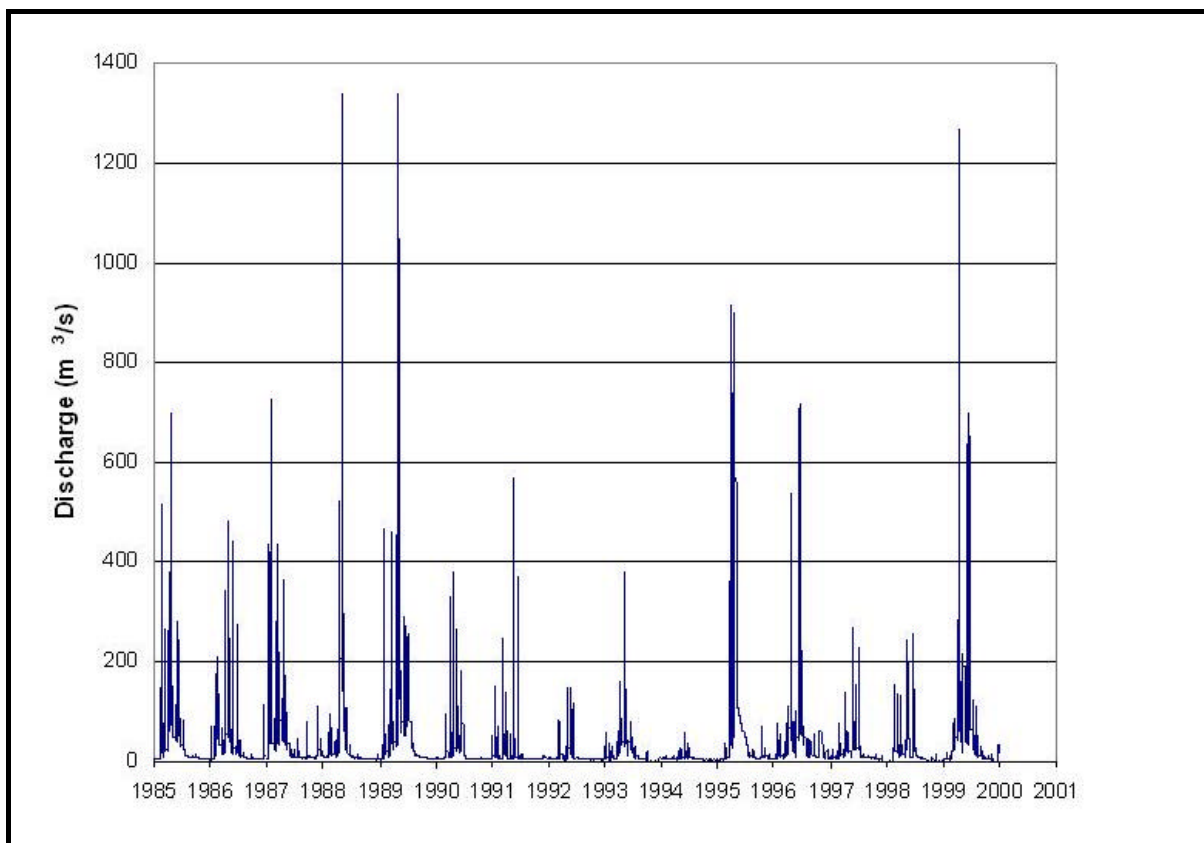


Fig 8.7 Post-dam flows at proposed Jana Dam site

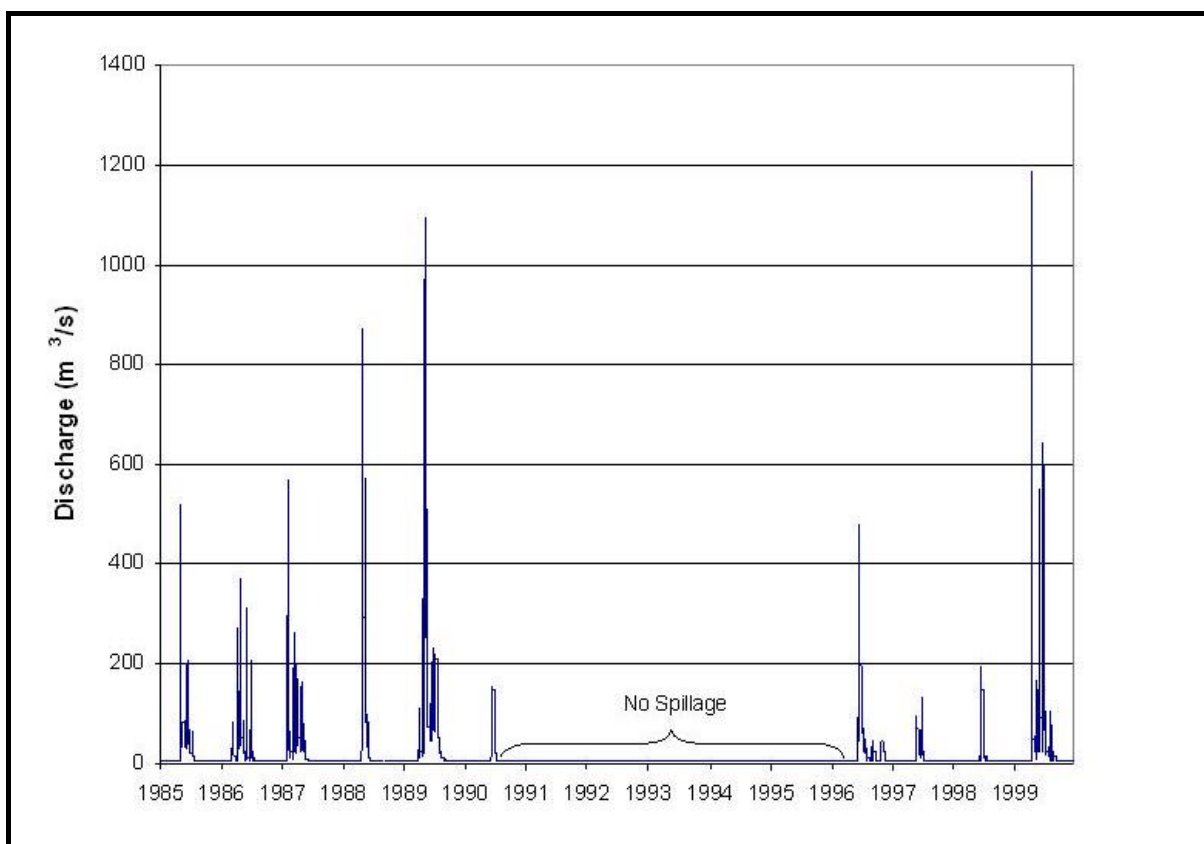


Fig 8.8 Pre-dam flows at proposed Mielietuin Dam site

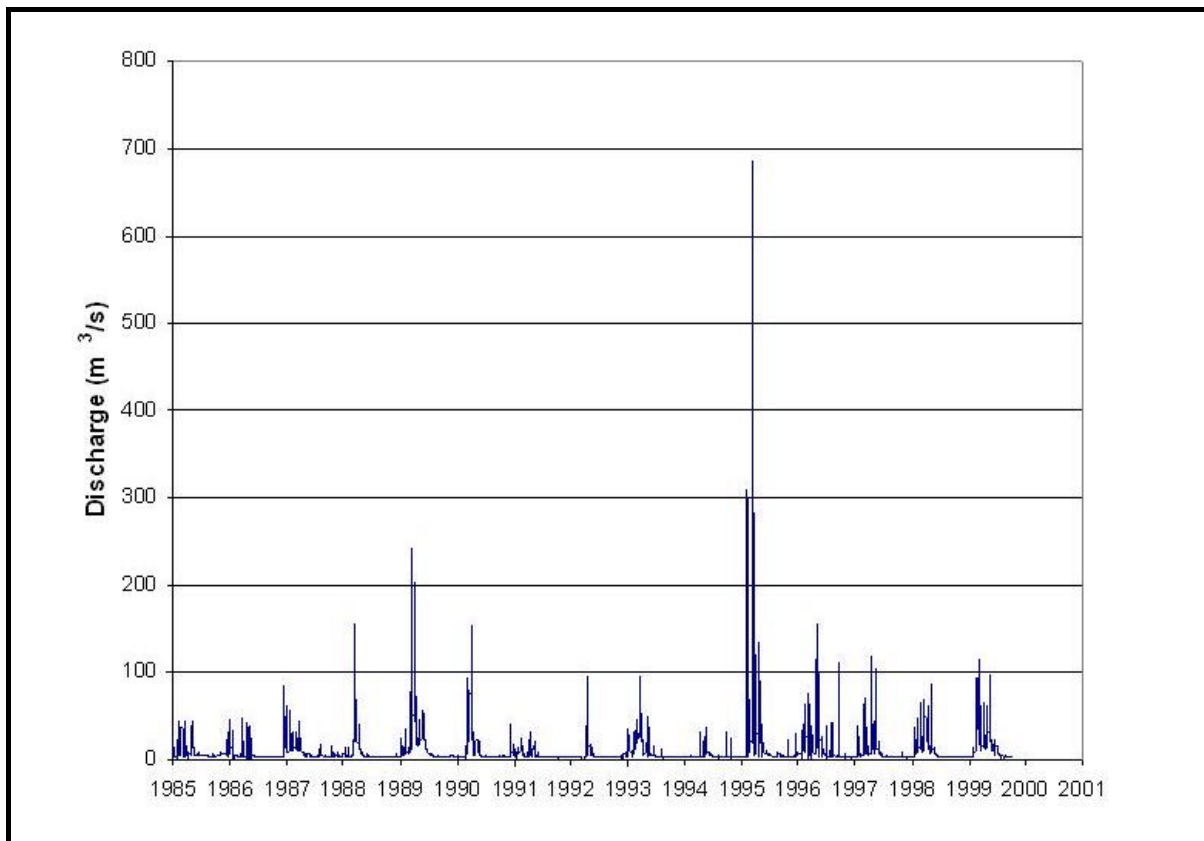


Fig 8.9 Post-dam flows at proposed Mielietuin Dam site

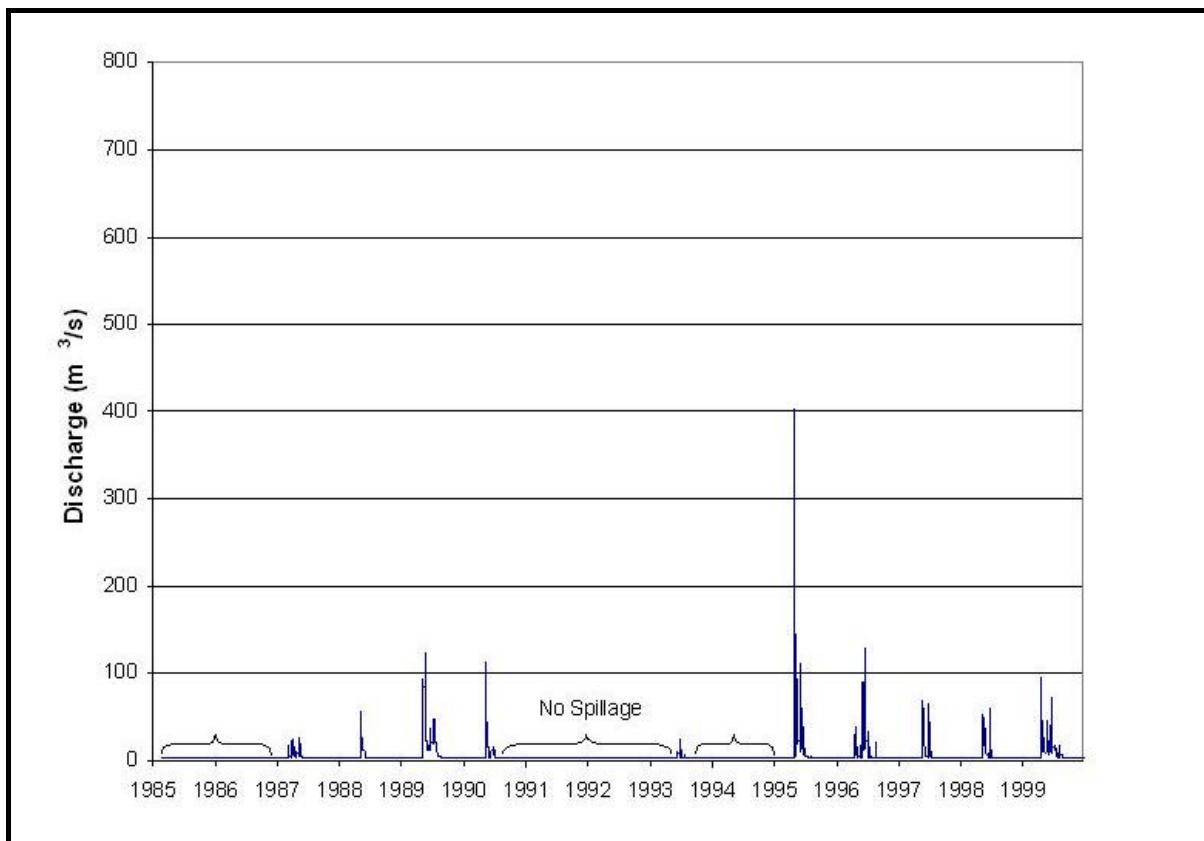


Fig 8.10 Pre-dam flows at Thukela Estuary

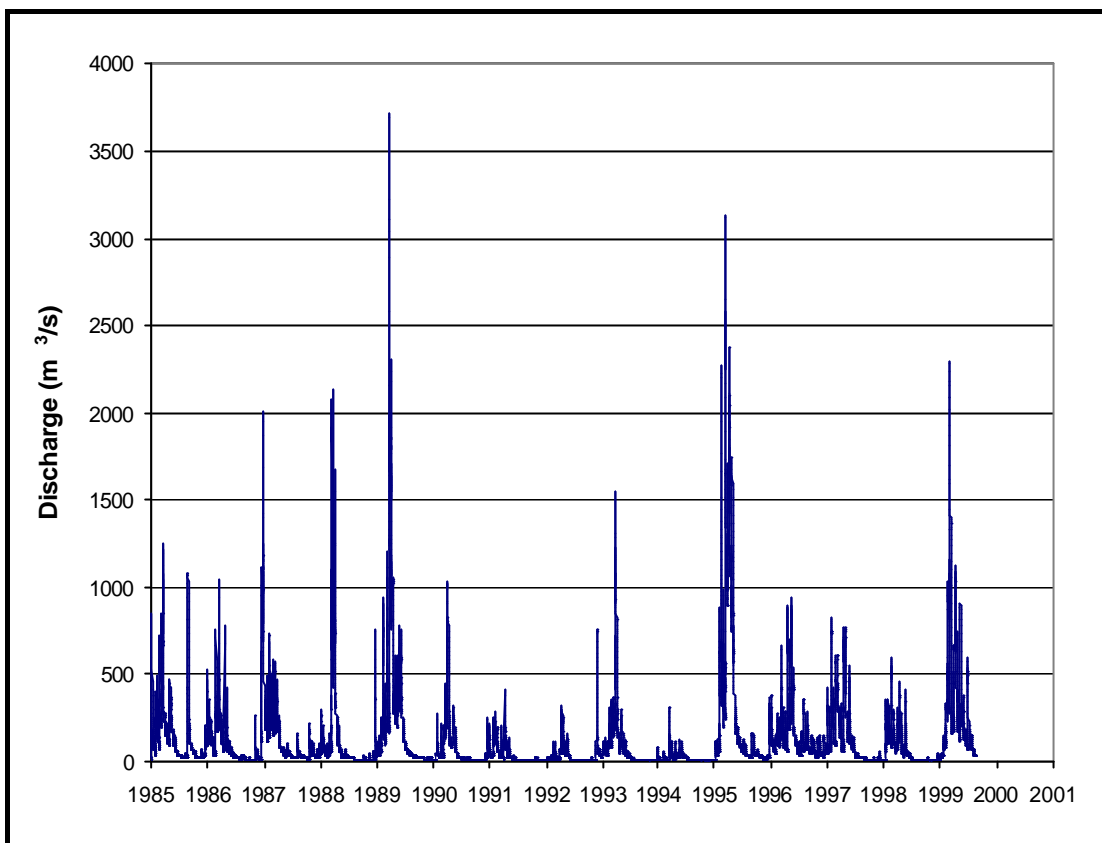
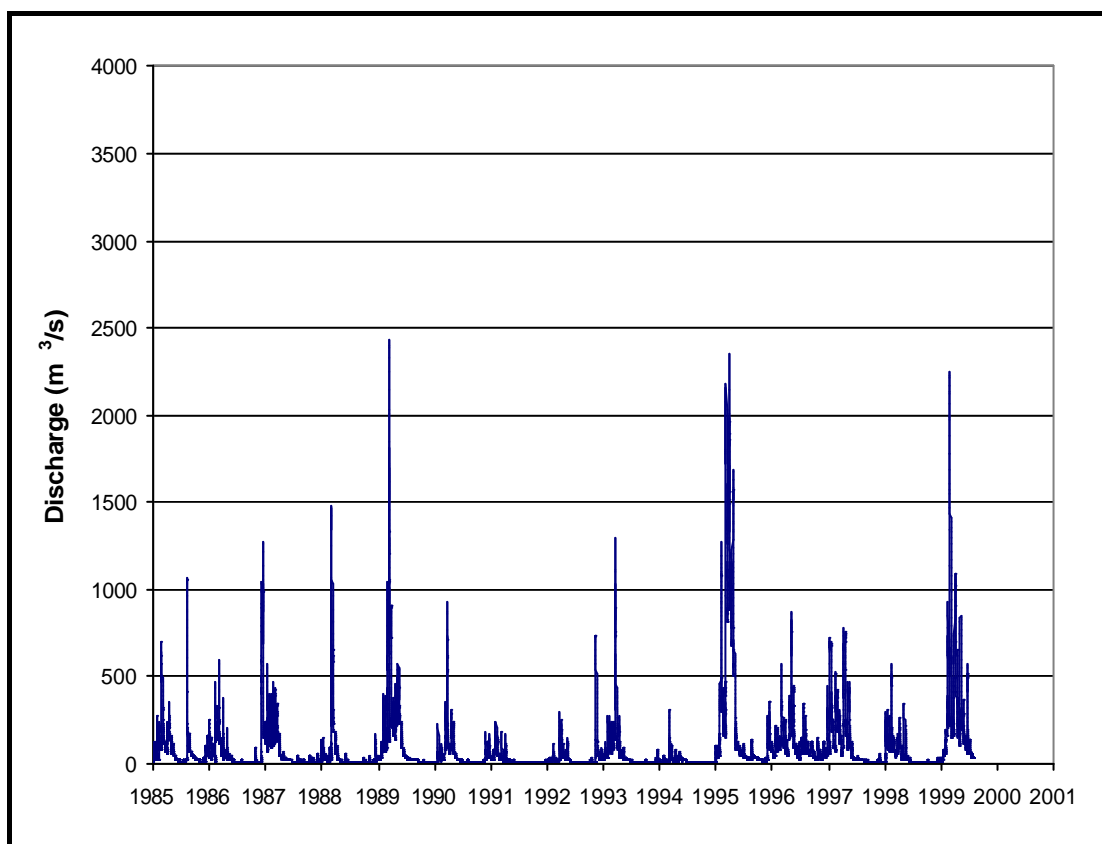


Fig 8.11 Post-dam flows at Thukela Estuary



As can be seen from these figures, the dams do not have a very dramatic effect on the flows at the estuary, because they are located relatively far up in the catchment and the incremental downstream catchment area comprises still more than 50% of the total catchment. Immediately downstream of both dams, however, many years have no flood spillage, which will have to be rectified by the release of freshets and floods for the river.

The present day, as well as post-dam recurrence interval flood peaks is indicated in Table 8.4. The present day recurrence interval flood peaks were determined based on the statistical analysis of the complete flow record V5H002 (39 years). The post-dam flood peaks were determined by adjusting the pre-dam flood peaks (based on the complete flow record) by a factor based on the reduction in flood peaks during the 15 years simulated as a result of the dam developments.

Table 8.4 Pre-dam and Post-dam flood peaks

Recurrence interval (Years)	Present day flood peaks (m ³ /s)	Post-dam flood peaks (m ³ /s)
2	1000	850
10	4500	3600
20	6800	5400
50	11000	8700

8.4 THUKELA ESTUARY MODEL SET-UP

With the generated flow sequences for the scenarios the model for the estuary could be set up. Cross-sections were obtained from a survey done by DWAF in 1996 (Appendix 8), spaced between 200 and 500m apart (closer at the mouth). The model extends from the John Ross Bridge to the estuary mouth over 13km. The Manning n-value was taken as 0.042 for the main channel and 0.055 for the more densely vegetated higher ground (see Figure 8.4), as obtained from calibrations done in 1990 (Basson and Rooseboom, 1990).

Two sediment fractions ($d_1 = 0.035\text{mm}$ and $d_2 = 0.22\text{mm}$) were specified in the bed material (see Table 8.5). The first fraction represents the median particle size of bed samples taken during 1990 at the N2-bridge (Basson and Rooseboom, 1990). More samples taken at the estuary in 2001 are shown in Table 8.6. The data are from core samples taken in the estuary. Although these samples do not indicate the presence of cohesive material, it was found during a site visit that there are areas with cohesive sediments as indicated in Figure 8.12. Fine sediment deposition occurs at the banks in reed beds. Finer material is generally present in the suspended load, which is not always present in the bed since it generally moves right through the system. It was found that about 50% of the suspended load consists of sediment finer than 0.22 mm, which was represented by fraction 2 during the simulations.

Table 8.5 Graded sediment (as simulated)

	Fraction 1: 0.035 mm	Fraction 2: 0.22 mm
Bed material	5%	95%
Suspended load	50%	50%

Table 8.6 Sediment core samples/grading analysis

No 1	Depth (m)	Coordinate: 29°12'92"S 31°28'50"E				
Sieve Size (mm)	0 - 0.15	0.15 - 0.3	0.3 - 0.45	0.45 - 0.6	0.6 - 0.8	
4.75	100%	100	100	100	99.96	
2.36	99.68	99.6	99.96	99.87	99.78	
1.18	97.56	98.46	99.16	97.38	98.58	
0.6	76.99	85.85	91.27	69.22	79.1	
0.3	33.62	41.68	58.42	20.31	23.32	
0.15	1.92	1.22	1.28	1.63	0.7	
0.075	0.06	0.08	0.04	0.06	0.04	
<0.075	0	0	0	0	0	
No 2	Depth (m)	Coordinate: 29°13'30"S 31°29'19"E				
Sieve Size (mm)	0 - 0.15	0.15 - 0.3	0.3 - 0.45	0.45 - 0.6	0.6 - 0.75	
4.75					100	
2.36	100%	100	100	100	99.98	
1.18	99.78	99.86	99.9	99.94	99.82	
0.6	90.39	92.55	93.35	93.51	98.28	
0.3	29.64	21.82	23.44	21.49	40.5	
0.15	1.02	0.82	0.76	0.74	2.06	
0.075	0.02	0	0	0	0.04	
<0.075	0	0	0	0	0	
No 3	Depth (m)	Coordinate: 29°13'60"S 31°29'87"E				
Sieve Size (mm)	0 - 0.15	0.15 - 0.3	0.3 - 0.45	0.45 - 0.6	0.6 - 0.75	
4.75						
2.36						
1.18	100%	100	100	100	100	
0.6	98.98	98.6	99.22	98.86	98.92	
0.3	42.82	45.35	29.74	45.93	45.98	
0.15	1.8	1.56	1.34	2.36	1.62	
0.075	0.06	0.06	0.02	0.1	0.06	
<0.075	0	0	0	0	0	
No 4	Depth (m)	Coordinate: 29°13'60"S 31°30'07"E				
Sieve Size (mm)	0 - 0.15	0.15 - 0.3	0.3 - 0.45	0.45 - 0.6	0.6 - 0.75	0.75 - 0.9
4.75						
2.36	100%	100	100	100	100	100
1.18	99.74	99.8	99.76	99.7	99.28	99.82
0.6	86.62	87.92	88.33	86.07	73.59	93.14
0.3	19.7	30.32	31.97	23.28	13.02	33.3
0.15	0.42	0.7	0.9	0.66	0.14	0.8
0.075	0	0	0	0	0	0
<0.075	0	0	0	0	0	0
No 5	Depth (m)	Mouth				
Sieve Size (mm)	0 - 0.15	0.15 - 0.3	0.3 - 0.45			
4.75						
2.36	100%					
1.18	99.96	100	100			
0.6	82.47	91.64	93.7			
0.3	18.92	15.19	27.65			
0.15	0.8	0.42	1.4			
0.075	0	0	0			
<0.075	0	0	0			

Fig 8.12 Thukela Estuary

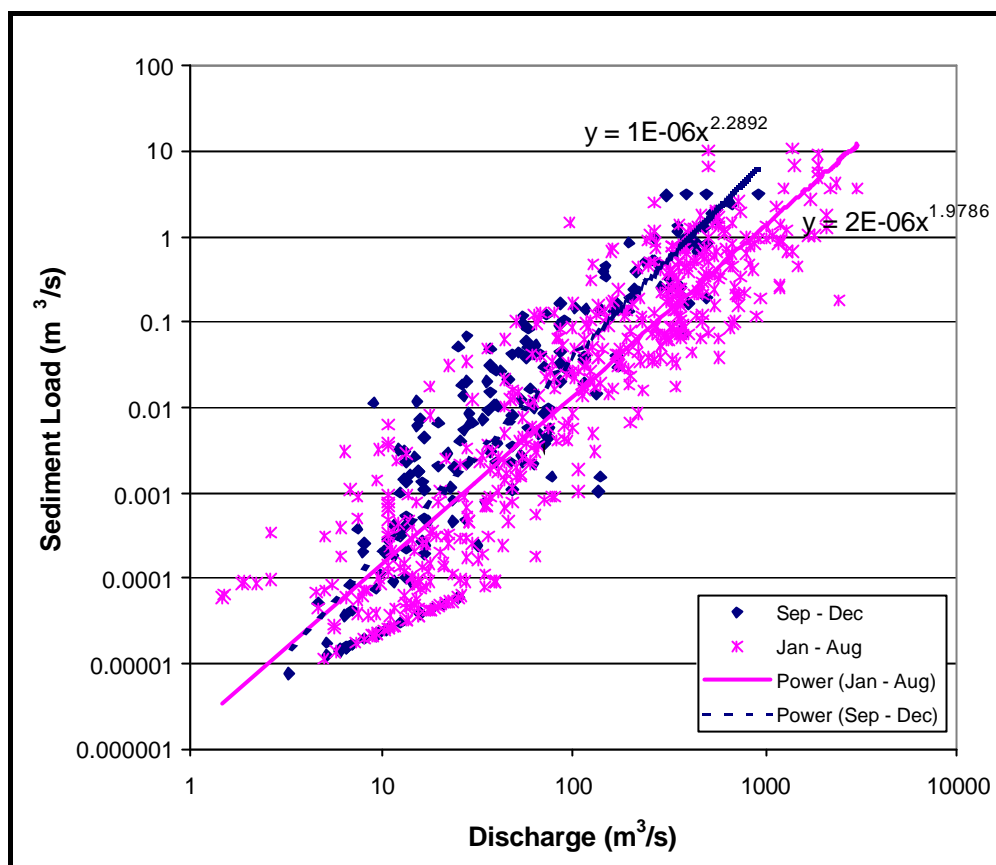


Fig 8.13 Presence of cohesive sediment at Thukela Estuary (Left bank at mouth)



The upstream boundary of the model consisted of the above-mentioned flow sequence together with a sequence of sediment loads. The sediment loads were determined with the aid of a sediment load–discharge rating curve obtained from suspended sediment samples taken between 1971 and 1984 at V5H002. There was a seasonal variability in the suspended sediment samples, with higher concentrations observed during the beginning of the rainy season. For this reason a different rating curve was used between September and December than for the rest of the year as indicated in Figure 8.14.

Fig 8.14 Sediment load-discharge relationship



The sediment loads determined with these rating curves had to be adjusted in order to obtain the adopted sediment yield. There is a significant variability (between 184 and 559 ton/km².a) in the sediment yields for different parts of the Thukela system found in literature (Dollar, 2001), but only those applicable at the estuary are shown in Table 8.7.

Table 8.7 Sediment yields

Reference (Dollar, 2001)	Place	Catchment area (km ²)	Yield (ton/km ² .a)
Orme (1974)	Thukela	29046	375
Dingle & Scrutton (1974)	Thukela	29046	427
Flemming & Hay (1983)	Thukela	29046	386
Goodlad (1986)	Thukela	29046	406
Nicholson (1983)	Thukela	29046	390

Average value

The average sediment yield for the lower Thukela obtained from those shown in Table 8.7 is about 400 ton/km².a. The sediment yield obtained from the suspended sediment samples is the similar at 395 ton/km².a (including 25% for non-uniformity and bed load). A maximum sediment yield of 571 ton/km².a was found by Rooseboom (1992), but this was obtained from samples taken at Colenso, which is high up in the catchment, which generally has a higher sediment yield than further downstream, and the period was also relatively wet (1950 – 1958). A sediment yield of 400 ton/km².a was therefore thought to be representative for the present state.

The sediment yield under natural conditions is difficult to determine, since very little information is available. There is, however, an indication that the sediment yield could have been lower than at present from observations that indicate that the estuary was a lot longer than at present. The lowest sediment yield from those mentioned above is just under 200 ton/km².a. However, the source of some of those observations is questionable and therefore the sediment yield under natural conditions is estimated to be no lower than 200 ton/km².a.

For scenarios 1 and 2 a sediment yield of 400 ton/km².a is actually somewhat high because no large floods occur in that period, but this situation is representative of a relatively dry period just before a large resetting flood occurs, when the availability of the sediment is not limited. However, for scenarios 3 and 4 the sediment availability is very much limited, especially during the resetting flood. The highest concentration observed at V5H002 was around 40 000 mg/l, and no data are available on concentrations during large floods. During the Domoina flood of 1984, the average volumetric concentration on the Pongola River (further north) was about 2%. It was assumed that the same average concentration could be expected on the Thukela River during a large resetting flood. The concentrations during the flood were calculated with the aid of the sediment load-discharge rating curve and then scaled down to reduce the average volumetric concentration during the flood to 2%. The average sediment yield for the simulation period was kept at 400 ton/km².a. For scenario 5 the sediment yield was increased to 600 ton/km².a, which could occur if increasing areas of the catchment are under cultivation and with overgrazing.

Due to the fact that the planned reservoirs will trap most of the incoming sediment, the sediment loads had to be adjusted again for the second scenario, because the mean annual sediment load will reduce by up to 27% if all the sediment is trapped in the reservoirs.

The downstream boundary of the model consisted of a time series of tidal water levels based on tidal constituents from the Richards Bay area. 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 changing geometry of the mouth was not incorporated in the model because it was found that most of the time the tidal action dominates the downstream water level, and only at flows of over 300m³/s does the river flow begin to dominate, at which stage the mouth should be completely open. Also, should the mouth close, it will not affect the sediment transport in the estuary, since the flows at that stage are very low and the mouth also does not stay closed for long periods. A study done on the width changes of the mouth opening (Pollard, 2001) has shown that the width of the mouth is a function of the discharge in the form of a regime equation (with a maximum width of 500 m):

$$W = aQ^b$$

where W = mouth width (m)
 Q = discharge (m³/s)

with $a = 9.6$
 $b = 0.59$

The simulations were carried out with the one-dimensional MIKE 11 model, where the sediment transport and hydrodynamics (fully hydrodynamic) are coupled at each time step, with one minute time steps for the hydrodynamics and two minute time steps for the sediment transport calculations.

8.5 SIMULATION RESULTS

Under natural conditions due to the lower sediment yield the estuary would have been quite

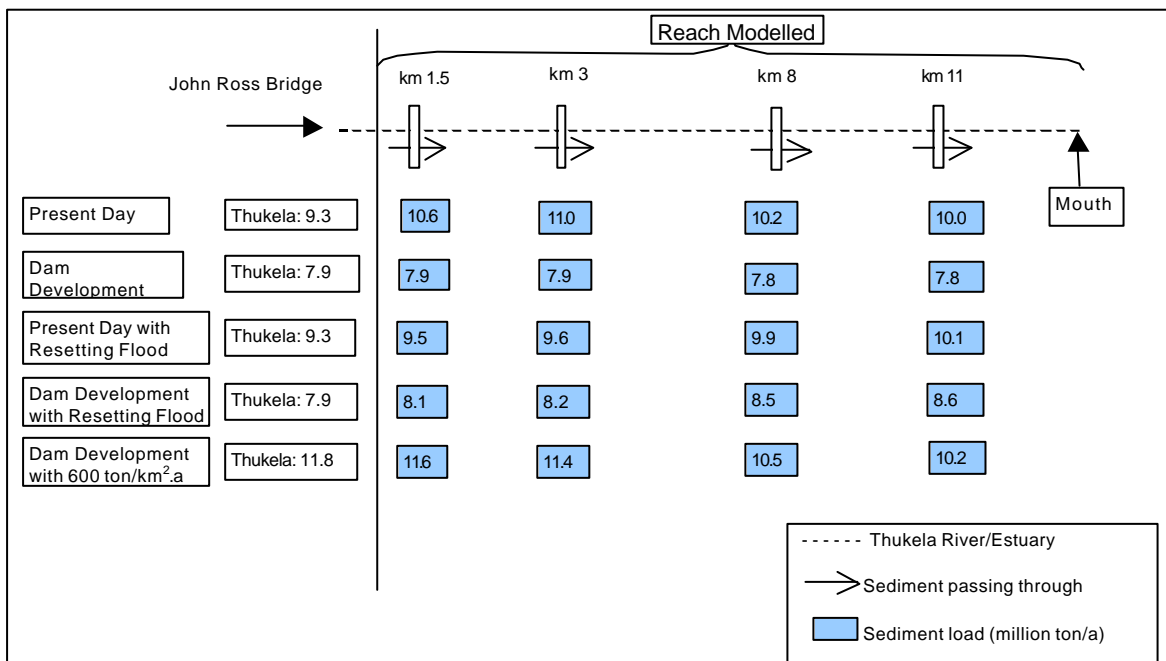
long (around 8.5 km) and deep (see Figure 8.15). The mean annual sediment load would have been around 5.9 million ton.

The present mean annual sediment yield of the Thukela is quite high, with more than 9 million ton at the estuary. The simulations of the present day scenario still show very high sediment loads transported through the estuary (see Figure 8.16), although there is a slight decrease in the annual sediment loads towards the mouth. This is probably due to the decreasing velocities as the river enters the estuary, and sediment deposits. From the bed levels shown in Figure 8.17, the same trend can be observed, as some deposition occurred up to 6km from the mouth. The estuary, however, is in dynamic equilibrium, with the bed level changing constantly throughout the simulation period (maximum and minimum values are indicated in Figure 8.17).

Fig 8.15 Bed levels – scenario 0 (15 year simulated period)



Fig 8.16 Simulated long-term sediment balance (annual sediment loads in million ton/a)



With the Jana and Mielietuin Dams fully developed the incoming sediment load is of course reduced, as mentioned in Section 8.4. The effect becomes evident when looking at the simulated annual sediment loads in Figure 8.15, which are also reduced by about 36% from the sediment loads simulated under present day conditions. The combination of reduced incoming sediment and flood peaks is the reason why there is no evidence of severe scour or aggradation in the estuary (see Figure 8.18). The band (i.e. maximum and minimum) within which the bed level seems to move is also narrower than for the present day scenario. However, this could indicate that a further reduction in the streamflow due to further catchment development could lead to aggradation in the estuary, especially if the sediment yield should increase due to changing land use.

Simulations of scenario 5 have indicated aggradation of up to 2m. This means that the estuary becomes somewhat shorter (at a stage only 3.5 km), but the aggradation is confined mainly to the river and the estuary itself will not become much shallower (see Figure 8.19 for details). Figure 8.15 also shows that the annual sediment loads have decreased by more than 1 million ton at the estuary, indicating that the sediment has deposited upstream in the river.

Fig 8.17 Bed levels - scenario 1 (15 year simulated period)

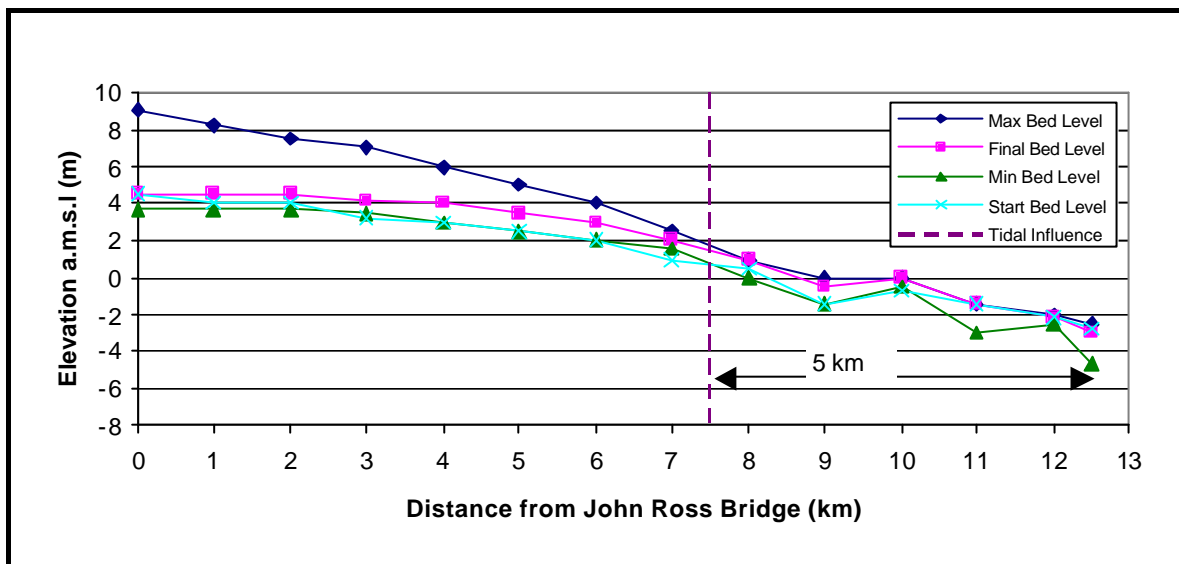


Fig 8.18 Bed levels - scenario 2 (15 year simulated period)

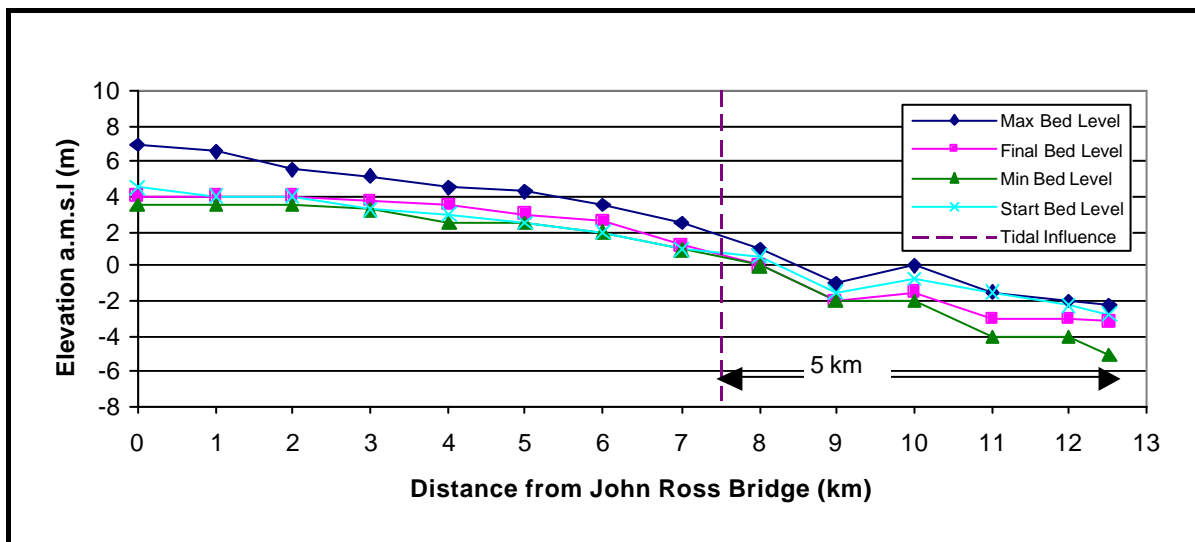
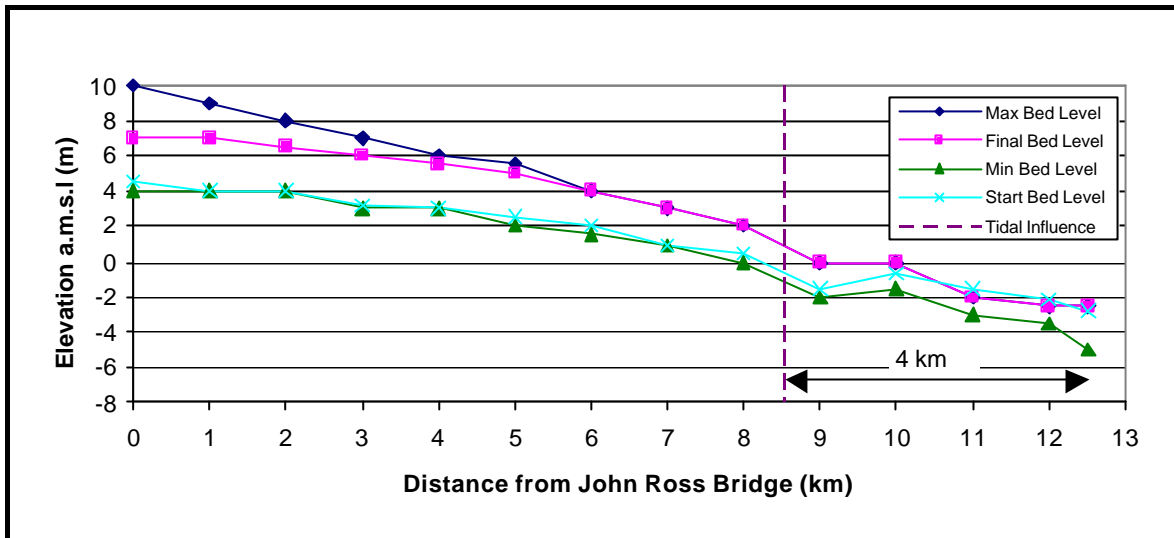


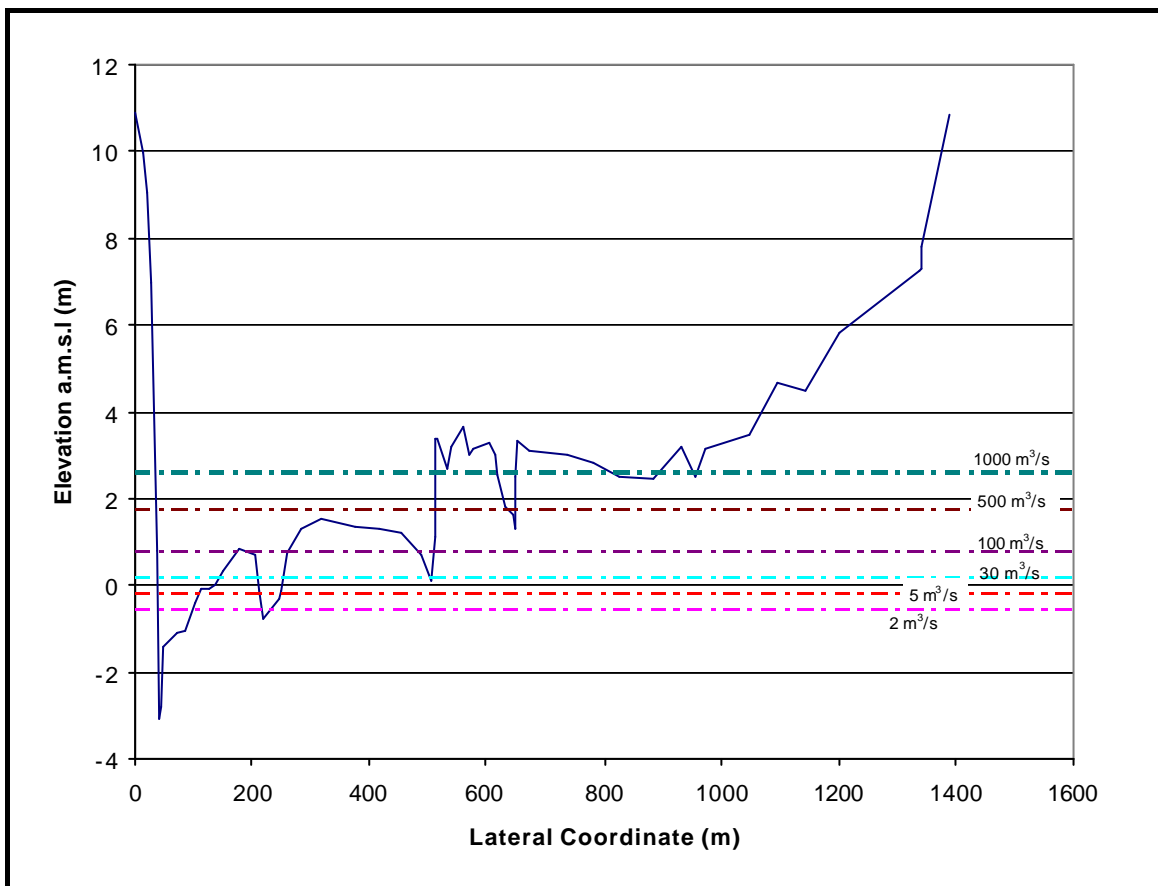
Fig 8.19 Bed levels – scenario 5 (15 year simulated period)



The length of the estuary (about 5km) did not change very much, varying between 5 and 6 km, for the present day scenario. The same is true for the post-dam scenario, which is a result of the fact that no dramatic scouring or aggradation took place for both scenarios.

At discharges up to around 50 m³/s the flow stays mainly in the main channel(s) and only around 300 m³/s does the flow rise above the sand banks in the river and the estuary is no longer influenced by the tides, as indicated in Figure 8.20, which shows the water level at various discharges at a relatively deep cross-section 2.5 km from the mouth.

Fig 8.20 Minimum water levels (no tidal influence) at various discharges (2.5 km from mouth)

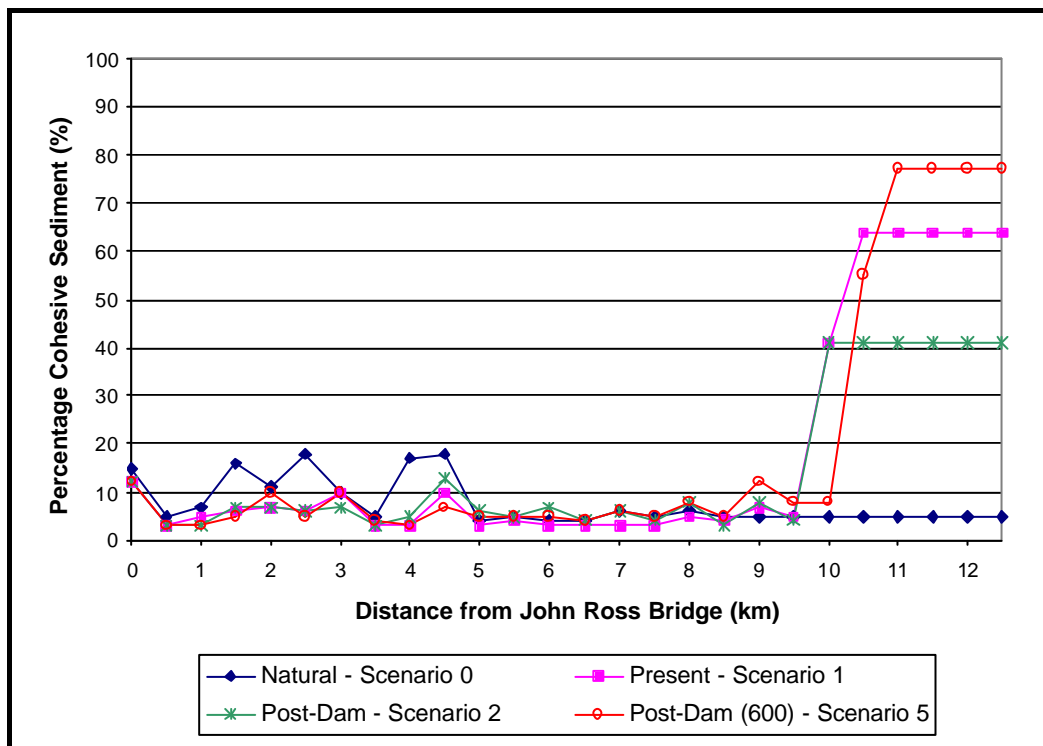


As mentioned in Section 8.4 cohesive sediments were found in the estuary and the simulations have shown that the proportion of fraction 1 could increase dramatically between flood events, but would decrease again during a flood. During the present day scenario fraction 1 would on average build up from 5 to 60% in the bed, and during the post-dam scenario to about 40%. The amount of cohesive sediment might therefore decrease as a result of the dam developments, but there will still be large quantities present. The system is, however, very dynamic and the mean percentage of cohesive sediment in the bed may be as low as 5%. All this is only applicable to the estuary and more than 7km from the mouth the percentage of cohesive sediment will remain between 5 and 10%.

The percentage cohesive sediment in the bed sediment depends mostly on the availability of sediment as well the size of the estuary, since the larger the estuary the larger the area over which the sediment can be distributed. Under natural conditions (with a mean annual sediment load of 5.9 million ton at the estuary) the percentage fine material rarely builds up to more than 40%, generally staying between 20 and 30%, starting from the mouth and progressively building up back into the estuary for about 5 to 6km. Under present day conditions (mean annual sediment load of 9.3 million ton) the fine sediment build-up is greater (generally up to 60%) extending 2 to 4km into the estuary from the mouth. In future with the dams the fine sediment will still extend for about 2 to 4km but will only build up to about 40%. With an increased sediment yield the percentage fine material builds up to about 75% extending only 2 to 3km into the estuary from the mouth. Further upstream in the estuary and the river the fine fraction will generally remain between 5 and 10% for all scenarios but will vary from place to place along the river (see Figure 8.21 for an example).

The amount of time that the fine sediment remains in the estuary depends on the occurrence of floods. If there are no floods in the dry season the fine sediment can stay in the estuary for about five months from May to October, which was the case in nine out of the fifteen years that were simulated. Even with floods the fine sediment can remain in the estuary for at least a month in the dry season.

Fig 8.21 Example of simulated fine sediment build-up in the estuary (at a certain point in time)



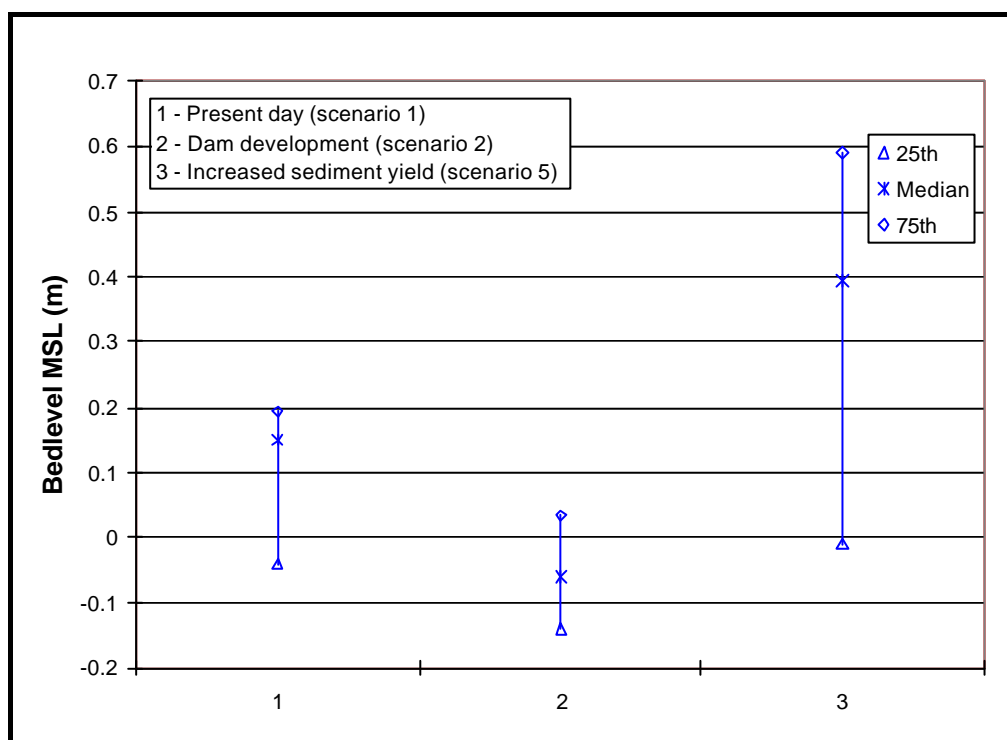
As a result of the reduction in flood peaks the estuary could become narrower. Based on regime equations developed during a current Water Research Commission study (Basson and Beck, 2002) the estuary could narrow by about 11% (from present state) cross-section could reduce to around 445m.

Together with the changes in the flow regime the velocities and other hydraulic parameters in the estuary will also change. The average velocity could decrease by up to 7%, while the average hydraulic radius (equivalent to depth in wide shallow flow) could decrease by about 4.5%. The changes in frequency of certain velocities are shown in Table 8.8 and an indication of the variability of the bed levels is shown in Figure 8.22.

Table 8.8 Change in frequency of velocities in estuary

	Pre-dam frequency	Post-dam frequency	Change
> 0.3 m/s	81%	77%	-6%
> 0.4 m/s	69%	58%	-11%
> 0.5 m/s	45%	36%	-21%
> 1.0 m/s	6%	4%	-35%
> 1.5 m/s	0.7%	0.3%	-59%

Fig 8.22 Variability of bed levels for scenario 1, 2 and 5



Resetting Floods

Since the largest flood in the simulation period is only about a 1:10-year flood, it was important to also investigate what the effect of a large resetting flood, such as the 1:50-year flood, could be on the estuary. These floods are generally not affected to a great degree by dams, but Jana Dam does have a large storage capacity and therefore the flood peak could be reduced. The resetting flood was included in the simulations for both scenarios, right at the start of the simulation period. The resetting floods for the two scenarios and the corresponding concentrations are indicated in Figures 8.23 and 8.24.

Fig 8.23 Resetting flood (1:50-year) for scenario 3

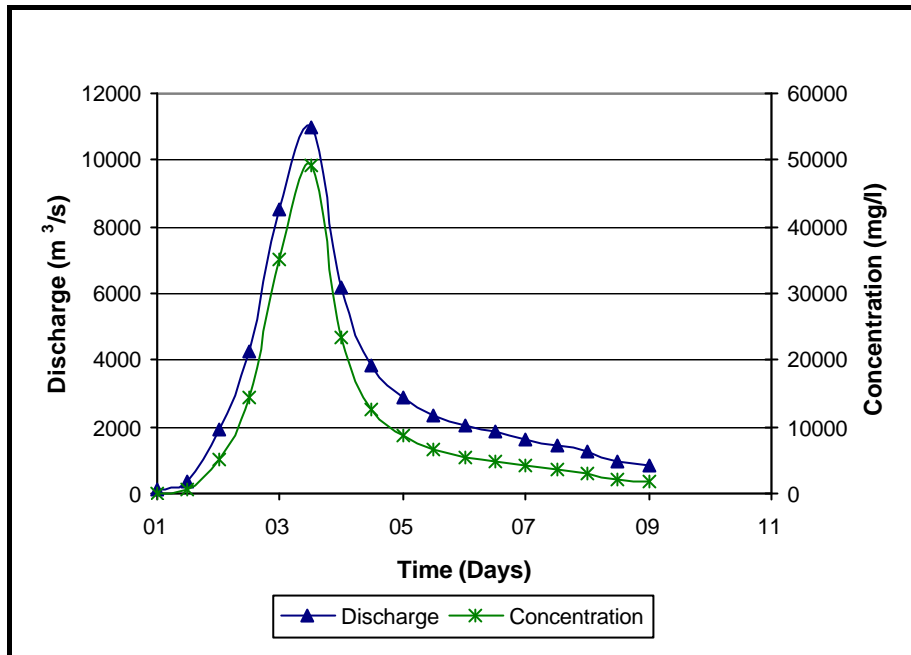
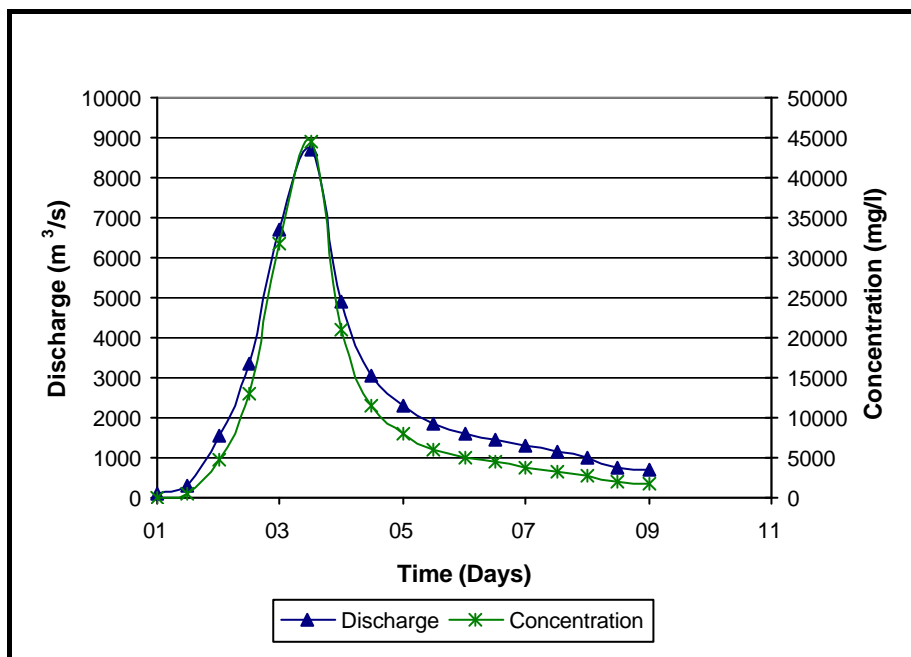


Fig 8.24 Resetting flood (1:50-year) for scenario 4



The surprising result was that for both scenarios some aggradation actually took place immediately after the flood in the upper part of the reach modelled, but severe scouring was simulated in the estuary itself closer to the mouth (see Figure 8.25 and 8.26). The overall effect was that the bed slope increased dramatically during the flood, but returned to normal within a few months. It took only a few months to remove most of the sediment again, and because the resetting flood carries so much sediment, less sediment is available for the rest of the time and therefore eventually the bed level ended up lower than at the start of the simulations. The fact is that these floods can have a major effect on both the Thukela River and the estuary, but it looks like the estuary is able to recover to a certain degree.

Fig 8.25 Bed levels - scenario 3 (15 year simulated period)

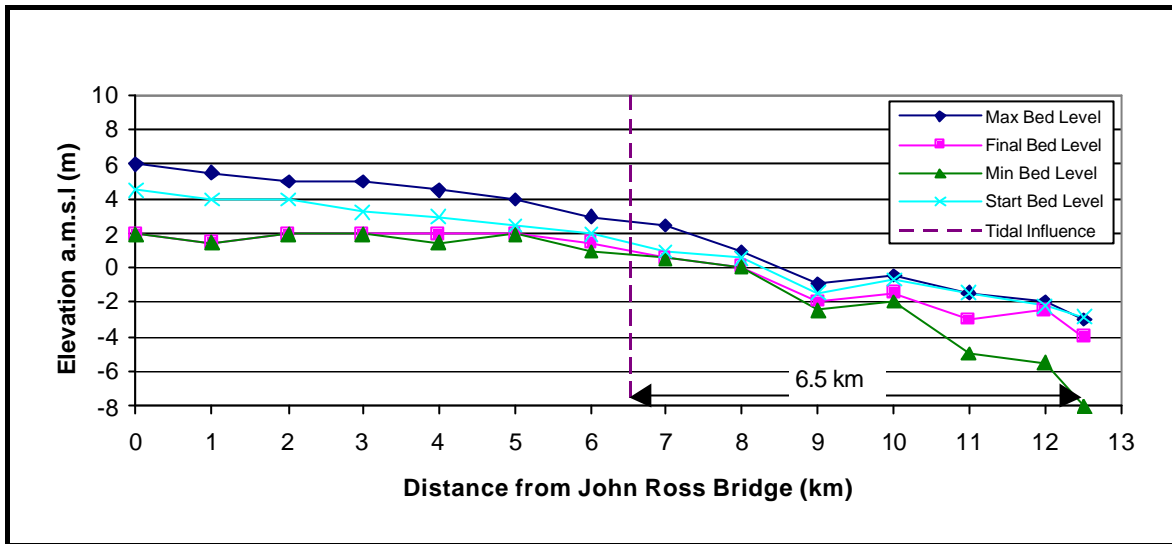
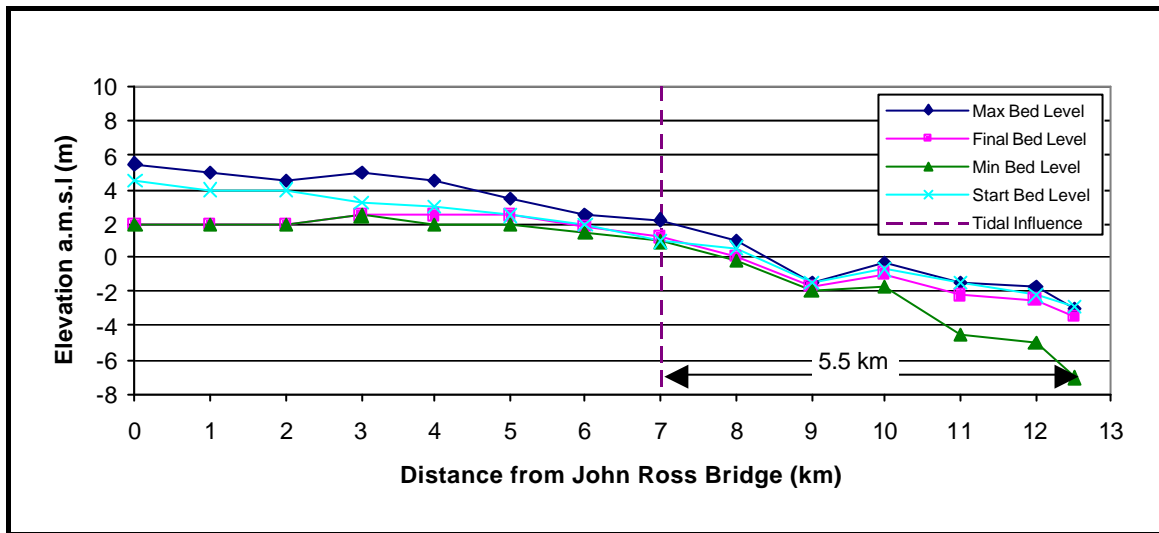


Fig 8.26 Bed levels - scenario 4 (15 year simulated period)



8.6 CONCLUSIONS AND RECOMMENDATIONS

The key findings are:

- A number of large dams have been constructed high up in the catchment. Their effects on floods and sediment dynamics at the estuary are, however, minimal. The decrease in flood peaks at the estuary from natural to present day condition is estimated at 8%, while from present day to post-dam conditions the average peak discharge decrease is 19%.
- The estuary sediment dynamics is in a dynamic equilibrium under present day conditions. Simulations for the post-dam (worst case) scenario also indicate dynamic equilibrium of the fluvial morphology similar to present day conditions.
- Under natural conditions (assuming that the sediment yield would have been lower than at present) the estuary would have been about 8.5km long and deeper than at present.
- The typical present-day (pre-dam) as well as future post-dam estuary length is 5km.
- The flood attenuation, caused by the proposed dams, will decrease the estuary width by about 11% from present state, equivalent to 55m on a 500m wide cross-section.
- The mean flow velocity and flow depth in the estuary will decrease minimally with

the post-dam scenario.

- If the sediment yield from the catchment increases in future, it would shorten the estuary and it will become shallower. It is recommended that suspended sediment sampling at the flow gauging station V5H002 is resumed as soon as possible for at least a continuous five year period to confirm the current sediment yield.
 - The role of the large resetting floods is important in scouring the river mouth, especially previously deposited cohesive sediments. Regular floods are therefore required to limit possible consolidation of cohesive sediment.
 - The pre-dam and post-dam scenarios indicate a decrease in flood peaks at the estuary, but the floods are still regular enough with high sediment transport capacity to maintain the sediment balance in the estuary. No artificial flood releases from the Jana or Mielietuin Dams are therefore recommended for the estuary morphology, but this should be considered for the river immediately downstream of both dams during long periods without spillage.
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10 ANNEXURE 1: WATER QUALITY RAW DATA

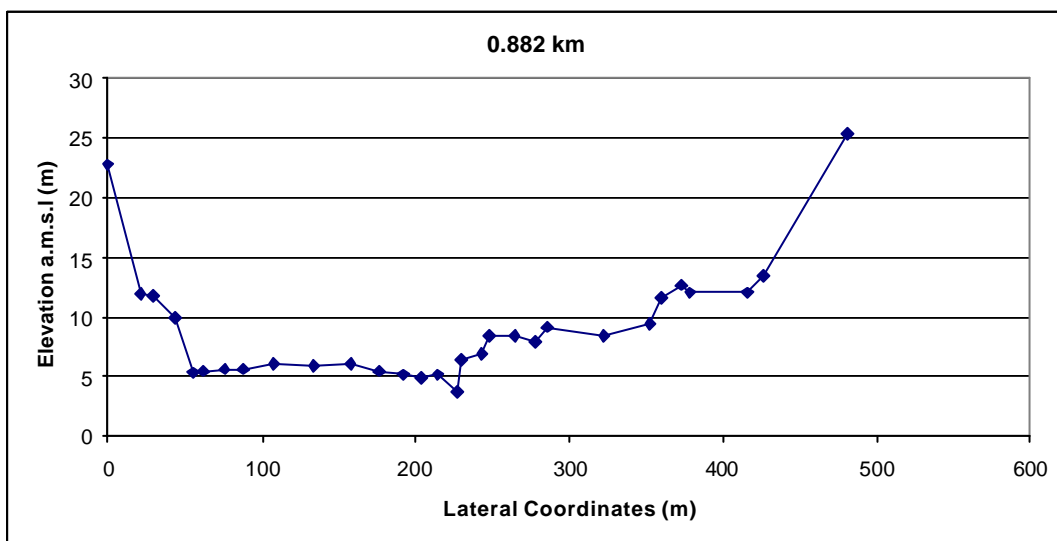
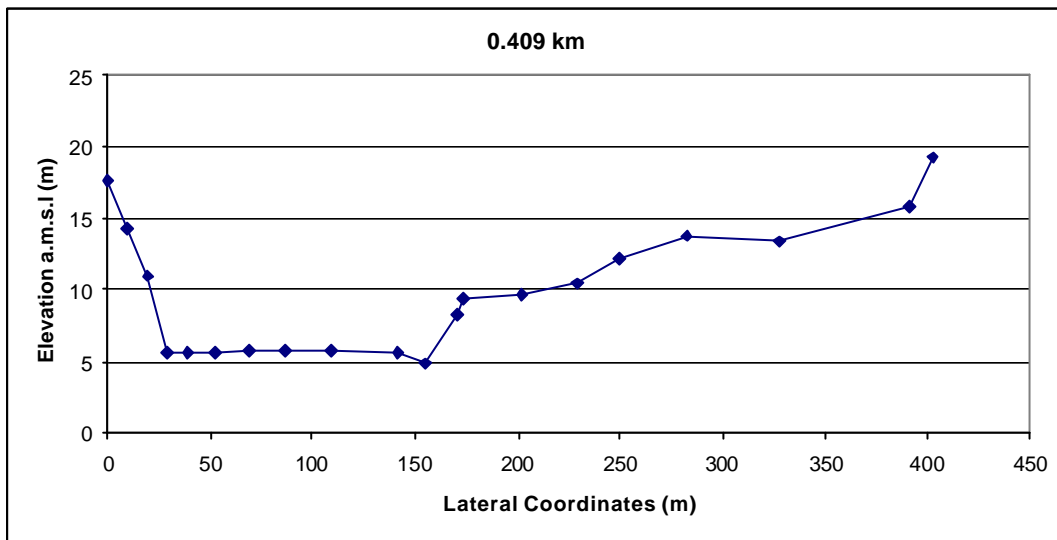
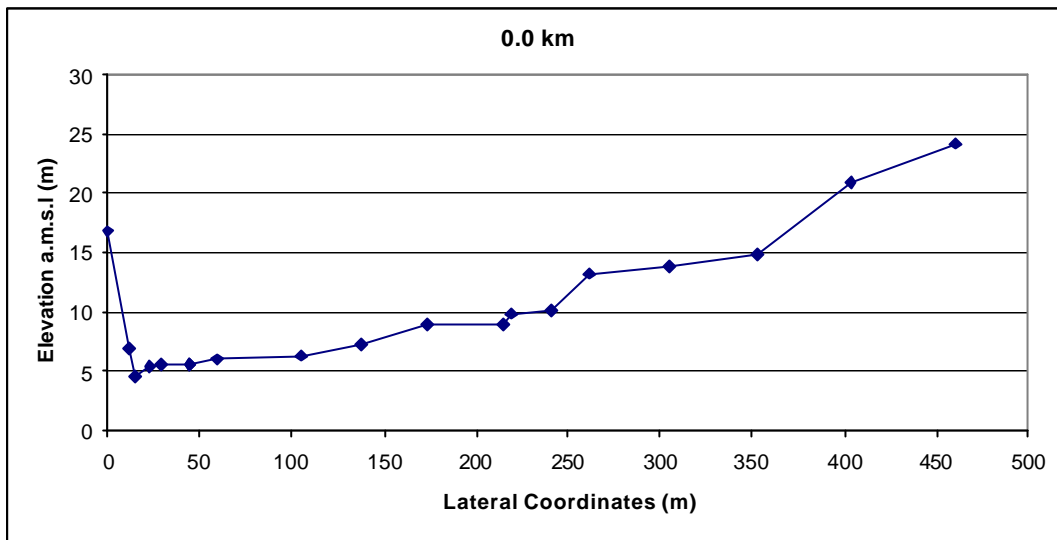
Thukela Field Trip: 20 August 2001 (Water column samples)						
Low Tide						
Time	Distance from mouth (km)	Coordinates (WGS84-Magellan)		Depth (m)	Temp	Salinity (ppm)
		Deg Min S	Deg Min E			
11:14	0.5			1.05	21.05	28.58
	0.5			0.50	21.10	25.64
	0.5			0.00	20.94	24.58
11:20	0.75	29 13.56	31 30.05	1.23	21.06	33.26
	0.75			1.00	20.93	33.15
	0.75			0.70	20.71	14.23
	0.75			0.60	20.51	13.41
	0.75			0.50	20.42	12.96
	0.75			0.00	20.42	12.93
11:36	1.25	29 13.39	31 29.95	1.00	20.82	31.33
	1.25			0.75	20.89	29.41
	1.25			0.50	20.77	18.81
	1.25			0.00	20.89	5.44
11:46	1.75	29 13.32	31 29.58	2.00	20.93	33.86
	1.75			1.50	20.91	33.68
	1.75			1.00	20.72	33.48
	1.75			0.75	20.73	25.93
	1.75			0.60	20.96	19.53
	1.75			0.50	21.15	5.12
	1.75			0.00	21.31	4.87
13:14	2	Near Fiona's Station 4		0.70	22.30	4.86
	2			0.60	22.36	3.26
	2			0.00	22.39	0.64
12:37	2.3	29 13.41	31 29.60	1.00	22.07	0.59
	2.3			0.50	22.07	0.60
	2.3			0.00	22.09	0.59

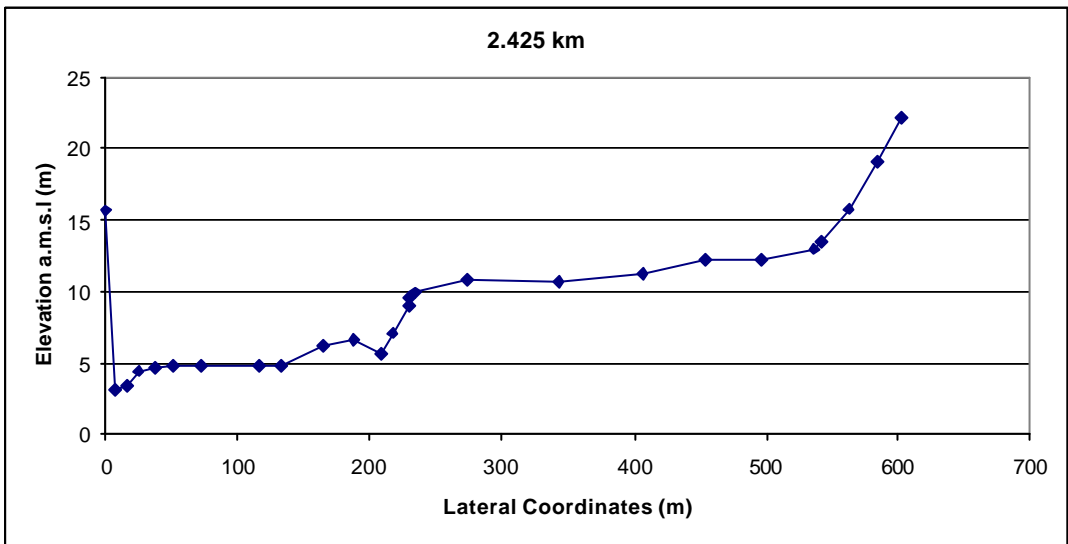
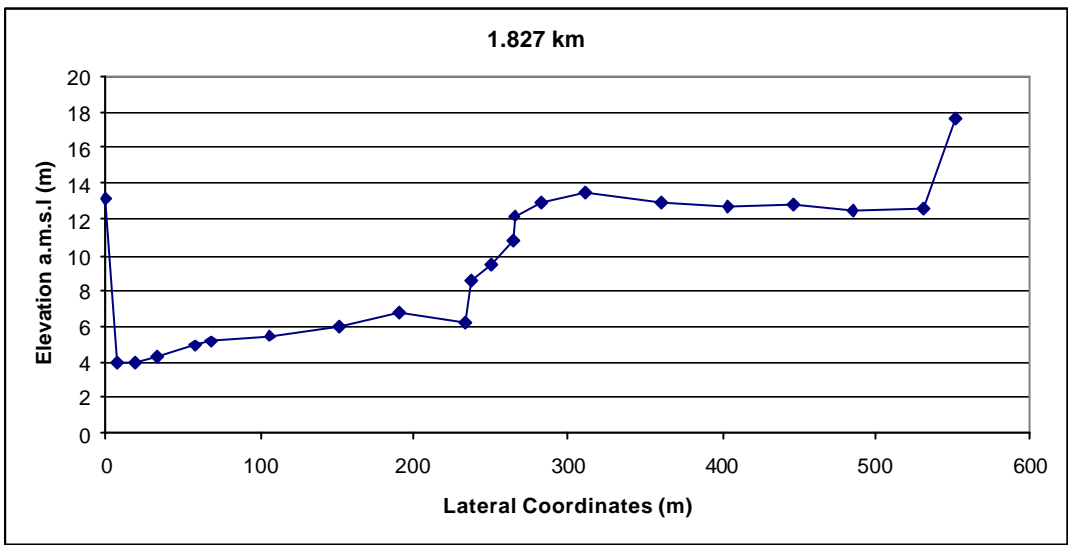
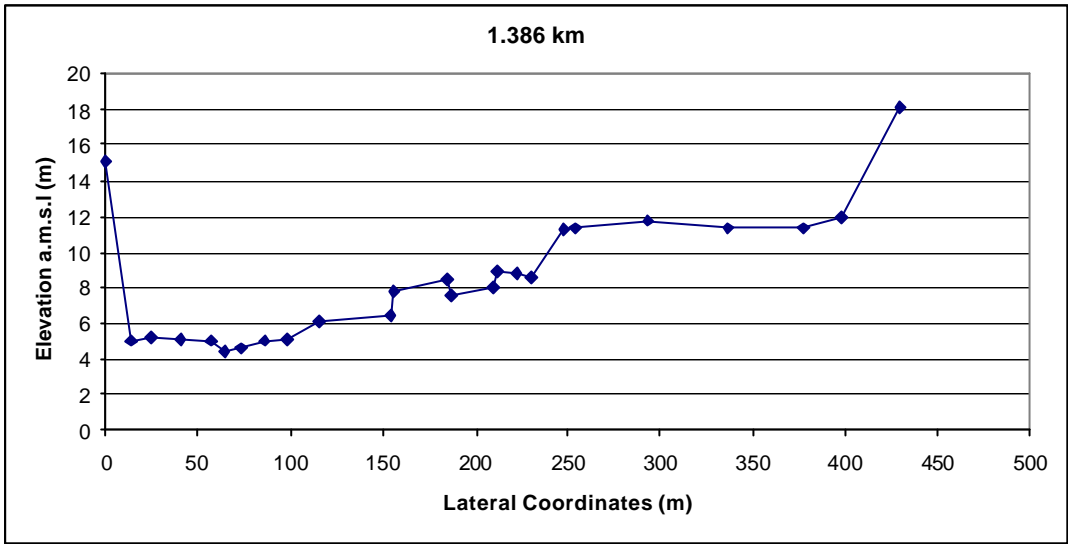
Thukela Field Trip: 20 August 2001 (Water column samples)															
High Tide															
Time	Distance from mouth (km)	Coordinates (WGS84-Magellan)		Depth (m)	Temp	Salinity (ppm)	SS (mg/L)	pH (ntu)	Turbidity (ntu)	DO (mg/L)	NO ₃ -N	NO ₂ -N	NH ₃ -N	PO ₄ -P	SiO ₄ -Si
		Deg Min S	Deg Min E												
14:30	Sea			0.00	21.75	35.00	6	8.01	1.5		<10	<10	<25	<10	<80
14:50	0.5			0.00	21.56	35.50	14	7.94	6.0	7.7	<10	<10	<25	<10	<80
15:20	0.75	29 13.56	31 30.05	1.04	21.63	33.86	32	7.86	9.0	7.8	<10	<10	<25	<10	202
	0.75			0.50	21.74	33.59									
	0.75			0.00	21.70	30.40	10	7.91	4.5	7.2	<10	<10	<25	11	539
15:37	1.25	29 13.39	31 29.95	1.40	21.59	35.32	24	8.07	4.5	8.2	<10	<10	<25	<10	<80
	1.25			1.00	21.62	35.18									
	1.25			0.50	21.64	35.01									
	1.25			0.00	21.56	32.04	20	7.95	2.5	7.9	<10	<10	46	24	<80
15:55	1.75	29 13.32	31 29.58	2.40	21.71	33.95	36	8.05	7.5	8.2	<10	<10	34	<10	202
	1.75			2.00	21.71	34.04									
	1.75			1.50	21.71	34.04									
	1.75			1.00	21.71	33.86									
	1.75			0.50	21.78	31.78									
	1.75			0.25	21.83	24.56									
	1.75			0.00	21.81	16.74	24	7.61	2.0	7.1	<10	<10	52	21	1330
16:20	2.3	29 13.41	31 29.60	1.80	21.60	27.96	32	7.85	2.5	7.1	<10	<10	<25	11	804
	2.3			1.50	21.61	27.91									
	2.3			1.00	21.65	26.47									
	2.3			0.75	21.69	26.21									
	2.3			0.50	22.02	17.54									
	2.3			0.25	22.28	10.31									
	2.3			0.00	22.41	8.05	8	7.64	1.0	8.1	<10	<10	94	39	2892
16:50	3	29 13.32	31 29.25	2.13	22.75	3.68	8	7.57	3.0	7.8	<10	<10	32	55	3235
	3			1.00	22.75	3.52									
	3			0.50	22.75	3.65									
	3			0.00	22.72	2.82	6	7.72	1.5	7.2	<10	<10	37	54	3186
17:18	3.5			0.50	22.41	0.20									
	3.5			0.00	22.43	0.20	12	7.82	2.0	6.7	<10	<10	<25	50	3431
21-Aug	River	N2 Bridge		0.00	22.00	0.30	20	7.02	3.0	6.0	<10	<10	<25	23	3333

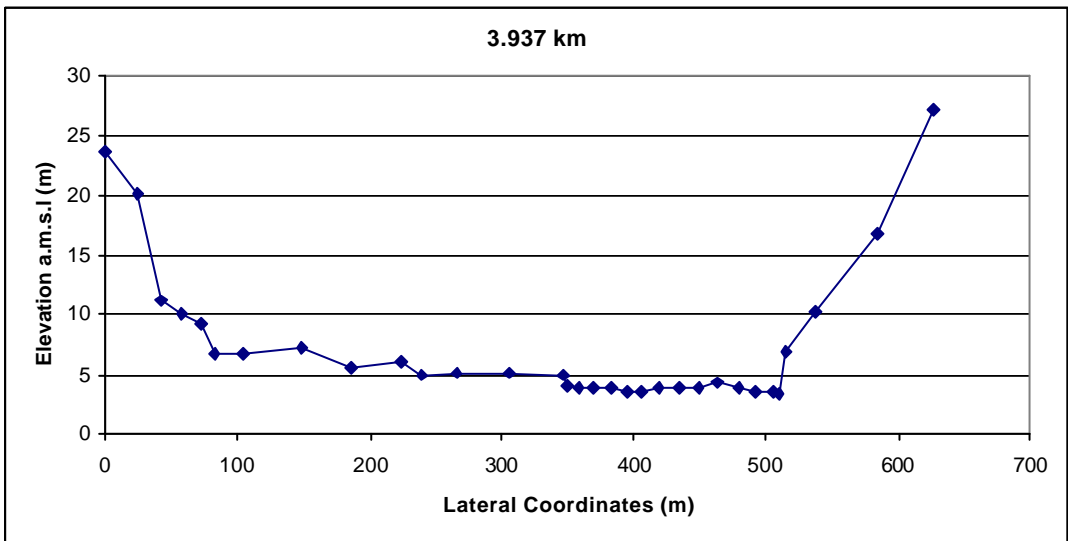
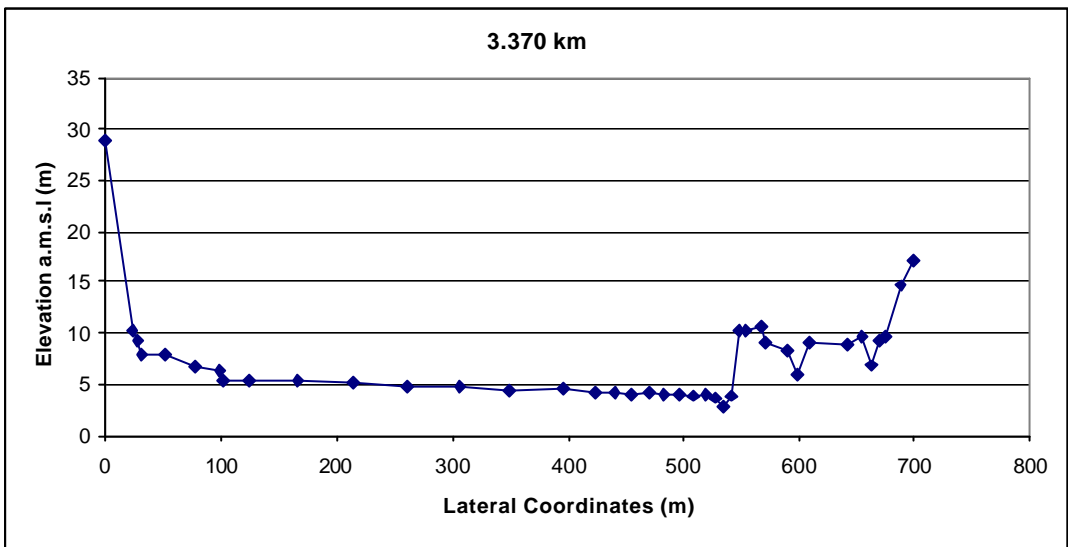
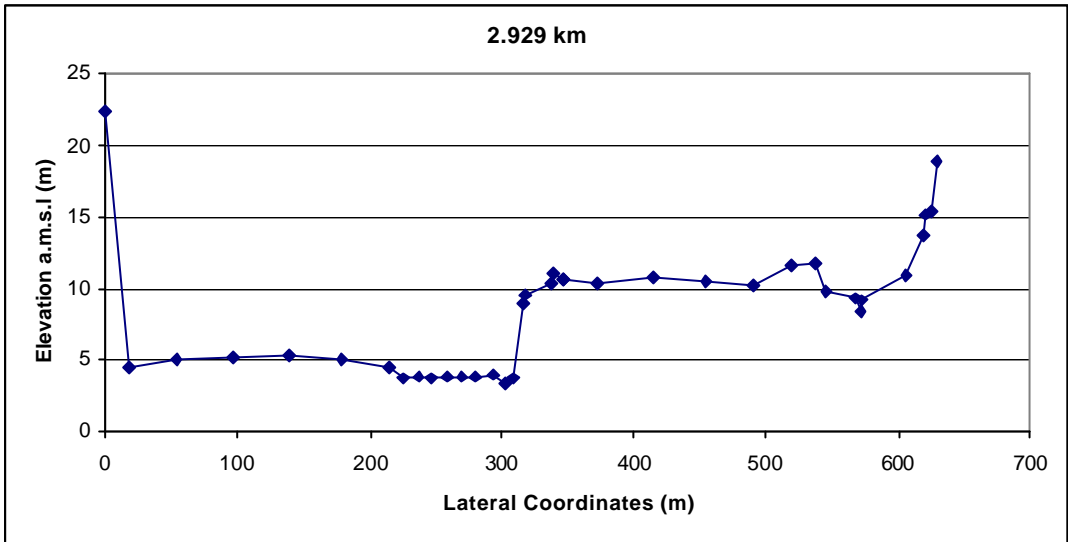
Thukela Field Trip: 20 August 2001 (Sediment Samples)											
Distance from mouth (km)	Coordinates (WGS84 - Magellan)		Particle Size Distribution in microns								
	Deg Min S	Deg Min E	>2000	2000-1000	1000-500	500-250	250-125	125-163	<63		
0.50	29 13.60	31 30.07	0.00	0.21	10.20	69.33	19.88	0.38	0.00		
0.75	29 13.38	31 29.89	0.00	0.00	0.55	2.91	4.07	3.04	89.43		
1.40	29 13.08	31 28.86	0.00	1.14	27.13	60.62	10.81	0.18	0.12		
1.85	29 13.30	31 29.19	0.00	0.00	7.93	75.78	15.94	0.21	0.14		
2.30	29 13.41	31 29.46	0.13	3.89	38.78	50.84	6.25	0.11	0.00		
3.50	29 12.92	31 28.50	5.45	0.94	18.00	59.44	15.80	0.37	0.00		
Distance from mouth (km)	Coordinates (WGS84 - Magellan)		(Trace metals in µg/g)								
	Deg Min S	Deg Min E	Al	Cd	Cr	Cu	Hg	Ni			
0.50	29 13.60	31 30.07	4938	<0.25	14.1	5.6	<0.50	7.3	6.5	12.0	
0.75	29 13.38	31 29.89	44117	<0.25	69.3	42.0	<0.50	49.4	18.0	71.2	
1.40	29 13.08	31 28.86	6995	<0.25	25.3	8.8	<0.50	11.4	6.0	18.6	
1.85	29 13.30	31 29.19	7246	<0.25	20.8	7.7	<0.50	10.8	6.4	21.2	
2.30	29 13.41	31 29.46	6338	<0.25	24.8	9.3	<0.50	13.6	5.8	18.4	
3.50	29 12.92	31 28.50	6918	<0.25	19.9	7.8	<0.50	10.9	6.1	12.0	

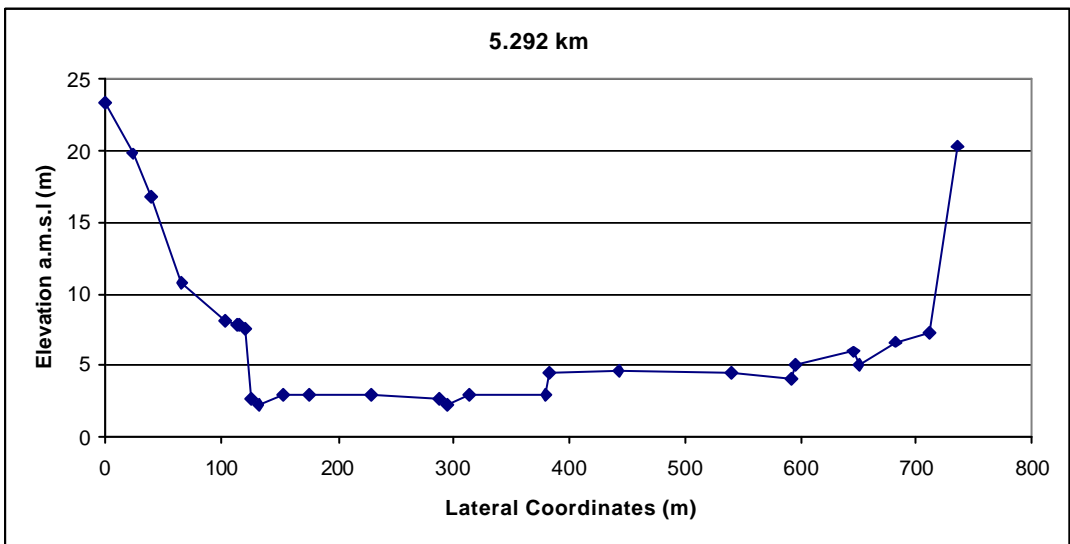
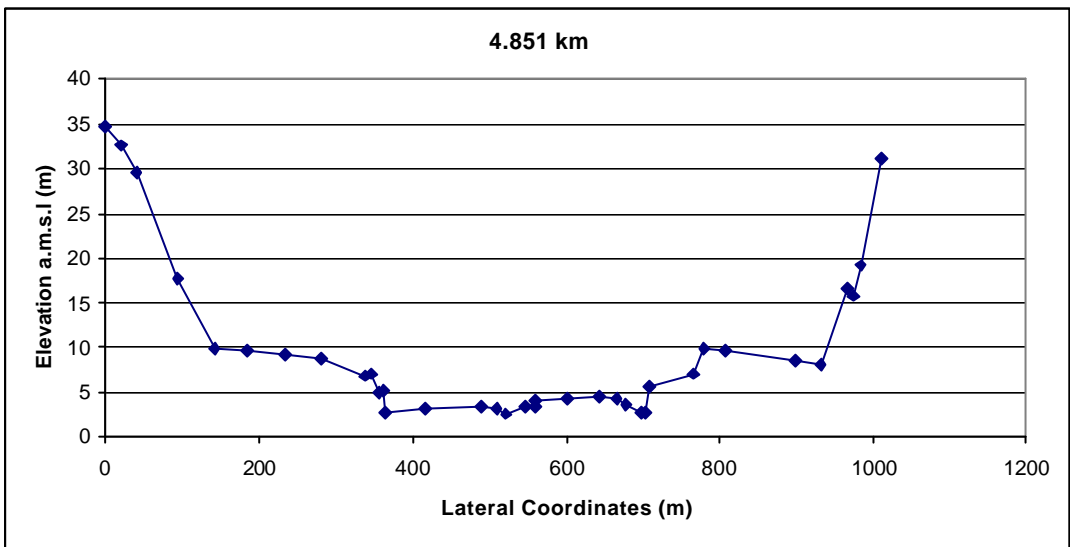
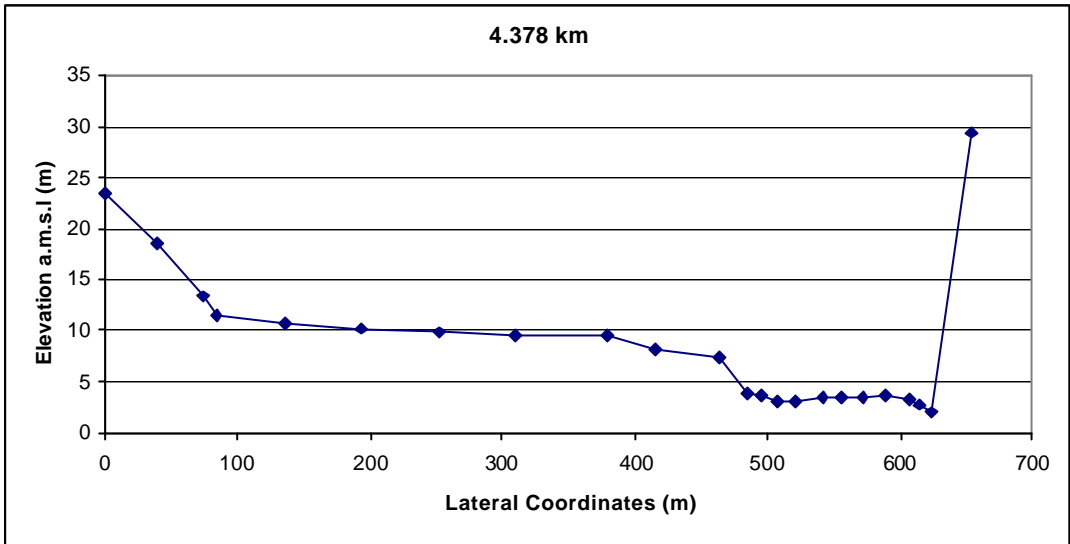
Thukela Field Trip: 12 February 2002										
Water Column Samples										
High tide (Flood tide)										
Time	Stn	Distance from mouth m	Coordinates (WGS84 - Magellan)		Depth (m)	Temp	Salinity (ppm)	DO (mg/l)	Turbidity (NTU)	pH
			Deg Min S	Deg Min E						
11:27 AM	U	2500	S29 ⁰ 13'03.3"	E31 ⁰ 29'00.5"	0.0	26.97	0.1	6.73	147.5	7.79
11:27 AM	U	2500	S29 ⁰ 13'03.3"	E31 ⁰ 29'00.5"	1.0	26.97	0.1	6.89	153.6	7.79
12:19 PM	M	1750	S29 ⁰ 13'19.1"	E31 ⁰ 29'15.9"	0.0	27.10	0.1	6.98	113.4	7.95
12:19 PM	M	1750	S29 ⁰ 13'19.1"	E31 ⁰ 29'15.9"	1.8	27.09	0.1	7.14	157.8	7.94
1:26 PM	L	750	S29 ⁰ 13'30.5"	E31 ⁰ 30'00.1"	0.0	27.57	0.1	6.73	137.3	7.82
1:26 PM	L	750	S29 ⁰ 13'30.5"	E31 ⁰ 30'00.1"	1.2	27.55	0.1	6.82	122.3	7.82
Low tide (Ebb tide)										
Time	Stn	Distance from mouth m	Coordinates (WGS84 - Magellan)		Depth (m)	Temp	Salinity (ppm)	DO (mg/l)	Turbidity (NTU)	pH
			Deg Min S	Deg Min E						
4:20 PM	U	2500	S29 ⁰ 13'03.3"	E31 ⁰ 29'00.5"	0.0	27.56	0.1	6.75	176.6	7.81
4:20 PM	U	2500	S29 ⁰ 13'03.3"	E31 ⁰ 29'00.5"	1.0	27.57	0.1	6.76	154.5	7.81
5:14 PM	M	1750	S29 ⁰ 13'19.1"	E31 ⁰ 29'15.9"	0.0	27.24	0.1	6.94	170.1	7.95
5:14 PM	M	1750	S29 ⁰ 13'19.1"	E31 ⁰ 29'15.9"	1.9	27.27	0.1	7.21	161.1	7.95
5:55 PM	L	750	S29 ⁰ 13'30.5"	E31 ⁰ 30'00.1"	0.0	27.19	0.1	6.76	164.6	7.87
5:55 PM	L	750	S29 ⁰ 13'30.5"	E31 ⁰ 30'00.1"	1.9	27.20	0.1	6.79	175.5	7.88

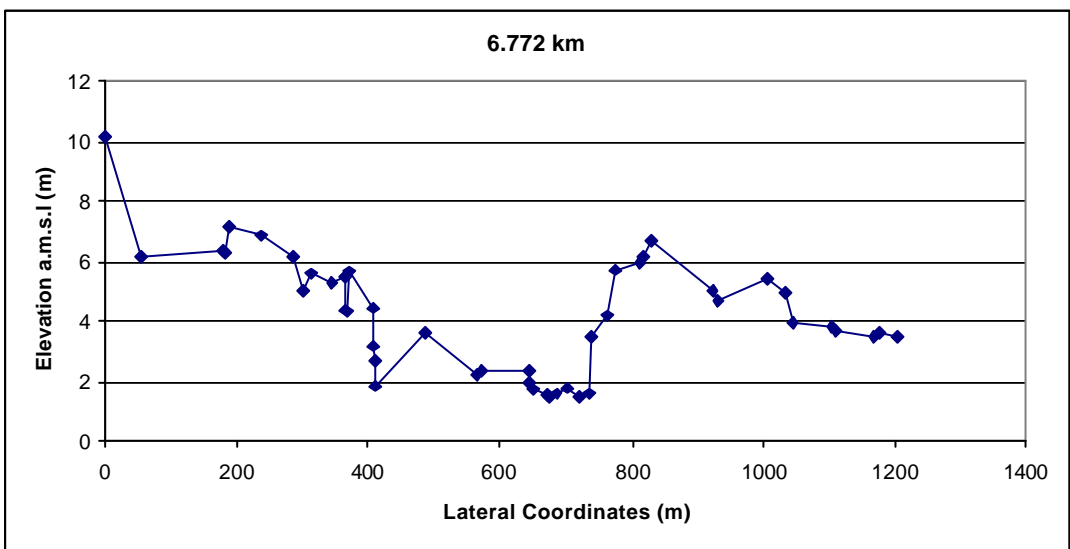
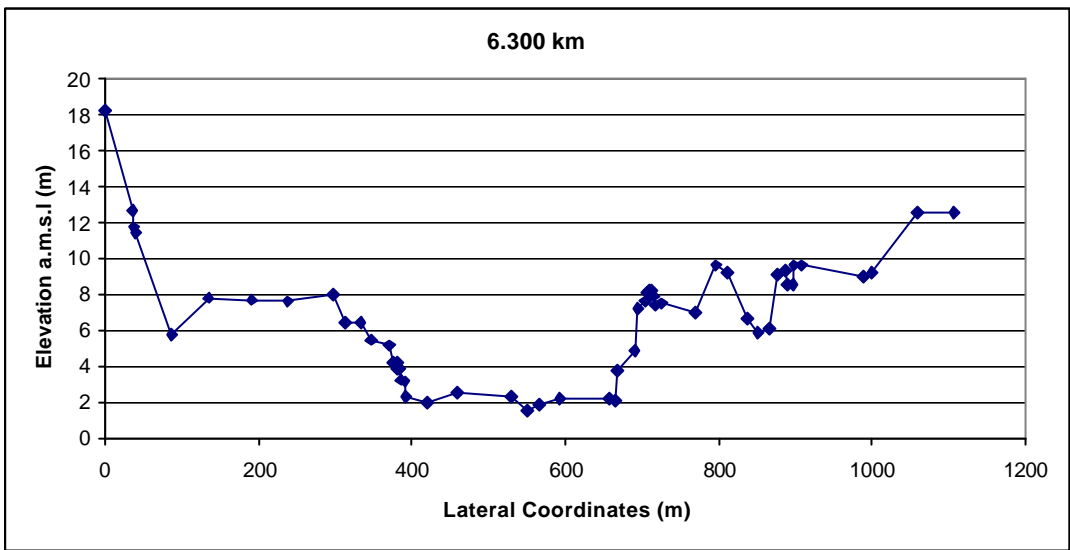
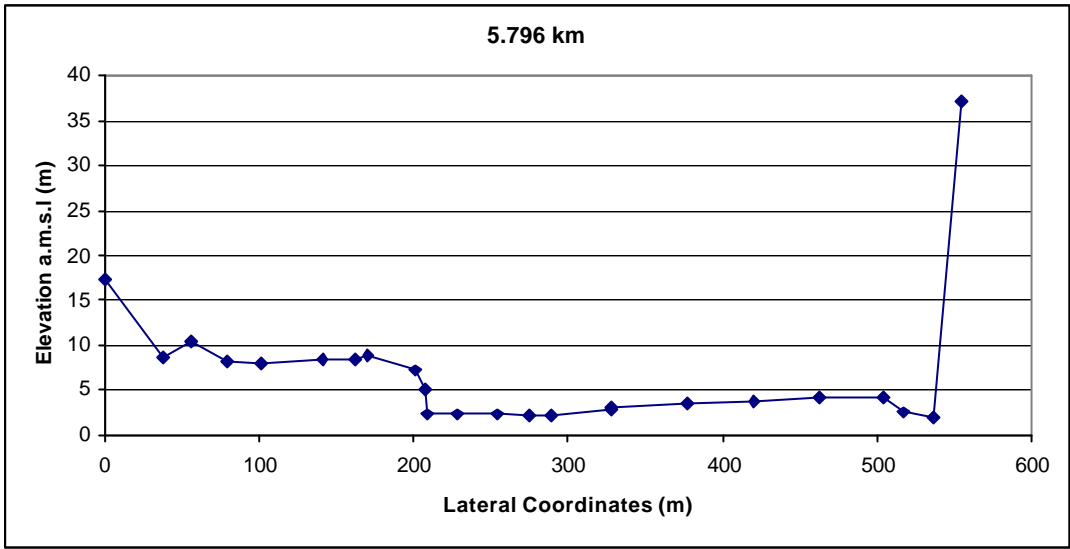
11 ANNEXURE 2: CROSS-SECTIONS OBTAINED FROM A SURVEY DONE BY DWAF IN 1996

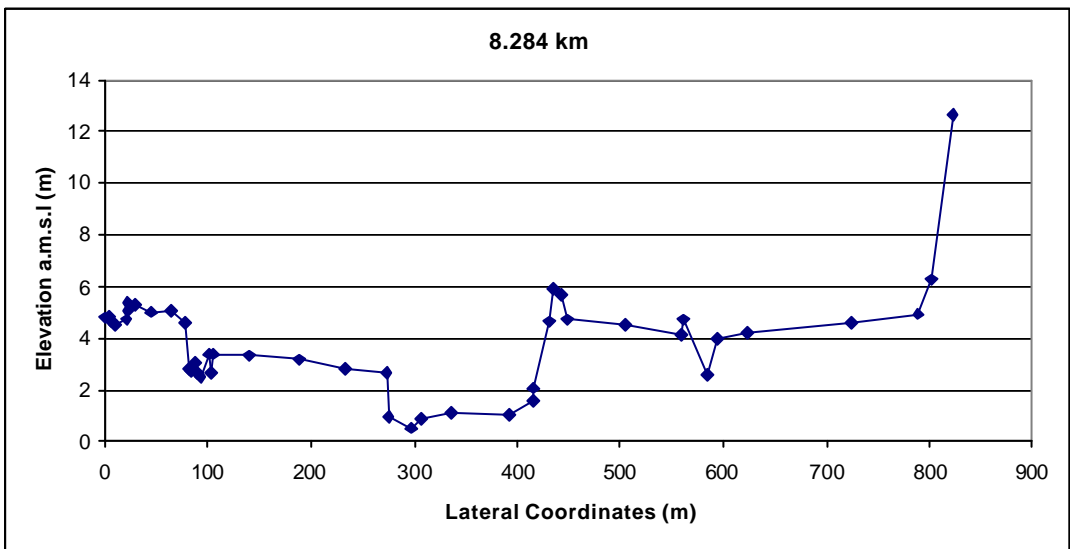
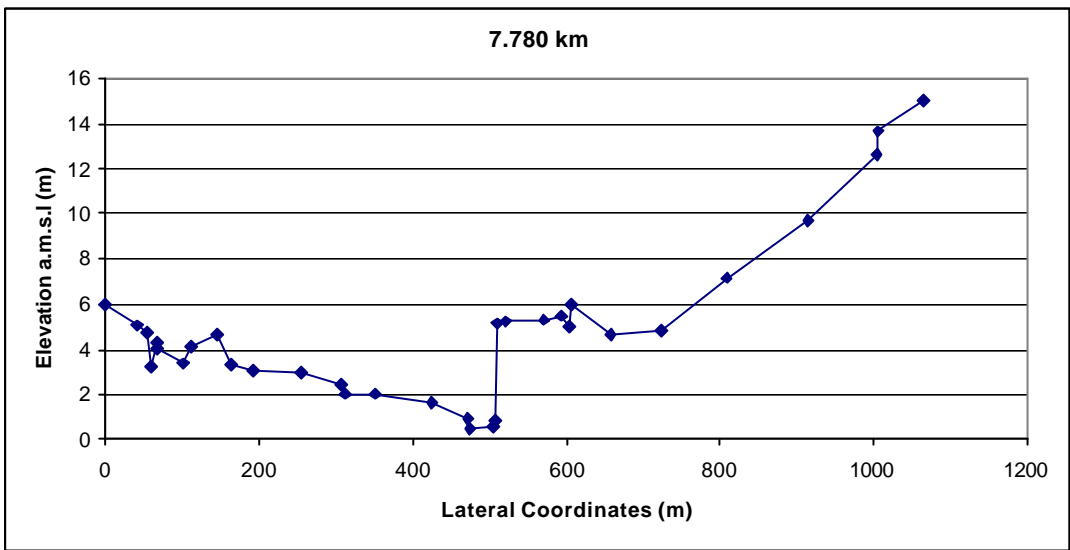
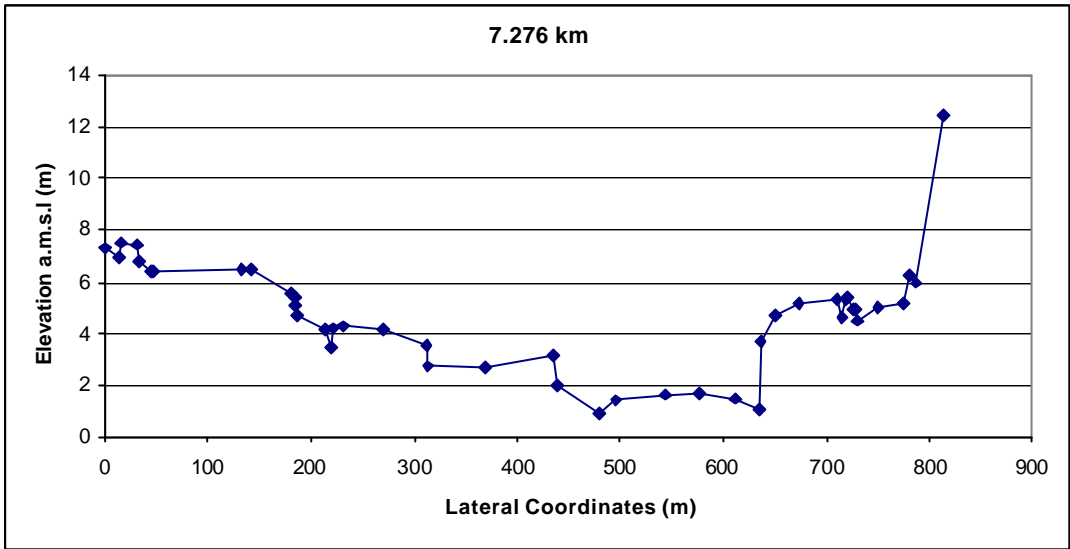


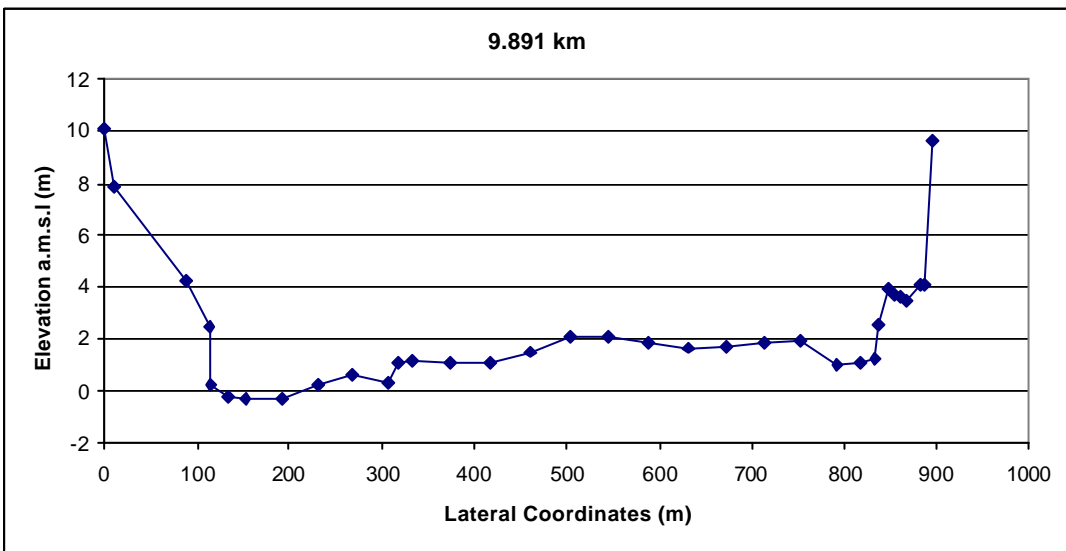
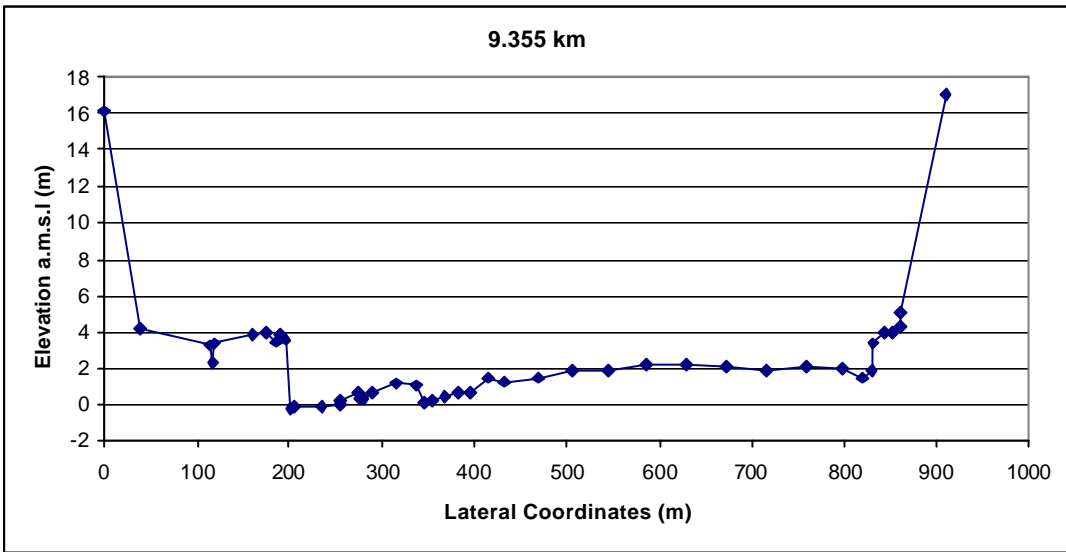
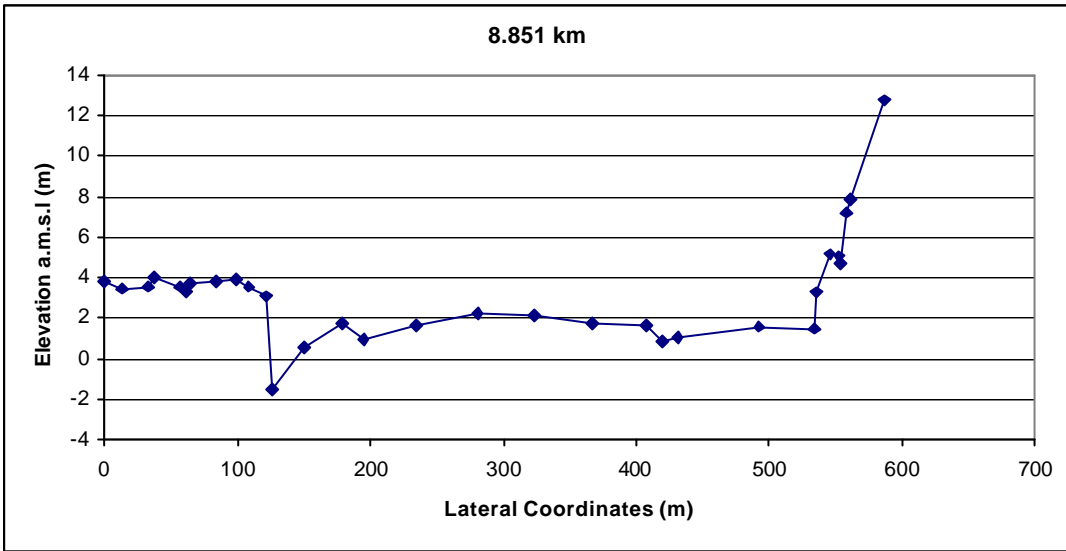


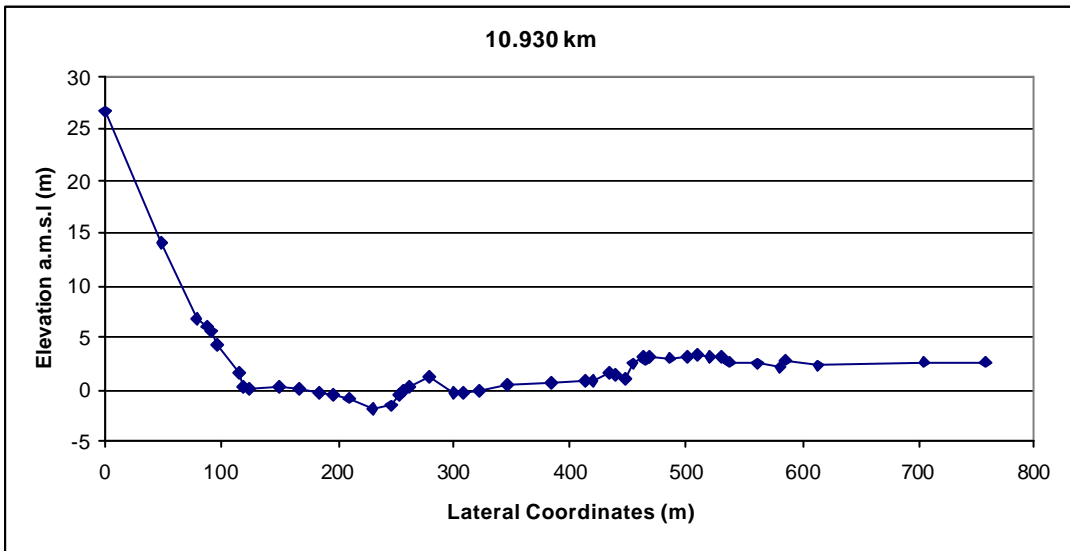
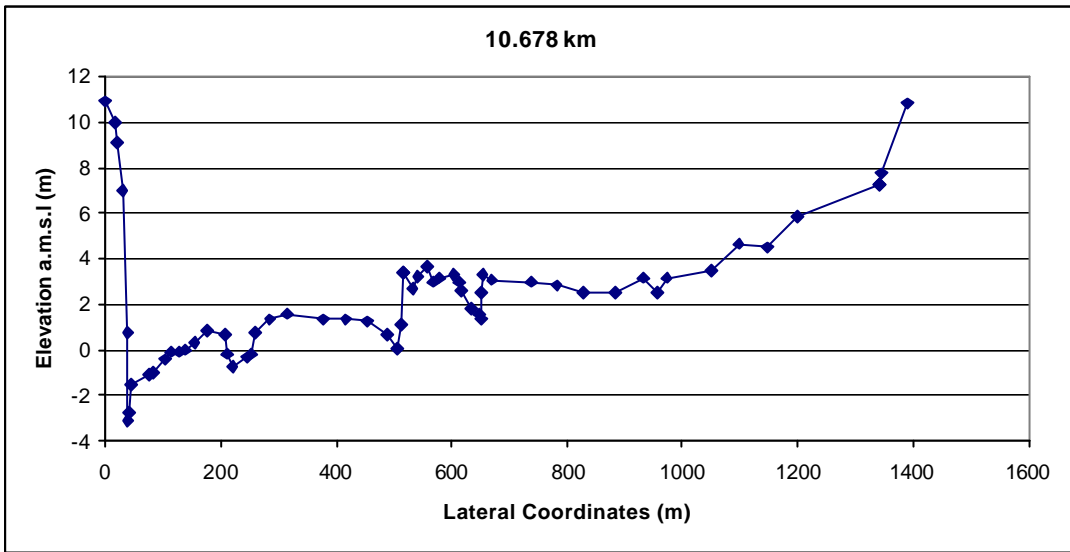
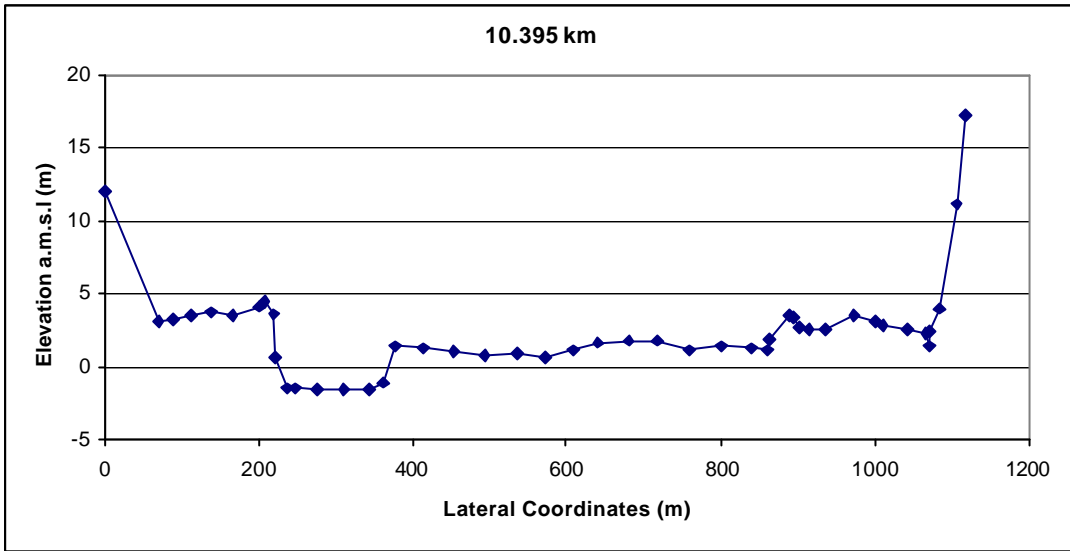


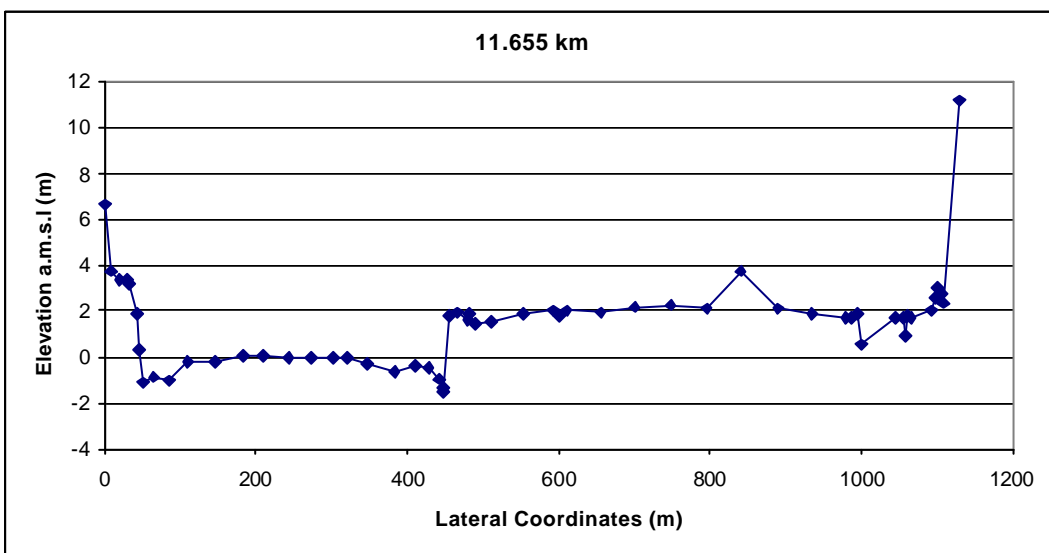
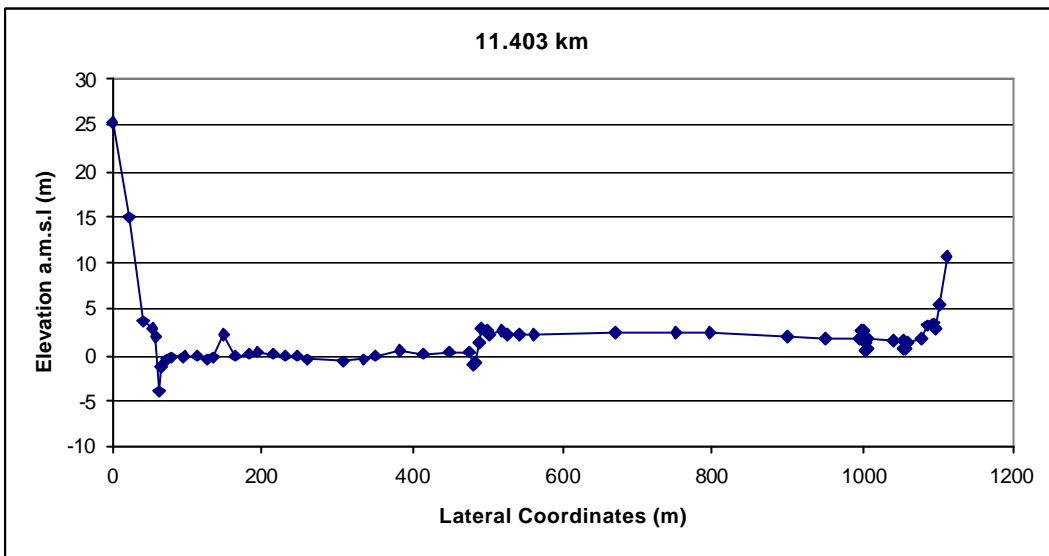
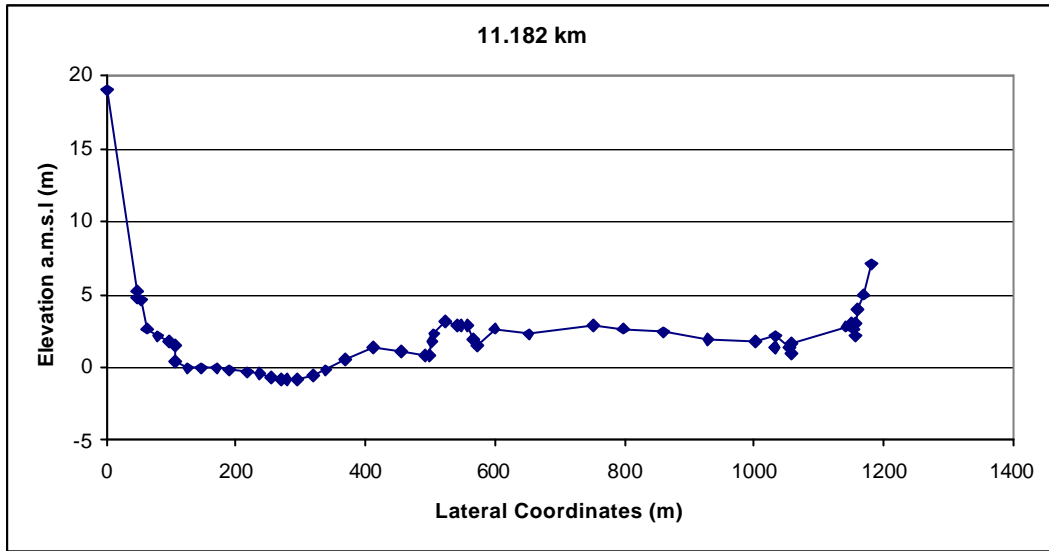


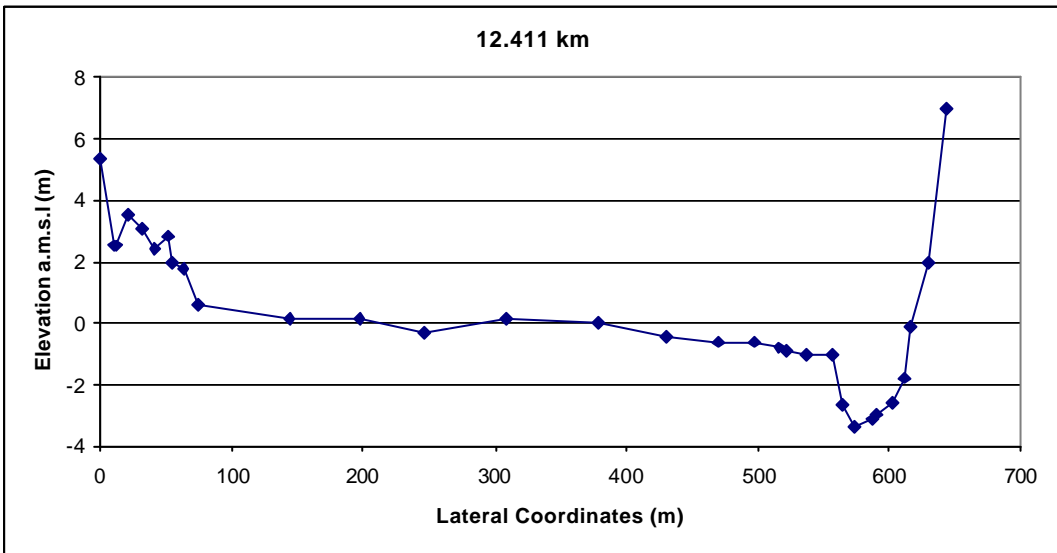
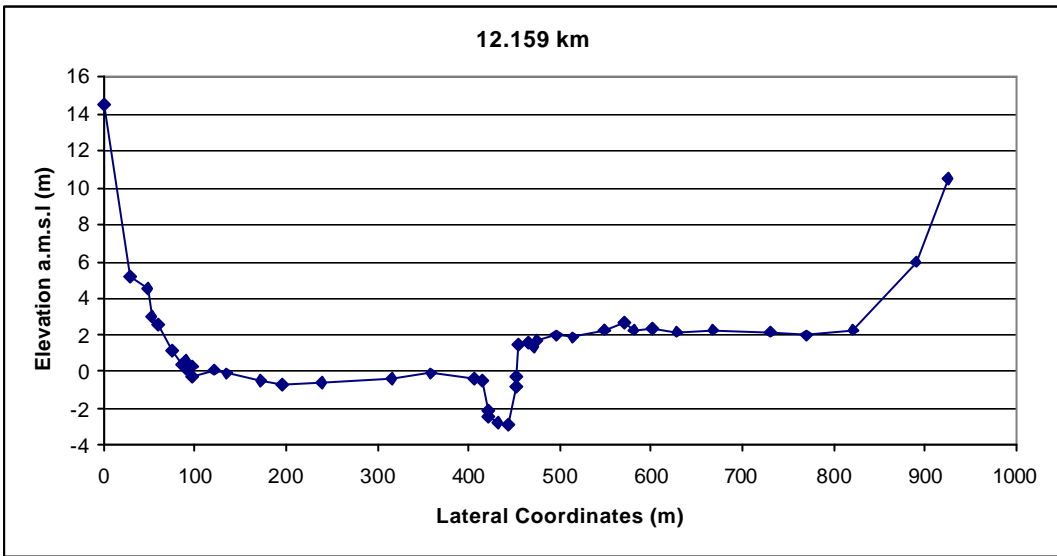
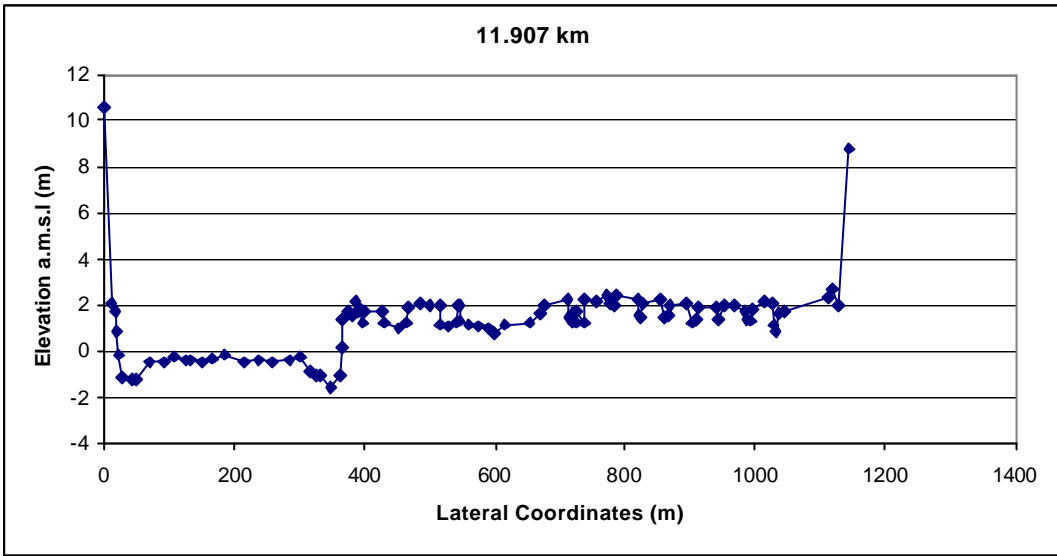


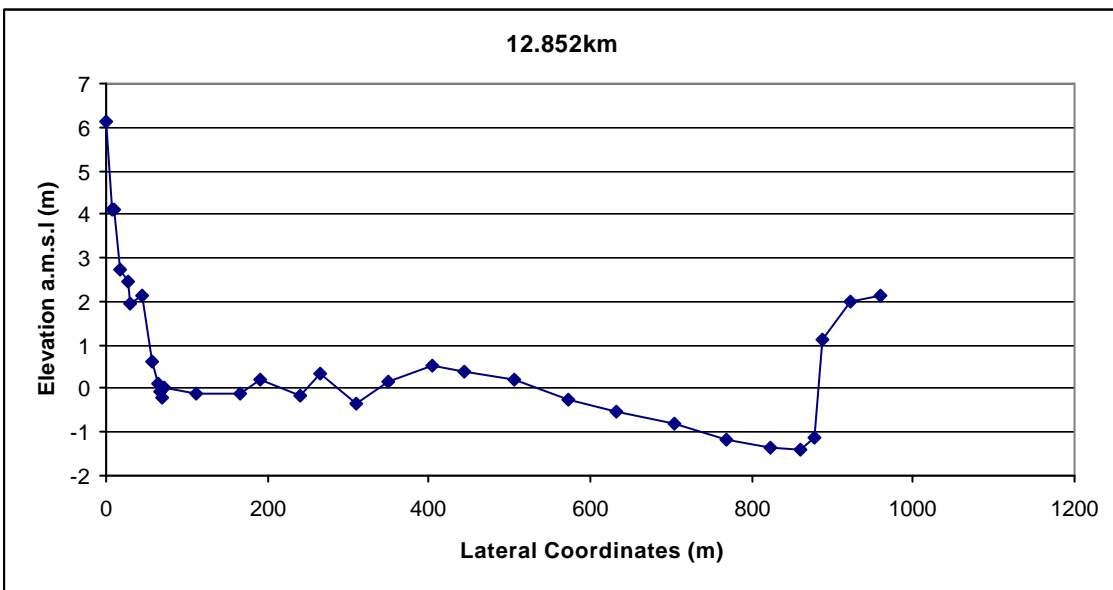
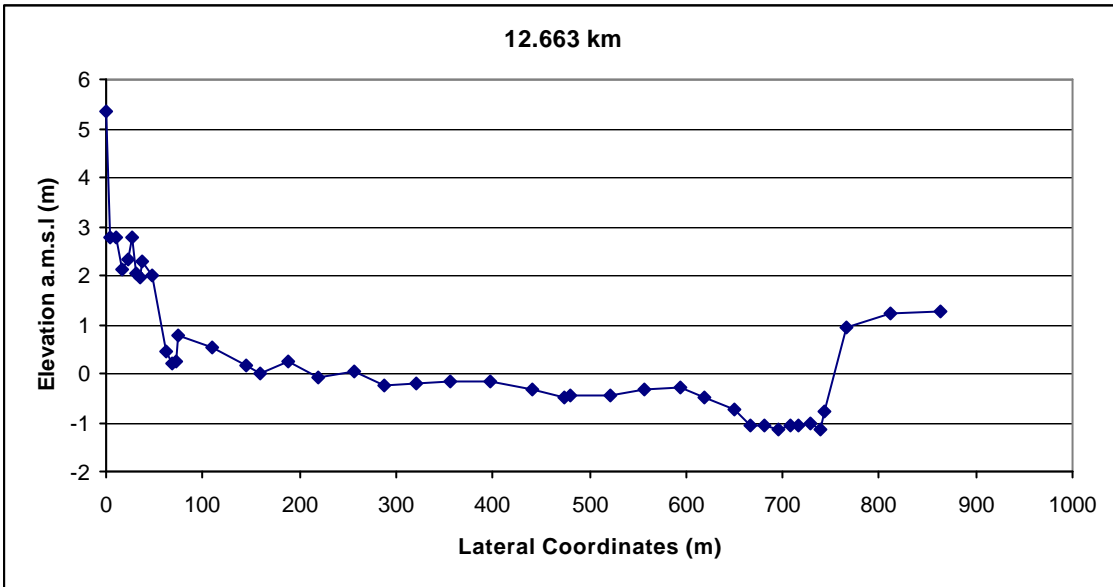












Appendix D

Microalgae of the Thukela Estuary

G.C. Snow, P.T. Gama and J.B. Adams

Department of Botany, University of Port Elizabeth, PO Box 1600, Port Elizabeth, 6000.

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SUMMARY

PART A: PHYTOPLANKTON OF THE THUKELA RIVER ESTUARY

Information regarding the ecology of microalgae, specifically phytoplankton, of the Thukela River estuary is essential in understanding the driving forces concerning the capture of energy input and its subsequent transfer up the trophic states.

Phytoplankton spatial distribution along the horizontal axis of the estuary is strongly influenced by the dynamic interaction between river inflow and the incoming tide. Changes in river inflow will alter the position of the riverine / estuarine interface zone resulting in a change in the region of highest phytoplankton production, which will impact on food web dynamics.

Saltwater intrusion into the estuary will encourage a marine tolerant phytoplankton assemblage while mouth closure will increase the water level shifting the estuary toward a benthic driven ecosystem.

Low flows ($<5 \text{ m}^3 \cdot \text{s}^{-1}$) will encourage sedimentation of fine particulate matter that when re-suspended can reduce the photic depth and thus phytoplankton production.

PART B: BENTHIC MICROALGAE OF THE THUKELA ESTUARY

Under present conditions flood peaks into the Thukela estuary have been reduced by ~8 % from the natural state. Nutrient and suspended particulate matter are discharged into the Thukela river just upstream of the estuary. Microalgal biomass in the estuarine sediment ranged from 2.5 to 20.5 $\mu\text{g g}^{-1}$ dry sediment during a recent (20/08/2002) sampling session when flow was $\sim 6 \text{ m}^3\text{s}^{-1}$. Biomass was highest in the fine sediment in a sheltered part of the estuary 1 km from the mouth. AFDW (an indicator of organic content) and most trace metal concentrations were highest at this site. A longitudinal salinity gradient provides conditions ideal for diatom taxa that are usually found exclusively in marine (*Nitzschia subconstricta*), brack (*Nitzschia constricta* and *N. clausii*) and freshwater (*Cymbella* cf. *similis*) habitats. *Cyclotella meneghiniana* is a brackwater taxon that was common in the estuary and has been previously recorded in the eutrophic Manzimtoti estuary (Watt 1998).

If the MAR entering the estuary is reduced but flow is managed in such a way as to keep the estuary mouth open (river categories A to D) then conditions in the estuary would become more favourable for benthic microalgae. The water-column would become less turbulent and turbid, nutrients entering the estuary would have a longer residence time and sediments would become more stable (aided by biostabilization). A major change in community composition is not expected but biomass would be likely to increase substantially. The increased residence time of nutrients could favour the increased dominance of nuisance algae such as cyanophytes.

If the MAR was reduced to 51 % and the mouth closed for up to 32 % of the year (worst case scenarios 1 and 2) then there would be significant changes in the microalgal biomass, community composition and a shift from a phytoplankton dominated estuary to one in which benthic microalgae become the dominant primary producers. During extended mouth closure the intertidal zone would become submerged and backflooding could result in a 2.5 m increase in water level. Nutrient concentrations are expected to increase and dissolved oxygen could become low ($< 2 \text{ mg l}^{-1}$) in places. The loss of intertidal habitat will result in the loss of the high biomass intertidal microalgae. Increased water level will result in new habitats being created leading to an overall increase in total benthic biomass. However, high nutrient and low oxygen concentrations could result in an increase of nuisance algae such as cyanophytes. If the water in the estuary became fresh after a long period of closure, then marine and many brackish taxa of diatoms could disappear during that period.

1 INTRODUCTION

The Thukela River estuary has been characterised as a one of two river mouth estuaries along the entire coast of South Africa (Begg, 1978; Whitfield, 2000). River mouths are unique estuarine environments characterised by particular hydro-geomorphic features that include high levels of discharge and concomitant levels of sediment transport (Day, 1981; Day et al., 1989). Because of the dynamic nature of estuaries phytoplankton are generally considered not to be an important contributing source of carbon (Day, 1981), however some studies have shown the significance phytoplankton play in supporting a vast array of secondary production (Cloern, 1982; Jones, 1990; Gosselain *et al.* 1994; Bledsoe & Philips, 2000). Shallow estuaries like the majority found along the South African coastline, however exhibit different patterns of phytoplankton biomass production and distribution in contrast to ones found in the northern hemisphere. The limited water depth, increased nutrient input through river inflow and the high light availability at depth promotes the establishment of a benthic primary producing community tilting an estuary toward a benthic driven ecosystem (Day, 1981; Fielding et al., 1988; Goldfinch & Carman, 2000). River flow in estuaries is extremely crucial as it governs the residence time a particle would take to traverse the length of an estuary before exiting out to sea. This period is crucial in determining the doubling time of a planktonic alga before being removed out of the estuary. During periods of high river discharge ($>30 \text{ m}^3 \cdot \text{s}^{-1}$) residence times can be considerably reduced than during periods of low flows ($<5 \text{ m}^3 \cdot \text{s}^{-1}$) thus limiting phytoplankton production. At its height of discharge the Thukela river has been recorded to peak at flows greater than ($>800 \text{ m}^3 \cdot \text{s}^{-1}$) rendering the estuary a river mouth. Flows above $30 \text{ (m}^3 \cdot \text{s}^{-1})$ occur about 4 months out of a year during which the estuary establishes some distance offshore (Begg, 1978; Whitfield, 2000). High turbidity levels associated with these flow limit the photic depth for phytoplankton photosynthesis. However, during periods of low flow ($<30 \text{ m}^3 \cdot \text{s}^{-1}$) the Thukela river estuary functions like a regular estuary with a horizontal salinity gradient and resident phytoplankton populations at lower, mid, and upper estuary reaches.

The botanical component of the Thukela intermediate reserve study of the Thukela Water Project (TWP) required data on microalgae. The specified data requirements for the comprehensive reserve determination included two microalgal surveys that would determine present biomass estimates and importance of the microalgae in the estuary. The study assessed the present state of the phytoplankton community and predicted the natural condition and how much the Thukela river estuary would deviate from present state under various flow scenarios. The riverine /estuarine interface zone has been shown to be critical in producing regions within the estuary that have high microalgal production that significantly influence secondary production (Adams et al., 1999; Jerling & Wooldridge 1991, Snow *et al.* 2000).

2 STUDY APPROACH

A phytoplankton survey was conducted during August 2001 during a low flow condition. Logistical difficulties precluded the gathering of data that would have captured high flow conditions; therefore the data that will be reported on in this report is from a single field survey. Quantitative data were obtained to estimate phytoplankton biomass under low flow conditions and thus estimate the time it would take a planktonic alga to double, which will be related to residence time.

2.1 METHODS AND MATERIALS

2.1.1 Water Quality of the Estuary

Water quality measurements and associated data were collected by the Council for Scientific and Industrial Research (CSIR-Environmentek). This assessment is based on a single field survey taken at 7 sites within the estuary and at two other sites outside the estuary during August 2001. This timing was set to approximate low-flow conditions. The quality of water in most estuaries results from the natural hydrological forcing that causes water to flow above as well as permeate below the soil surface interacting with organic and inorganic material on the catchment. Upon entering the estuary water is further transformed by its interaction with the bed and basin of an estuary. The cumulative history of the water imparts unique physico-chemical properties that shape biotic response. Increasingly a number of estuaries are facing an escalation in population growth and development thus placing them under increased anthropogenic influence and environmental stress. Water abstraction from rivers is one of the anthropogenic influences that are severely impacting on the inflow to estuaries.

2.1.2 Physical and Chemical Parameters

Samples for water chemistry and physical measurements were collected at or near the sites selected for biological samples and were all collected at the same time. This was done to ensure that the results are considered and interpreted together. Chemical parameters sampled included ammonia, nitrate, nitrite, inorganic phosphate, and silicon. Physical parameters included temperature, pH, salinity, turbidity, and suspended solids (Table 3.1).

2.1.3 Biomass Estimation and Phytoplankton Enumeration

Samples for planktonic microalgal biomass and community structure were collected from six sites along the 4-km of the Thukela estuary and included two sites one from the surf-zone and the other a river site. Sampling was undertaken at low river inflow and at high tide in order to determine the extent of marine water intrusion into the estuary, secondly to enable characterisation of the riverine estuarine interface (REI) zone as it impacts phytoplankton biomass, and thirdly to enable phytoplankton characterisation along a vertical profile. Sampling sites were positioned approximately 0.3 and 0.5km from one another along the 4-km stretch of the estuary. At each of the sites vertical profiles of the water column were taken at 0.5m intervals for both chlorophyll *a* and phytoplankton cell counts. Chlorophyll *a* extraction and analysis followed that of Lorenzen (1967). Water samples (500ml) were filtered onto Whatmann GF/C filter paper layered with a few drops of a saturated solution of MgCO₃ then folded in aluminium foil and kept frozen until analysis in the laboratory. Filters were kept in a cool room at 4°C during pigment extraction overnight in 90% acetone whereupon they were corrected for background interference by reading absorbances at 750 nm and corrected for phaeopigments by reading absorbances at 665 nm before and after acidification with 1N HCL using a GBCUV spectrophotometer. Water samples for phytoplankton enumeration were collected 0.5m below the water surface (Top) and 0.5m above the bottom sediments (Bottom) and preserved in buffered 4% formalin solution. Samples were then placed in 60ml settling chambers and allowed to settle for 24hrs then counted following the Utermöhl method of cell enumeration as modified by Snow et al.

(2001). Functional and dominant groups were categorised into flagellates, dinoflagellates, greens, blue-greens, diatoms, and euglenoids.

3 RESULTS AND DISCUSSION

3.1 PHYSICAL AND CHEMICAL PARAMETERS

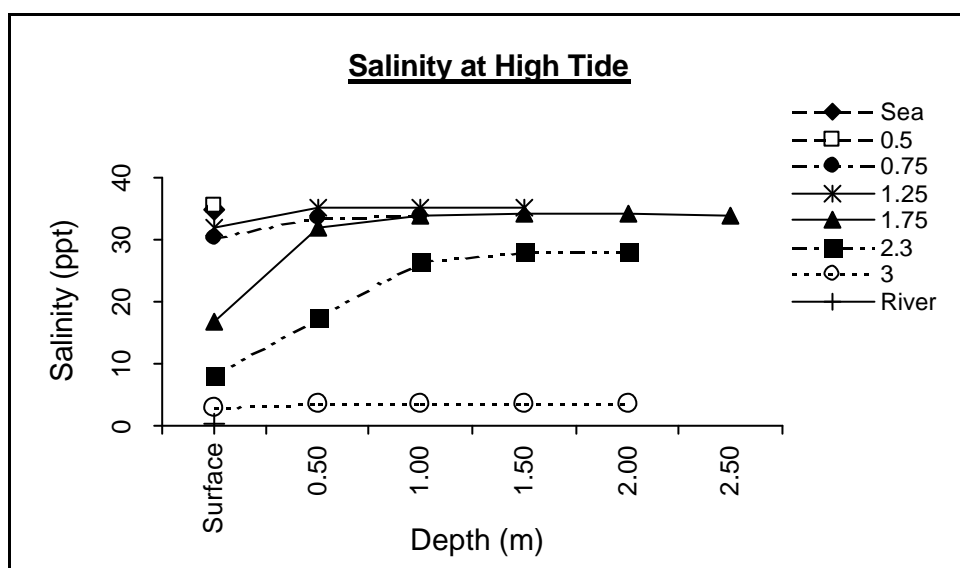
3.1.1 Temperature

Temperature measurements taken on the same day showed that most of the lower sites were cooler than upstream ones. In addition the water column was well mixed, as temperatures recorded at the surface were similar to those taken at the bottom. Temperature patterns at low tide showed a clear horizontal gradient with cooler waters at the mouth and progressively getting warmer up stream typical of warmer waters emanating from the inflowing river (Table 3.1).

3.1.2 Salinity

The estuary showed a distinct salt wedge reaching approximately 2km up the estuary at site 4. The estuary had a clear axial salinity gradient with salinities reaching 28 ‰ at the mouth and falling to levels approaching a freshwater state of 0.6 ‰. Such conditions have been known to occur particularly during the drier periods of the year at low tide, however their duration is generally short lived. The middle reaches of the estuary showed strong salinity stratification starting 1km from the mouth spanning a length of about a 1 km up the estuary. This region of high salinity stratification delineated a zone of increased fresh water in the upper layer and saline water in the bottom layer of the water column (Table 3.1).

Fig. 3.1 Vertical salinity profile taken during high tide. Legend denotes site (i.e. distance from the sea)



Vertical salinity stratification was clearly evident in the middle reaches of the estuary with the lower reaches being very saline both at the surface and at depth. Salinity levels in the upper reaches were similar from top to bottom of the water column suggestive of mixing of surface water with bottom water (Figure. 3.1). This scenario was noticeably evident during high tide as the penetration of the seawater pushed the zone of acute salinity stratification a further 1km from that at low tide by limiting it to an area approximately 0.6km in axial length. Previous reports have suggested evidence of sporadic episodes of seawater intrusion up the estuary and creating patchy zones of highly saline water. During low tide salinity patterns within the estuary were generally similar to those observed at high tide, however there were residual pockets of high saline water in the middle reaches of the estuary

Table 3.1 Physical and chemical variables measured during high tide within the Thukela mouth and estuary in August 2001. Values for nitrates and nitrites were below detectable levels

Distance from Sea (km)	Depth (m)	Temp °C	Salinity (ppt)	SS (mg/L)	pH	Turbidity (NTU)	DO (mg/L)	NO ₃ -N (µg/L)	NO ₂ -N (µg/L)	NH ₃ -N (µg/L)	PO ₄ -P (µg/L)	SiO ₄ -Si (µg/L)
Sea	0.00	21.8	35.0	6	8.01	1.5	N/S	<10	<10	<25	<10	<80
0.79	0.00	21.6	35.5	14	7.94	6.0	7.7	<10	<10	<25	<10	<80
	1.04	21.6	33.9	32	7.86	9.0	7.8	<10	<10	<25	<10	202
1.07	0.00	21.7	30.4	10	7.91	4.5	7.2	<10	<10	<25	11	539
	1.40	21.6	35.3	24	8.07	4.5	8.2	<10	<10	<25	<10	<80
1.50	0.00	21.6	32.0	20	7.95	2.5	7.9	<10	<10	46	24	<80
	2.40	21.7	34.0	36	8.05	7.5	8.2	<10	<10	34	<10	202
2.10	0.00	21.8	16.7	24	7.61	2.0	7.1	<10	<10	52	21	1330
	1.80	21.6	28.0	32	7.85	2.5	7.1	<10	<10	<25	11	804
2.67	0.00	22.4	8.1	8	7.64	1.0	8.1	<10	<10	94	39	2892
	2.13	22.8	3.7	8	7.57	3.0	7.8	<10	<10	32	55	3235
3.36	0.00	22.7	2.8	6	7.72	1.5	7.2	<10	<10	37	54	3186
4.00	0.00	22.4	0.2	12	7.82	2.0	6.7	<10	<10	<25	50	3431
River	0.00	N/S	0.3	20	7.02	3.0	6.0	<10	<10	<25	23	3333

N/S Not Measured

3.1.3 Total Suspended Solids

Suspended solids values showed marked horizontal and vertical changes (Table 3.1). The lower to middle reaches of the estuary at depth showed increased total suspended values, which can possibly be attributed to the re-suspension of bottom sediments by the flooding tide. The upper part of the estuary had very low levels suggestive of little suspended matter entering the head of the estuary, however water taken from the N2 bridge indicates an increase in total suspended solids. Although that was the case it does however suggest that most of that sediment settles out prior to reaching the upper part of the estuary at these flows. The influence of suspended solids on phytoplankton biomass has been shown to limit production by removing planktonic algae by co-flocculation (Cuker *et al.*, 1991, Burkholder *et al.*, 1997), however these flocculates may be consumed by zooplankton. During present flow conditions suspended solids remained low such that phytoplankton biomass peaked at 1.3×10^6 cells.ml⁻¹ at site-6 (approx. 3km from the mouth) (Figure. 3.2).

3.1.4 Turbidity

Turbidity levels during the study were consistent with the total suspended solids which suggests that turbidity levels are closely linked to suspended inorganic silt carried by river flow and that any appreciable increases will be as a result of increased river flow discharges.

3.1.5 Dissolved Oxygen

Dissolved oxygen did not show any strong horizontal nor vertical patterns however the lower and upper part of the estuary had reduced values compared to those of the middle portion of the estuary indicative of possible improved mixing and an increased transient phytoplankton biomass (Table 3.1).

3.1.6 Nutrients

During the study nutrient concentrations for nitrate, nitrite and ammonia (except in some sites up the estuary where higher concentrations of ammonium were recorded) were below detectable levels. However from previous surveys levels greater than 1000 $\mu\text{g. N l}^{-1}$ have been reported for nitrogen (Quinn & Whitfield, 1999). Orthophosphate concentrations also showed a pattern of increase in the upper reaches of the estuary indicative of the influence of riverine input. Such patterns are consistent with a land derived nutrient source that can be important in the supply of nutrients to the phytoplankton in the estuary. Anthropogenic allochthonous nutrient inputs under low flow conditions can promote large biomass production particularly of undesirable forms of planktonic microalgae altering the phytoplankton community structure. Silica concentrations depicted a pattern of elevated levels in the upper reaches of the estuary suggestive of the allochthonous nature of the nutrient. Silica levels showed a pattern of a marked reduction from the upper reaches toward the mouth. The marked difference in silica levels at the mouth and the upper reaches was suggestive of either being rapidly taken up by the silicon requiring planktonic and benthic microalgal community or it just quickly settled out of the water column.

3.2 BIOLOGICAL CHARACTERISTICS

3.2.1 Phytoplankton Biomass (Standing Crop)

Biomass for this study was estimated as chlorophyll *a* concentration. Chlorophyll *a* concentration is a widely used measure of microalgal standing crop within aquatic water bodies (Wetzel, 1983; Goldman and Horne, 1983). The ease and reasonable reliability with which this can be accomplished lends itself to the wide use of this technique in assessing autotrophic water column standing crop. The phytoplankton biomass in the surface layers increased in the middle reaches of the estuary compared to the lower upper reaches during the August survey (Fig. 3.2a and b). The lower part of the water column however showed a different pattern in biomass distribution depicting an increase in chlorophyll *a* concentrations from the middle to the upper reaches of the estuary. At site 6, maximum chlorophyll *a* concentrations were recorded at approximately 2.0m depth, which may be attributable to an improved photic depth and freshwater conditions even at depth. This was consistent with the phytoplankton occurring there, which included euglenoids and some gelatinous forms of green algae. These planktonic algae may have originated upstream, however occurrences of similar forms of algal types have been shown to occur in fresh to brackish estuaries (Bold and Wynn, 1985).

The chlorophyll concentrations of the surface (0-0.5m) and the lower (0.5-2.0m) layers of the water column were integrated along a vertical salinity stratification gradient. From this it appeared that near the mouth chlorophyll concentrations were pronounced at the surface however in the middle reaches of the estuary biomass was highest in the mid to lower part of the water column. This may be as a result of the stimulation of phytoplankton production due to the mixing of freshwater and saline water at depth. When comparing the phytoplankton biomass of the Thukela estuary to that of other estuaries in the Eastern and Western Cape Provinces that were within similar salinity ranges, it is clear that the Thukela system has higher biomass. Thukela chlorophyll *a* biomass was 6-fold the biomass of the Sundays estuary and 9-fold that of the Berg estuary (Adams et al., 1999). Unlike other estuarine systems from the Eastern and Western Cape where correlations have been made between levels of nitrate and levels of biomass in the water column, nitrate concentrations in the Thukela estuary were below detectable limits. Phosphorus however was higher in the upper reaches of the Thukela estuary and related with higher chlorophyll *a* concentrations.

3.2.2 Phytoplankton Community Structure

The phytoplankton community structure in the Thukela estuary was composed of six functional groups that were identified as important in characterising the planktonic microflora

(Fig. 3.4). Flagellates were dominant in the water column from the mouth right up to the upper reaches of the estuary. In the lower estuary and the sea flagellates were co-dominant in the upper layers of the water column, whereas in the middle reaches flagellates were more dominant (Fig. 3.3a). Flagellated cell abundances peaked at approximately 460×10^3 cells mL^{-1} at site-6 with diatoms co-dominating the upper water column at 238×10^3 cells mL^{-1} . The spatial distribution pattern of flagellates along the bottom layers of the water column showed a gradual increase in abundances from the mouth to a maximum 3 km upstream (Fig. 3.3b). The presence of dinoflagellates, albeit occurring in small densities, was observed from the middle reaches and peaking at site-6. A number of the dinoflagellate species encountered included *Peridinium*, and *Gymnodinium* species.

Fig. 3.2 a) Phytoplankton biomass as chlorophyll a measured from the mouth to approximately 4km up stream measured at 0.5m intervals along the vertical profile of the water column. b) Chlorophyll a concentrations taken by integrating the upper part (0-0.5m) and the lower part (0.5-2.0m) of the water column

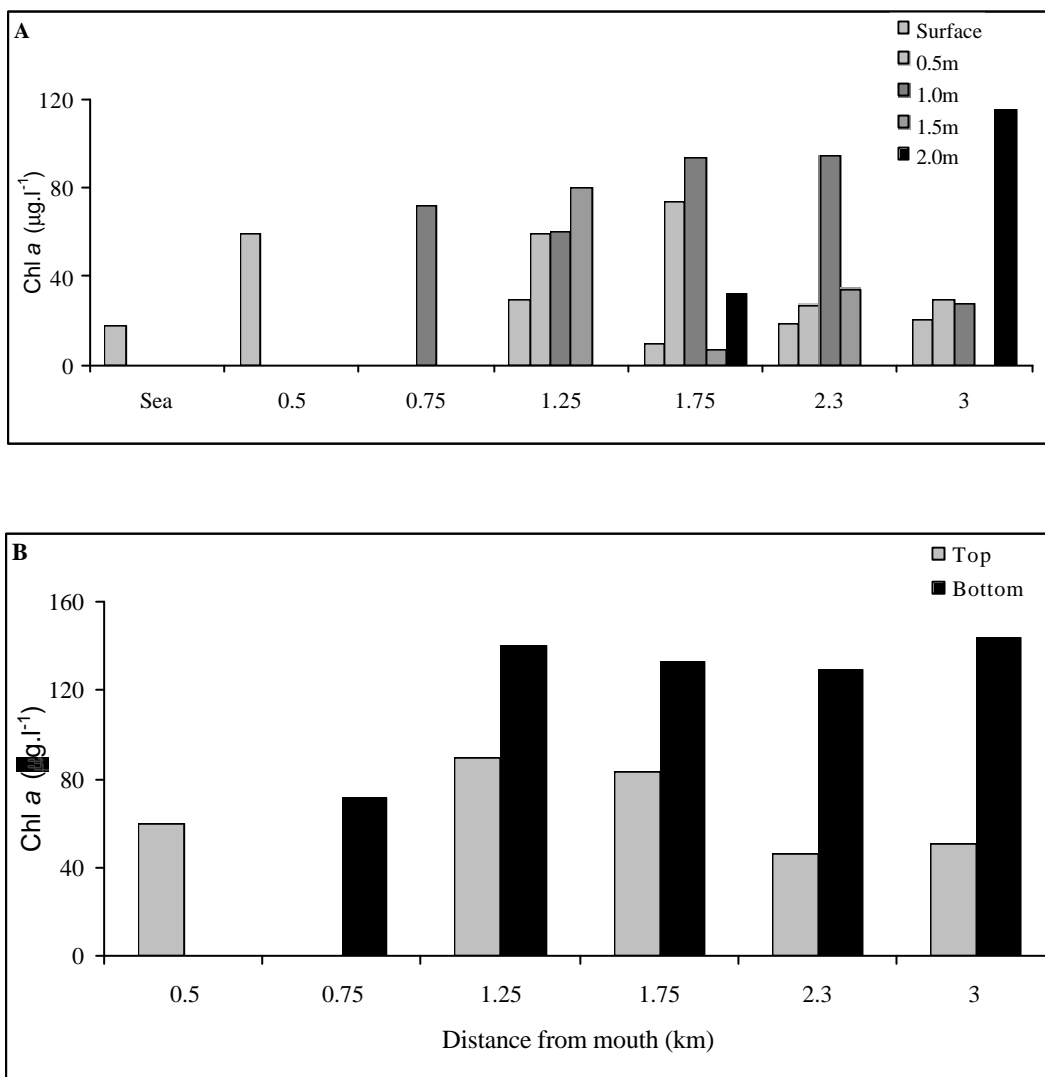


Fig. 3.3 Phytoplankton cell abundances as functional groups sampled along the length of the estuary. (a) Phytoplankton cell numbers sampled from the upper surface of the water column, and (b) lower part of the water column. (c) Total phytoplankton cell numbers from the upper (Top) and lower (Bottom) layers of the water column. Abbreviations in legend denote: Flagellates-Flag, dinoflagellates-Dino, diatoms-Diat, blue-greens-BI-Gr, euglenoids-Eug, and greens-Gr

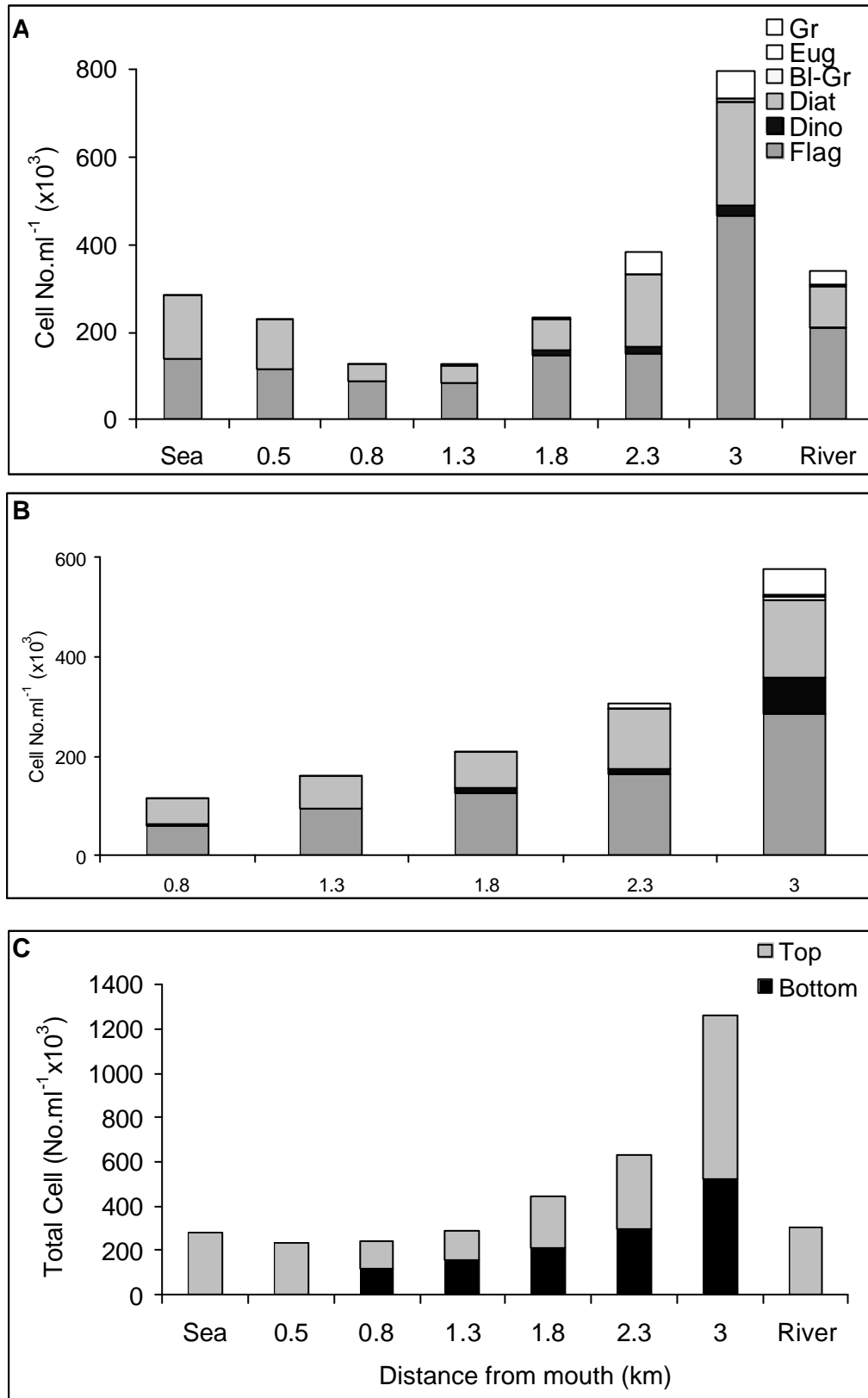
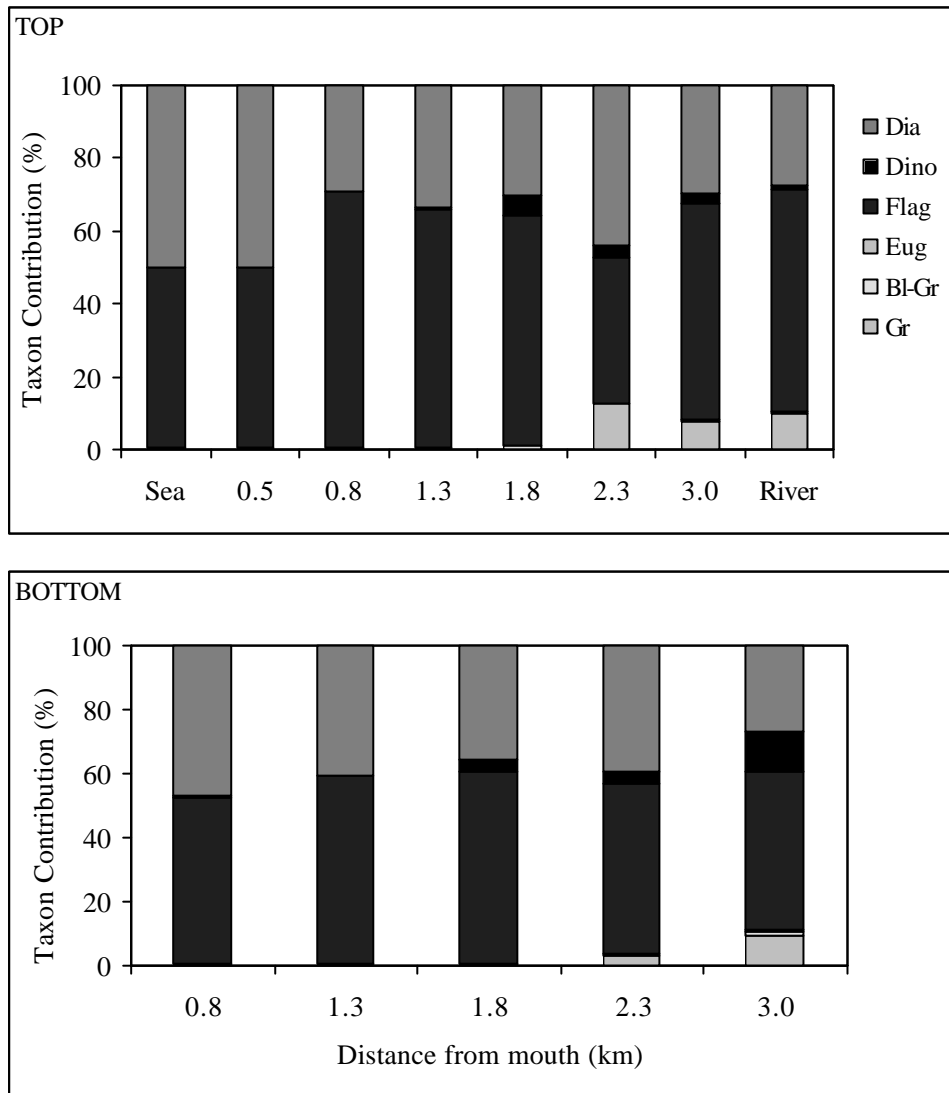


Fig. 3.4 Percent contribution of functional groups taken from the upper (Top) and lower (Bottom) of the water column along the length of the Thukela river estuary. Abbreviations in legend denote: Flagellates-Flag, dinoflagellates-Dino, diatoms-Diat, blue-greens-BI-Gr, euglenoids-Eug, and greens-Gr



A number of these dinoflagellates are small (~10-15 μm diameter) and are palatable to herbivorous zooplankton and hence play a crucial role in energy transfer up the food chain (Froneman, 2000). In the more saline waters of the lower estuary diatoms like *Nitzschia closterium*, *Asterionella glacialis*, *Cyclotella* sp. *Coscinodiscus* sp., constituted the dominant phytoplankton species. These species are generally found occurring in mesohaline to polyhaline estuarine habitats. Because of the freshness of the water in the upper reaches of the estuary, filamentous blue-green algae were present in the bottom layers of the water column (Fig. 3.4b). Although their densities were low it does however suggest that the potential exists for their proliferation under favourable conditions. Blue-green algae are notorious for their ability to rapidly divide and form blooms in a short period of time given low flow, high inorganic phosphate input and deep photic zones (Wetzel, 1983; Paerl, 1988). For this study, flows were $\sim 6 \text{ m}^3 \cdot \text{s}^{-1}$ giving an estimated residence time of ~ 2.5 days.

The percent contribution of euglenoids to total phytoplankton abundance is evident in the more fresh waters of the upper estuary suggestive of relatively poor water quality. Euglenoids, gelatinous type of greens and blue-greens are planktonic algae that are normally indicative of low water quality conditions. Given the land use practises in the catchment within the immediate vicinity of the Thukela estuary, these algal species have the potential

during low flow discharges, increased water level, excessive nutrient input, and poor light penetration at depth.

4 BOTANICAL IMPORTANCE

Phytoplankton is an important component to total botanical importance in estuaries particularly during low flow conditions, as they can be an integral part in the generation of carbon that supports heterotrophic production. Thus when river flow discharges are reduced below $<10 \text{ m}^3 \cdot \text{s}^{-1}$ then changes in water level will influence the type of microalgal community that will develop especially when there is mouth closure. The diverse assemblages of phytoplankton that occur in estuaries is extremely important in the sustenance of a varied heterotrophic community. From this study it was clear that there were different phytoplankton communities along the horizontal axis of the estuary. The lower and middle estuary was comprised of marine/brackish species whilst the upper estuary had more diverse groups.

5 EFFECT OF FUTURE SCENARIOS ON THE PHYTOPLANKTON

Assessment of the effects of changes related to future discharge scenarios on the phytoplankton communities was based on the Thukela River Estuary report on physical dynamics and water quality (Appendix C to this report). There were six scenarios in total and four corresponded to Ecological Reserve Categories (i.e. Scenario: River Category A, B, C, and D) for the river upstream whilst the last two scenarios corresponded to Worst Case 1 and 2. For the Thukela River Estuary four abiotic states were derived (Table 5.1). Each abiotic state was related to the extent and frequency of flow discharges.

Table 5.1 Four Abiotic States that were derived for the Thukela River Estuary

State 1:	Mouth Closed, from weeks to a few months at a time	0 – 2 m ³ .s ⁻¹
State 2:	Mouth Open, occasional mouth closure of a few days	2 – 5 m ³ .s ⁻¹
State 3:	Mouth Open, saline intrusion	5 – 30 m ³ .s ⁻¹
State 4:	Mouth Open, river dominated	> 30 m ³ .s ⁻¹

Under State 1, the water level would increase, deposition of suspended particulate matter would possibly occur with increased frequency therefore shifting the primary production base toward a benthic driven ecosystem. This state would surely alter the phytoplankton community structure favouring nuisance-forming types of planktonic microalgae in response to elevated nutrient concentrations, especially in the upper reaches of the estuary. For States 2 and 3 under these flow, blue-greens and euglenoids would become dominant in the phytoplankton.

The percentage incidence for the different States for each individual scenario is shown in Table 5.2. Under the Reference condition states 3 and 4 occurred approximately 33 and 67 percent of the time respectively. When considering the River categories A, B, C, and D, State 1 is not likely to occur at all and State-2 only occurs about 2% of the time for all categories combined. Under the Present state, State-2 occurs for more than 6% of the time (Table 5.2). This means that under the different river categories State 1 does not occur whilst State 2 will only occur for a combined period of approximately 2% of the time and therefore phytoplankton community structure would possibly favour communities that are similar to those found under States 3 and 4. The frequency and duration of floods are however lessened meaning that salt tolerant phytoplankton species would become more dominant.

Table 5.2 Percentage occurrence of States per Scenario

Scenario	State 1 (%)	State 2 (%)	State 3 (%)	State 4 (%)
Reference Condition	0	0	33.2	66.8
Present State	0.6	6.2	42.0	51.0
River Category A	0	0.4	38.0	61.6
River Category B	0	0.4	48.8	50.8
River Category C	0	0.5	62.6	36.9
River Category D	0	0.7	68.0	31.3
Worst Case 1	31.6	8.9	24.4	35.1
Worst Case 2	31.6	8.9	24.9	34.6

The percentage of time that the estuary is under State 1 for a period of time exceeding 30% is under both Worst Case 1 and 2. During these periods the estuary will be closed and the effects of mouth closure on the phytoplankton community structure have been alluded to earlier. Under River categories C and D the estuary will remain in State 3 for approximately 60 – 70% of the time, which means the estuary is more saline for a considerably longer

period than under Present conditions. Under this State the phytoplankton community would be characterised by the occurrence of co-dominant phytoplankton species that include flagellates and diatoms for a greater duration of the year.

6 CONCLUSIONS

Flow reductions that approximate Worst Case scenarios would have an impact on the phytoplankton assemblage within the Thukela River Estuary. These conditions would greatly encourage growth of nuisance planktonic/benthic microalgae especially in the upper reaches of the estuary given the industrial and agricultural activities upstream. In addition dissolved oxygen levels at depth within the upper reaches of the estuary might decline if flow is reduced such that there is little or no water exchange. River categories A and B scenarios, which have a percent mean annual runoff of 66 and 60 respectively, are quite similar to the Present state conditions such that there would be no adverse change in the phytoplankton community structure. Under River categories C and D, the estuary would become more saline quite frequently and for extended periods impacting the phytoplankton assemblages toward a more polyhaline assemblage.

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PART B: BENTHIC MICROALGAE OF THE THUKELA ESTUARY

1 INTRODUCTION

The influence of man-made alterations on estuarine structure and hydrodynamics, brought about by bridges and dams, and the likely impact on the transfer of impounded water between catchments alters the ecological function of estuaries. An Environmental Reserve Determination is required when abstraction of water from estuaries are considered and is the scope of this study. This report is aimed at predicting changes in estuarine benthic microalgal community structure and biomass in relation to hydrodynamic changes resulting from water being transferred out of the Thukela River catchment.

Estuaries are complex ecosystems in which many environmental factors vary on different spatial and temporal scales. Measurement of all physical and chemical factors that could be important determinants of ecosystem integrity is impractical. Biological indicators respond to altered physical and chemical conditions that may not have been measured. Using benthic diatoms as indicators of environmental conditions in aquatic systems is important for three basic reasons: (1) their importance and cosmopolitan abundance in ecosystems, (2) their utility as indicators of environmental conditions and (3) their ease of use, particularly with recent developments in digital imagery.

The microphytobenthos communities, mainly consisting of benthic pennate diatoms that live in and on the tidal flats, can be suspended and deposited (de Jonge 1985). Motile diatoms with low adhesion capacity tend to congregate near the thin surface layer of sediment and are termed 'epipellic'. These diatoms can easily be suspended from fine particle substrata that are exposed to currents and waves, resulting in them being transported to main channels. Consequently, diatoms with low motility that are firmly attached to sand particles ('episammic') tend to dominate more turbulent habitats (de Jonge 1985).

2 STUDY APPROACH

2.1 SITE DESCRIPTION

Benthic microalgal samples were collected on 20 August 2001 at four sites along the length of the Thukela estuary during a spring low tide. These sites overlapped with CSIR's sites 2-5. Site 1 of this study was approximately 1.0km from the mouth and sites 2, 3 and 4 were approximately 1.5, 2.0 and 2.5km from the mouth respectively. A fifth site was not included because the estuary became extremely shallow (<0.5 m) and fresh (<1.0 ppt) 2.5km from the mouth.

2.2 METHODS USED

2.2.1 Benthic microalgal biomass

Benthic microalgal biomass was estimated using 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 sediment cores from each site were frozen and stored in the dark before being freeze-dried. Freeze-drying eliminates the error related to water holding capacity of different sediment types and organic content. Once freeze-dried, 4 ml of 95 % ethanol (Merck 4111) was added to ~100 mg of sample then the pigment was left to extract in a fridge for 24 hours. After extraction the samples were well mixed, centrifuged and then injected into an HPLC for chlorophyll *a* analysis. The HPLC was standardised using pure chlorophyll *a* extract from the red seaweed *Plocamium corallorhiza*. Chlorophyll *a* concentration was calculated using the equation (modified from Nusch 1980):

$$\text{Chl-a biomass } (\mu\text{g g}^{-1}) = (((A_{\text{Ploc}} - (A_{\text{Ploc}}/1.7)) \times 29.6) \times V)/m$$

Where:

- A_{Ploc} = Chlorophyll *a* absorbance measured using the spectrophotometer
- 29.6 = constant calculated from the maximum acid ratio (1.7) and the specific absorption coefficient of chlorophyll *a* in ethanol ($82 \text{ g l}^{-1} \text{ cm}^{-1}$)
- V = volume of ethanol used to extract pigment (ml)
- M = mass of freeze-dried sample (g).

2.2.2 Ash free dry weight (AFDW)

Four intertidal sediment samples from each site were analysed for AFDW by drying the samples in an oven for 24 hours at 105°C, followed by ashing in a furnace at 550°C for an hour.

2.2.3 Cell counts and identification

Samples were collected based on the original plan to identify epipellic diatoms (motile diatoms inhabiting the surface of fine, cohesive sediment). The techniques used for collecting epipellic diatoms proved to be ineffective on the fine sand that dominates most of the Thukela estuary so only subtidal samples were analysed. Four subtidal sediment, samples per site were collected, by drawing a glass tube across the sediment surface and allowing it to fill up with a mixture of sediment and water.

A sub-sample of each subtidal sample was shaken and allowed to settle for 10 seconds (reduces sediment content on slides) before drawing off some supernatant. The diatom frustules in the supernatant were cleaned using saturated potassium permanganate and concentrated hydrochloric acid. The samples were then rinsed a number of times by centrifuging and replacing the supernatant with distilled water until there was no trace of acid. Once well mixed, one or two drops of sample were placed on a microscope slide, allowed to dry and then permanently mounted using Naphrax mounting medium (Northern Biological Supplies, U.K.).

Diatom frustules were examined under a Zeiss Axioplan light microscope with Differential Interference Contrast optics. Using a television camera (JVC KY-F3) linked to a PC, images were saved and analysed using the AnalySIS image analysis programme (Soft Imaging System). A minimum of 300 frustules was counted per sample using 1000 x magnification.

Empty diatom frustules could also be present in the acid-washed samples from dead cells that were originally at the site or were deposited from the water-column. To correct for this source of error, the percentage of live cells containing a chloroplast was calculated and the images of the acid-cleaned cells were used to identify cells present in the preserved material. This reduced the number of species from approximately 130 in the acid-washed samples to just 24 common taxa in the preserved sample.

2.2.4 Environmental variables

Microalgal samples were collected at the same sites and times as measurements and samples were taken by CSIR.

3 RESULTS

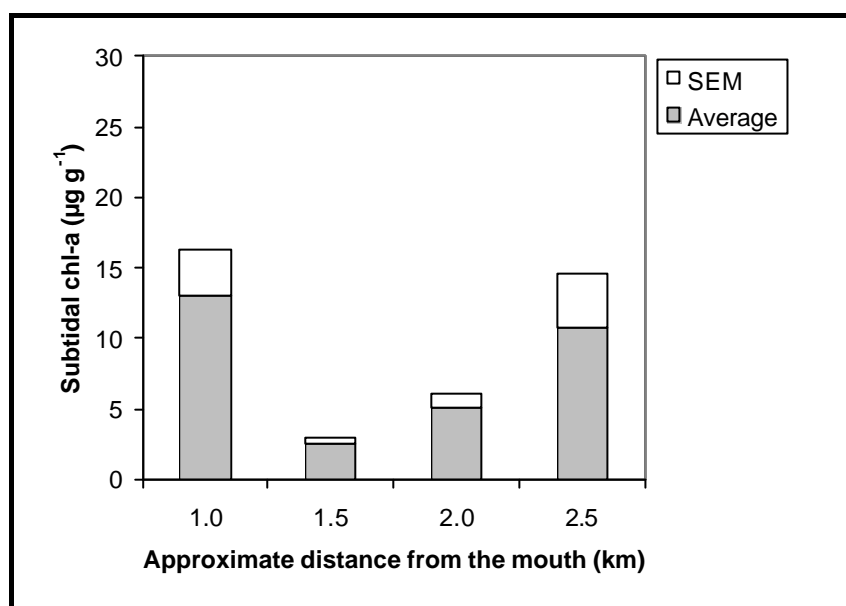
3.1 BENTHIC MICROALGAL BIOMASS

Intertidal and subtidal chlorophyll *a* biomasses were highest in the fine sediment about 1 km from the mouth ($20.54 \pm 7.60 \mu\text{g g}^{-1}$ and $13.04 \pm 3.28 \mu\text{g g}^{-1}$ respectively) (Figure 3.1). Chlorophyll *a* at all other sites increased towards the head of the estuary. Intertidal and subtidal chlorophyll *a* increased from $6.76 \pm 0.43 \mu\text{g g}^{-1}$ and $2.50 \pm 0.38 \mu\text{g g}^{-1}$ 1.5 km from the mouth to $18.85 \pm 2.88 \mu\text{g g}^{-1}$ and $10.70 \pm 3.89 \mu\text{g g}^{-1}$ respectively 2.5 km from the mouth. Average intertidal benthic chlorophyll *a* ($14.52 \pm 3.51 \mu\text{g g}^{-1}$) was almost double subtidal chlorophyll *a* ($7.82 \pm 2.16 \mu\text{g g}^{-1}$) but both followed similar trends along the length of the estuary.

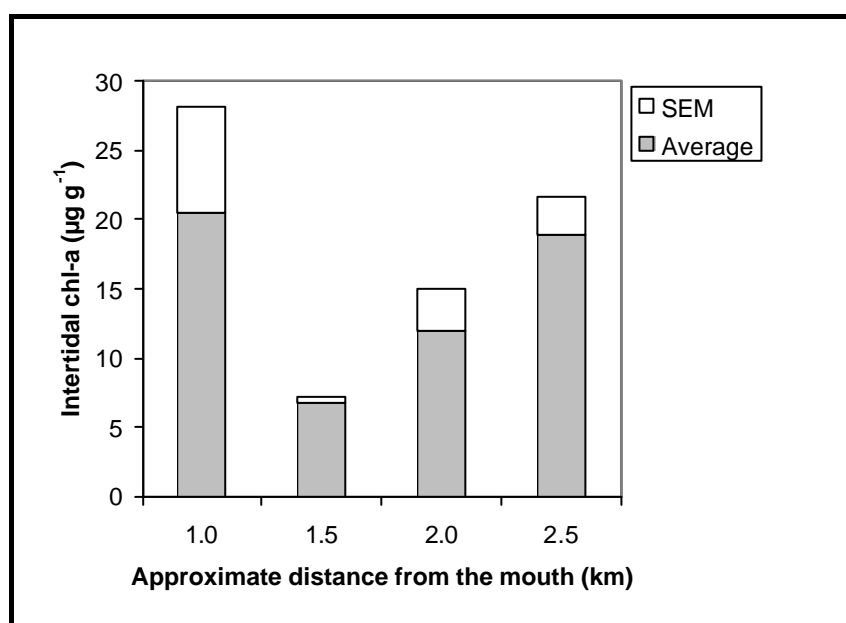
Fig. 3.1 Average (a) subtidal and (b) intertidal chlorophyll *a* biomass in the Thukela estuary, 20 August 2001

SEM – Standard error of the mean

(a)



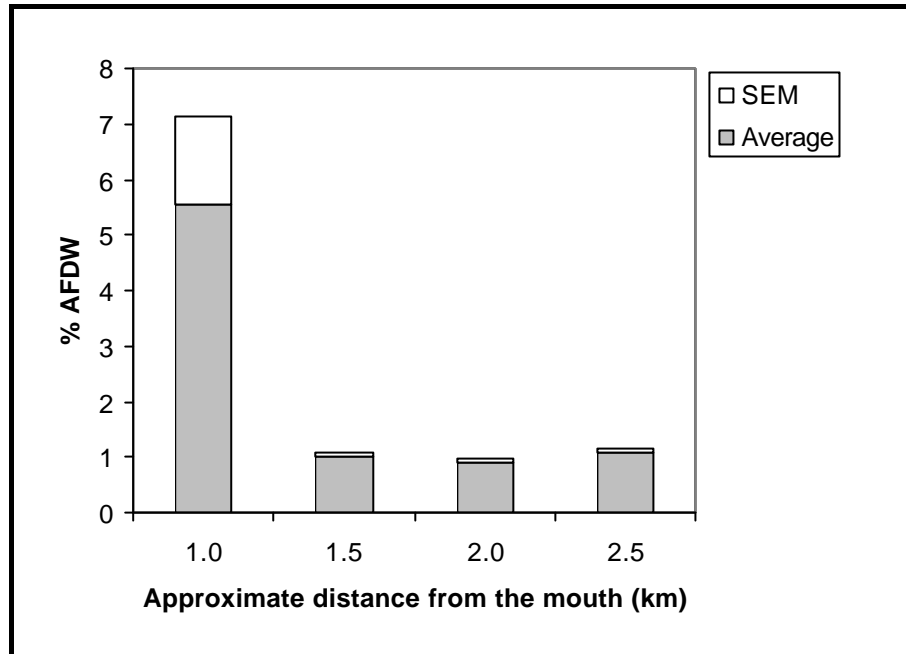
(b)



3.2 ASH FREE DRY WEIGHT

The ash free dry weight of the cohesive sediment in the protected site 1km from the mouth was five times greater (5.56 ± 1.58 %) than the fine sandy sediments at the other sites (range from 0.92 ± 0.06 % to 1.10 ± 0.07 % 2 and 2.5km from the mouth respectively) (Figure 3.2).

Fig. 3.2 Average ash free dry weight (%) in intertidal sediments of the Thukela estuary



3.3 DIATOM IDENTIFICATION AND RELATIVE ABUNDANCE

Over 5000 diatom frustules were counted in the four replicate samples from the four sites. More than 130 diatom taxa were identified in the acid cleaned samples but the majority of the frustules were from dead cells that had been deposited from the water-column or were the remnants of earlier communities within the sediment. Using the images of the acid cleaned cells for identification, 24 species were identified as commonly occurring and containing a chloroplast in the preserved material (Table 3.1). Relative abundances of the diatom taxa are presented in Appendix 2. Marine/brackish species were not necessarily associated with the site closest to the mouth. Some freshwater and brackish species (*Navicula towutiensis*, *N. viridula* var. *rostellata*, *Nitzschia acicularis*, *Nitzschia fonticola*) were only found in the upper reaches of the estuary.

There was no longitudinal gradient in salinity 1 to 2km from the mouth. Salinity was only noticeably lower 2.5km from the mouth relative to the other sites. Diatom taxa that had a high relative abundance at this site in particular were *Nitzschia reversa*, *N. aff. perindistincta*, *N. fonticola*, *N. acicularis*, *Navicula viridula* var. *rostellata*, *N. subrhyncocephala*, *Cyclotella* sp. and *Fragilaria* sp.

Table 3.1 Commonly occurring benthic diatoms in the Thukela estuary (20 August 2001). Information regarding distance from the mouth and preferred salinity region from literature (freshwater (F), brackish (B) or marine (M)) is included where possible (van Dam *et al.* 1994, Hartley 1996 & Witkowski *et al.* 2000). Please refer to Appendix 2 for relative abundance values

Sp. No.	Taxon	Authority	Distance (km)				Salinity
			1.0	1.5	2.0	2.5	
16	<i>Amphora exigua</i>	Gregory		x	x	x	B & M
11	<i>A. sabiniana</i>	Reimer		x	x		
9	<i>Bacillaria paradoxa</i>	Gmelin	x	x	x	x	F, B & M
44	<i>Cyclotella sp.</i>					x	
4	<i>C. meneghiniana</i>	Kützing	x	x	x	x	F & B
13	<i>Cymbella kappii</i>	Cholnoky	x	x	x	x	F & B
93	<i>C. cf. similis</i>	Krasske			x		F
6	<i>Diploneis puella</i>	(Schumann) Cleve	x	x	x	x	F & B
87	<i>Fragilaria sp.</i>					x	
120	<i>Gyrosigma scalproides</i>	(Rabenhorst) Cleve	x				
48	<i>Navicula sp.</i>		x	x	x	x	
2	<i>N. absidua</i>	Archibald	x	x	x	x	
8	<i>N. gregaria</i>	Donkin		x	x	x	F, B & M
12	<i>N. phyllepta</i>	Kützing		x	x	x	B & M
47	<i>N. towutiensis</i>	Cholnoky			x	x	F
20	<i>N. viridula var. rostellata</i>	(Kützing) Cleve				x	F & B
66	<i>Nitzschia acicularis</i>	(Kützing) W. Smith				x	F & B
73	<i>N. claussii</i>	Hantzsch	x				B
37	<i>N. constricta</i>	(Kützing) Ralfs non (Gregory) Grunow		x			B
43	<i>N. fonticola</i>	Grunow non sensu Hustedt				x	F & B
15	<i>N. granulata</i>	Grunow in Cleve & Moller	x	x			B & M
28	<i>N. aff. perindistincta</i>	Cholnoky			x	x	
17	<i>N. reversa</i>	Hustedt				x	F, B & M
52	<i>N. subconstricta</i>	Grunow	x				M

4 DISCUSSION

4.1 PRESENT STATE OF BENTHIC MICROALGAE

The present state of benthic microalgae in the Thukela estuary is based on the findings of the 20 August 2001 sampling trip. The mouth of the estuary was open and there was a distinct saline wedge that penetrated over 2km from the mouth during spring low tide and over 3km during the high tide. According to monthly-simulated runoff data (CSIR report) a longitudinal salinity gradient will only exist in the estuary for between 5 and 8 months a year, and the mouth can close occasionally.

The frequency of floods is similar to that for natural conditions but flood peaks have been reduced by about 8%. This has resulted in a lower sediment transport capacity through the estuary and reduced scouring with greater sediment deposition during major floods. These conditions represent a slightly more stable environment for benthic microalgae and can lead to sediments becoming more stable as a result of biofilms. Benthic microalgae, diatoms in particular, have been shown to stabilize sediments as a result of copious quantities of polymer (mucilage) being produced (Holland *et al.* 1974). Polymers on the bed enhance particle cohesion and reduce the roughness of the bed (Paterson 1997).

A large industrial area (including the Sappi Tugela mill, Mandini, Tugela Rail and the Sumdumbili Sewerage Treatment Works) is situated just upstream of the estuary. There are no DWAF monitoring points between these point site discharges and the estuary. Based on the type of effluent it is expected that the potential impact would be in terms of decreased oxygen levels and increased suspended solids/turbidity and inorganic nutrients (CSIR report).

4.1.1 Benthic microalgal biomass

Sediment chlorophyll *a* ranged from 2.5 to 20.5 $\mu\text{g g}^{-1}$ in the Thukela estuary. This microalgal biomass compares well with international results reviewed by MacIntyre *et al.* (1996), which ranged from <0.1 to 52.7 $\mu\text{g g}^{-1}$. Similarly, benthic chlorophyll *a* in the Langebaan Lagoon, Western Cape Province, generally ranged from 0 to 34 $\mu\text{g g}^{-1}$ (Fielding *et al.* 1988).

The slight decrease in flood peaks and the possible increase in water-column nutrients would favour an increase in microalgal colonization and abundance. Most sediment in the Thukela estuary is dominated by fine sand indicating areas of high turbulent flow. It is in the sheltered areas dominated by fine sediment where highest benthic chlorophyll *a* occurred. The slight increase in turbidity and the decrease in oxygen concentration could counteract the effect of increased nutrients and possibly increase the relative abundance of cyanobacteria.

4.1.2 Ash free dry weight

Intertidal ash free dry weight, which gives a good indication of organic matter content of the sediment, was more than 5 times greater in the fine sediment 1km from the mouth (5.6%) than the fine sand (~1%) throughout the rest of the estuary. In addition, unpublished results by CSIR (Appendix 1) showed a significantly higher trace metal content (aluminium, chromium, copper, nickel, lead and zinc) in this fine sediment. The metal concentrations were still within acceptable ecological limits and were probably bound to the organic matter within the sediment.

4.1.3 Diatom community composition

Sandy silts and sands generally support a lower microalgal biomass than sites with fine, cohesive sediment. With increasing sediment grain size, the proportion of epipelagic, motile taxa decreases and microphytobenthic assemblages in intertidal sands consist predominantly of small, virtually immobile, araphid and monoraphid diatom taxa that produce an extracellular polymeric pad for attachment (Underwood & Kromkamp 1999).

Diatoms in the estuary ranged from examples of exclusively marine (*Nitzschia subconstricta*), brackish (*N. constricta* and *N. clausii*) and freshwater taxa (*Cymbella* cf. *similis*) to a number of other commonly occurring diatoms that exist in overlapping salinity habitats (e.g. *Bacillaria paradoxa* and *Navicula phyllepta*). If mouth closure were to occur, it is expected that it will only occur for a short period (state 2) and should not impact the community composition significantly. On the other end of the scale, high flow conditions (state 4) would increase sediment scouring, suspend microalgae and reduce chlorophyll *a* within the sediment.

Two diatom taxa in this study were recorded in a study of the Manzimtoti and Mhlabatshane estuaries by Watt (1998). *Cyclotella meneghiniana* was most common in the eutrophic Manzimtoti estuary at brackish water sites (5-10 ppt) that were dominated by coarse sand and fine mud. *Amphora exigua* was found in both Kwazulu-Natal estuaries.

In a study by Giffen (1963), a number of diatoms were identified from estuaries in the Eastern Cape. Those that overlapped with species in this study include *Amphora exigua* (fresh to brackish), *Bacillaria paradoxa* (slightly brackish, ~1 ppt), *Cyclotella meneghiniana* (fresh to brackish), *Gyrosigma scalproides* (slightly brackish), *Nitzschia granulata* (strongly brackish, ~15 ppt) and *N. constricta* (moderate to strongly brackish).

4.2 EFFECT OF FUTURE SCENARIOS ON BENTHIC MICROALGAE

The most significant general trend from present state to category D is a general decrease in MAR from 73.4% to 51.0%. This results in the proportion of the year occupied by estuary state 3 increasing from 42% to 68%. This is as a result of the decreased input of freshwater and an increase in the longitudinal salinity gradient. Due to managed releases from dams within the catchment, mouth closure is extremely unlikely (<1.0%) during these scenarios.

High flow (>30 m³ s⁻¹) does not favour high benthic microalgal biomass because suspension of the sediment and microalgal cells could occur. As flow decreases, this allows more time for recolonisation and an increase in chlorophyll *a* biomass. Instead of the estuary acting as a river mouth, a full salinity gradient exists that can support a suite of marine to freshwater diatom taxa.

During worst case scenarios 1 and 2, the chances of mouth closure for periods longer than two weeks is very high (31% occurrence) and there is a chance that the low flow could intensify the effects of nutrient input. Closed mouth conditions can result in as much as a 2.5 m increase in water-column depth and there is no tidal action resulting in the intertidal region becoming submerged. Mouth closure would result in the entire estuary becoming fresh during a period when marine, brackish and freshwater taxa of diatoms would have been present. Higher nutrients (provided some flow still enters the estuary) and lower oxygen concentrations could result in euglenoids and cyanophytes becoming more abundant in the sediment. If mouth closure were to occur for an extended period (state 1) then the possibility of reduced salinity could decrease or eliminate diatom taxa adapted to higher salinity water such as *Amphora exigua*, *Navicula phyllepta*, *Nitzschia granulata* and *N. subconstricta*. Backflooding as a result of mouth closure would increase the number of habitats available for benthic microalgae, except intertidal communities that will be lost, and increase overall estuarine microalgal biomass.

There would be no significant change in community composition relative to present conditions during periods when the mouth is open.

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6 APPENDICES

6.1 APPENDIX 1

Appendix 1								
Summary table.								
Biotic and abiotic (CSIR unpub. data) variables in the Thukela estuary (20 Aug 2001).								
Low tide								
Site	Int chl	sub chl	Temp (°C)	Sal (ppt)				
1	20.54	13.04	20.6	19.7			Site 1 = 1.0 km from mouth	
2	6.76	2.50	20.8	18.5			Site 2 = 1.5 km from mouth	
3	11.93	5.05	21.0	22.2			Site 3 = 2.0 km from mouth	
4	18.85	10.70	22.1	0.6			Site 4 = 2.5 km from mouth	
High tide								
Site	Temp (°C)	Sal (ppt)	SS (mg l ⁻¹)	pH (ntu)	Turb. (ntu)	DO (mg l ⁻¹)		
1	21.7	32.6	21.0	7.9	6.8	7.5		
2	21.6	34.1	22.0	8.0	3.5	8.1		
3	21.7	30.1	30.0	7.8	4.8	7.7		
4	21.9	20.0	20.0	7.7	1.8	7.6		
Nutrient concentration (µg l ⁻¹)								
Site	NO ₃	NO ₂	NH ₃	PO ₄	SiO ₄			
1	0.0	0.0	0.0	5.5	370.5			
2	0.0	0.0	23.0	12.0	0.0			
3	0.0	0.0	43.0	10.5	766.0			
4	0.0	0.0	47.0	25.0	1848.0			
Trace metals (mg kg ⁻¹)								
Site	Al	Cd	Cr	Cu	Hg	Ni	Pb	Zn
1	44117	<0.25	69.3	42.0	<0.50	49.4	18.0	71.2
2	6995	<0.25	25.3	8.8	<0.50	11.4	6.0	18.6
3	7246	<0.25	20.8	7.7	<0.50	10.8	6.4	21.2
4	6338	<0.25	24.8	9.3	<0.50	13.6	5.8	18.4
Particle Size Distribution (µm)								
Site	>2000	2000-1000	1000-500	500-250	250-125	125-63	<63	
1	0.00	0.00	0.55	2.91	4.07	3.04	89.43	
2	0.00	1.14	27.13	60.62	10.81	0.18	0.12	
3	0.00	0.00	7.93	75.78	15.94	0.21	0.14	
4	0.13	3.89	38.78	50.84	6.25	0.11	0.00	

6.2 APPENDIX 2

Appendix 2												
Relative abundance (%) of commonly occurring live diatom taxa (refer to Table 3.1 for respective species names)												
Site	2	4	6	8	9	11	12	13	15	16	17	20
1	45.6	8.0	17.3	0	6.5	0	0	4.1	9.0	0	0	0
2	11.9	2.7	8.6	1.6	15.0	26.9	16.6	1.6	2.1	5.2	0	0
3	17.6	3.8	3.1	1.8	9.0	33.7	17.9	1.8	0	0.9	0	0
4	2.9	12.9	1.0	2.5	3.7	0	13.1	9.3	0	3.3	5.7	3.4
Site	28	37	43	44	47	48	52	66	73	87	93	120
1	0	0	0	0	0	2.4	1.0	0	3.0	0	0	3.1
2	0	1.5	0	0	0	6.3	0	0	0	0	0	0
3	6.7	0	0	0	1.5	1.1	0	0	0	0	1.1	0
4	16.7	0	4.2	3.2	12.6	1.1	0	4.0	0	0.5	0	0



Plate 1: Light microscope (oil immersion) image of *Navicula absidua* Archibald (1000x magnification)



Plate 2: Light microscope (oil immersion) image of *Cyclotella meneghiniana* Kützing (1000x magnification)

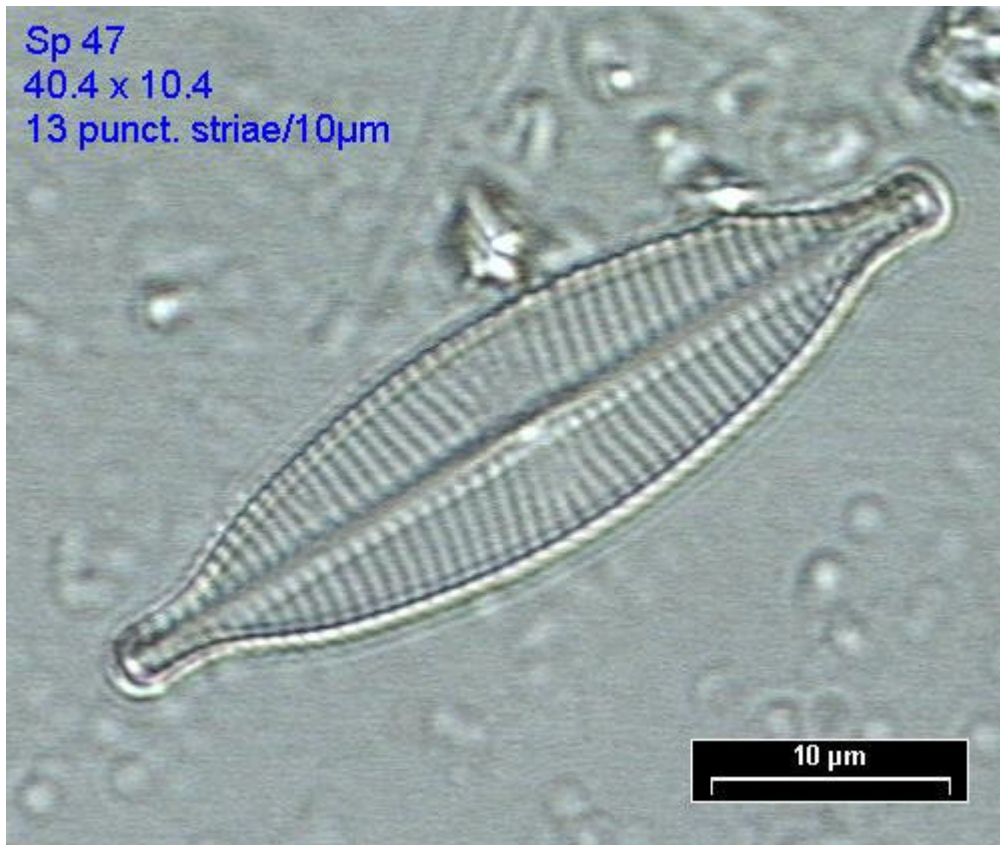


Plate 3: Light microscope (oil immersion) image of *Navicula towutiensis* Cholnoky (1000x magnification)



Plate 4: Light microscope (oil immersion) image of *Gyrosigma scalproides* (Rabenhorst) Cleve (1000x magnification)

Appendix E

Macrophytes of the Thukela Estuary

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SUMMARY

This report presents the results of the specialist study on the botanical (macrophyte) characteristics of the estuary, a component of the Intermediate Reserve study for the Thukela River estuary. Botanical surveys were undertaken in June 1996 and in August 2001. A vegetation map was compiled to indicate the present distribution of macrophytes.

The botanical importance score calculated for the Thukela estuary was 205 out of a possible 400. The low score of the Thukela estuary is similar to that obtained for the larger temporarily open / closed estuaries in KwaZulu-Natal e.g. Mloti and Mkomazi.

The vegetation of ecological importance includes 20.38 ha of the reed, *Phragmites australis*, 19.65 ha of sedge, *Schoenoplectus scirpoides* and 0.27 ha of swamp forest (*Barringtonia racemosa* and *Hibiscus tiliaceus*).

A total of 22 ha of reeds and sedges have been lost on the south bank, but the estuary has gained a sedge area of 19.32 ha on the north bank, so the overall change in area covered by reeds and sedges is smaller than expected. An area of 1.5 ha of swamp forest has been lost since 1937. Sugar-cane and other agricultural activities have encroached on the floodplain.

A reduction in freshwater input coupled with high nutrient input could result in reed and sedge encroachment into the main channel. On the north bank of the estuary the sedge *Schoenoplectus scirpoides* has colonized the mouth area since the 1996 flood.

An increase in the frequency of mouth closure and rise in water level to greater than 1 m will impact the reed and sedge beds if inundation persists for longer than 3 months. This effect will be greater in spring/summer compared to winter.

Seedling establishment is adversely affected by water level fluctuations and inundation. The seedlings of *S. scirpoides* are more capable of establishing and developing under water than *P. australis*. The buds and seeds of *P. australis* are sensitive to submergence.

There were no plants in the lower reaches of the Thukela Estuary that indicate a persistent saline influence. True mangroves and salt marsh species were absent. Species that are common in brackish waters (<15 ppt) occur i.e. *Phragmites australis* and *Schoenoplectus scirpoides*. If the mouth closed and the estuary became fresh and nutrient rich then plants such as the bulrush (*Typha* spp.) and the aquatic weed, water hyacinth (*Eicchornia crassipes*) may become dominant during the fresher months.

An assessment of the effect of the different river inflow scenarios on the macrophytes indicated that overall the estuary is less dynamic that it was in the past due to a reduction in the magnitude of large floods. Longer periods between high flushing flows would promote the growth of emergent reeds and sedges.

1 INTRODUCTION

The Thukela Water Project (TWP) Feasibility Study was completed in December 1996. Because of the National Water Act (Act 36 of 1998) some aspects of the study needed further investigation. One aspect was the Environmental Reserve Determination. This was required so that the available transferable yield to the Vaal River System could be confirmed. This report presents the results of the specialist study on the botanical characteristics of the estuary, a component of the Intermediate Reserve study for the Thukela River estuary.

Terms of reference for specialists were:

1. Identify key macrophyte species and their importance.
2. Identify the key abiotic factors that influence the macrophytes.
3. Define the present status of the macrophytes.
4. Predict the reference condition of the macrophytes.
5. Predict the effect of each of the 6 future development scenarios on the macrophytes.
6. Complete the Intermediate RDM specialist templates.

The area covered by the different macrophyte community types (e.g. swamp forest, reeds and sedges) was mapped from recent and past maps and aerial photographs. This was used to determine the present state and Botanical importance of the estuary so that Steps 3 and 4 of the reserve process could be completed. The distribution of the different plant community types was used to set the reserve for water quantity and quality as the plants are sensitive to changes in salinity and water level fluctuations.

The Thukela is the largest river in Natal and second only to the Orange River in the whole of southern Africa (Day 1981). The lower reaches have been classified as a river mouth (Begg 1978, Whitfield 1995). During summer the rate of flow is so high that the river is fresh to the sea and the mixing of salt and freshwater occurs offshore (Day 1981). During periods of low flow the river narrows to 200-330 m and a maze of mud banks and sand banks appears (Day 1981). Sediments from the Thukela supply sand to most of the beaches in northern Natal. The Thukela bank off the coast is a very large area of sandy mud fished by many Natal trawlers. Major impacts include the cultivation of sugar cane on the floodplain, litter at fishing sites near the mouth and some exotic vegetation (*Eucalyptus* plantations) on the north bank. Patches of indigenous forest and a sizeable stand of reeds and sedges add to the aesthetic appearance of the estuary.

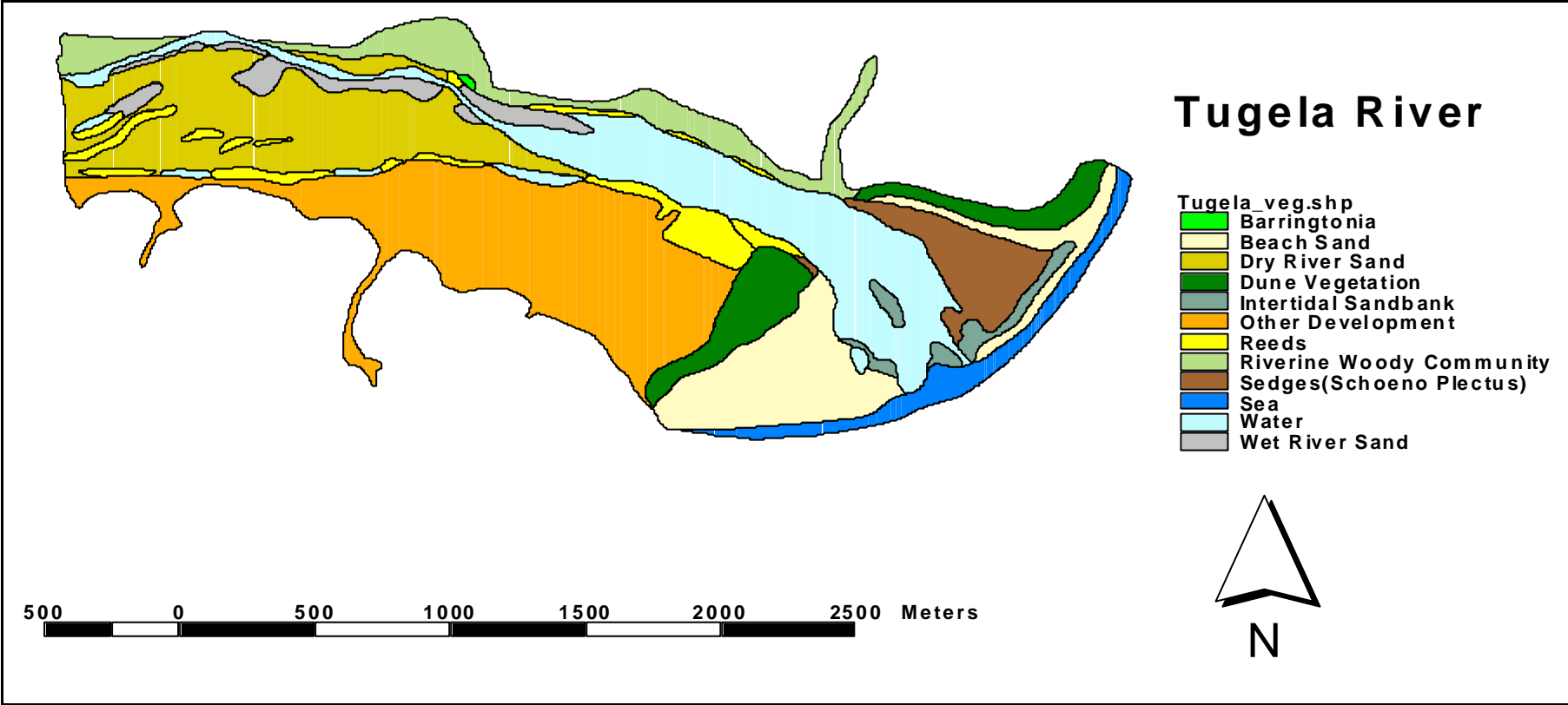
2 STUDY APPROACH

The results in this report are from a botanical survey in June 1996 and in August 2001. In 2001 areas that were not ground-truthed in 1996 were visited so that accurate assessments could be made of the change in vegetation over time. An assessment of changes from the natural (reference) to present condition is a step in the Intermediate Resource Directed Measures process. In 1996 the area investigated extended from the new N2 bridge to the mouth, a distance of approximately 8km. In 2001 the lower 4km of the estuary were investigated by boat.

The area covered by the different plant community types was assessed from oblique aerial photographs taken on 3 June 1996 and in August 2001. A vegetation map (Figure 2.1) was compiled following the ground surveys where plants were collected and later identified in the herbarium at the University of Port Elizabeth. All the different vegetation types present in the lower mouth reaches were visited separately and plant specimens taken or plant names recorded where they were known for certain. A list of all the plant species found in the Thukela Estuary is provided in Annexure 1. The vegetation boundaries were positioned using the aerial photographs in relation to 1992 orthophoto maps obtained from the Chief Directorate: Surveys and Land Information (Cape Town). A plant species list is provided for the lower reaches of the Thukela River.

The botanical importance rating system was applied to the Thukela estuary to assess the conservation importance of the estuary based on the vegetation. The habitat integrity index was also applied (Figure 3.1). This gives an indication of the change in the estuary over time. This is a comparison of reference (natural) and present state conditions.

Fig. 2.1 Vegetation map of the Thukela Estuary



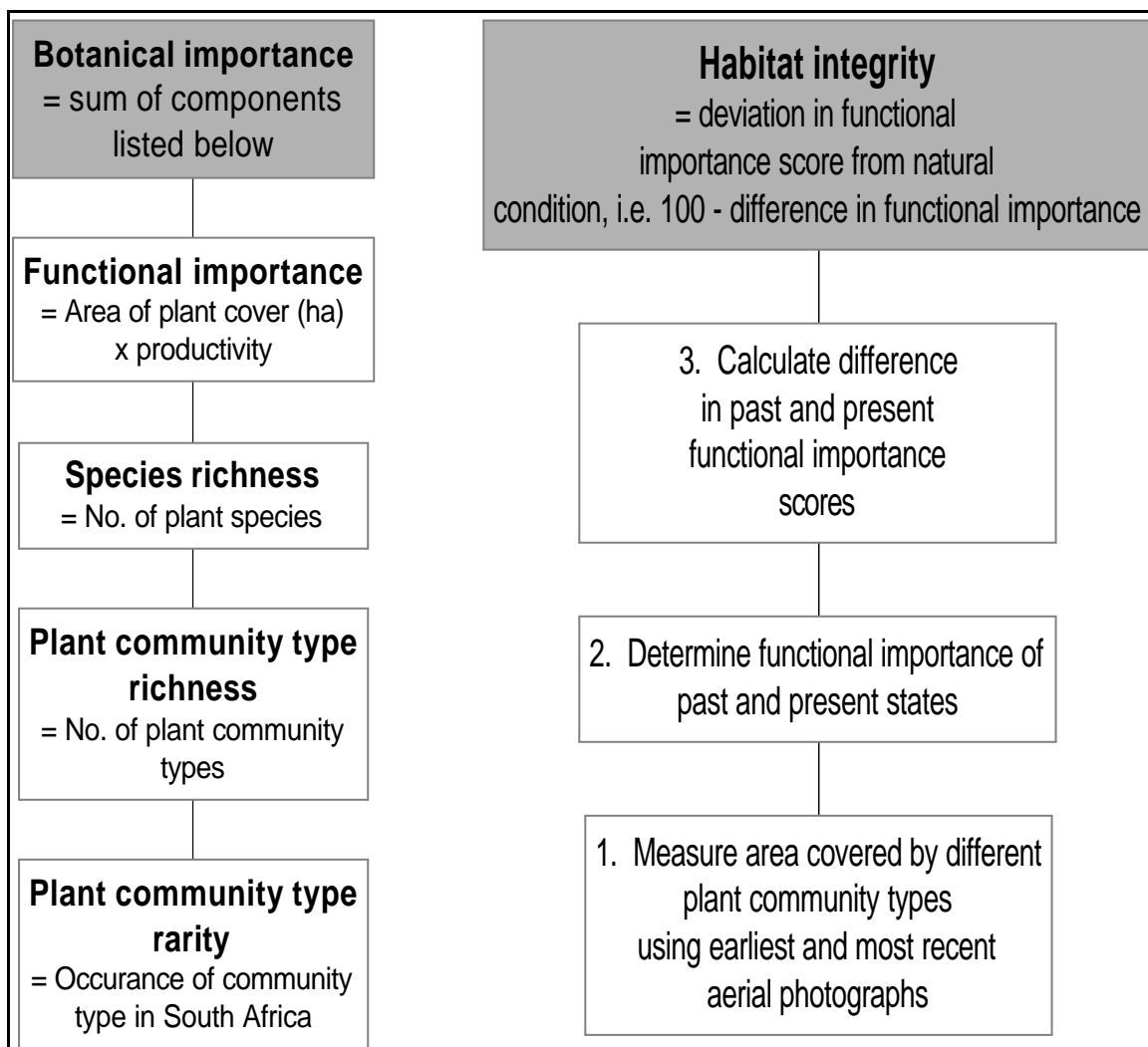
3 PRESENT DISTRIBUTION OF THE MACROPHYTES

3.1 SOUTH BANK

On the south bank coastal dune forest is found closest to the sea and at the waters edge of the estuary. A coast canopy tree, *Bridelia micrantha* was found as well as *Rhus chirindensis* which is the tallest example of the *Rhus* genus found in South Africa. Creepers such as *Ipomoea purpurea*, *I. palmata* and *Commelina africana* were abundant.

Behind the dune ridge and dune vegetation on the south bank there is a wetland area. The dominant plant is common reed, *Phragmites australis* (Figure 2.1). Within this wetland is a homogenous stand of the sedge, *Schoenoplectus scirpoides* and some patches of the lagoon hibiscus, *Hibiscus tiliaceus*. This species is referred to as the freshwater mangrove and often occurs closely associated with true mangroves. Isolated trees of *H. tiliaceus* occur along the waters edge (Plate 1). *H. tiliaceus* usually fringes estuaries and rivers, has striking white flowers and large heart-shaped leaves that are resistant to salt spray.

Fig. 3.1 Flow chart depicting the components of the botanical importance rating and habitat integrity index used in this study



The reed bed covers approximately 20 ha and contain both *Phragmites australis* and *P. mauritianus*. *P. australis* grows in swamps or vleis and in places with restricted drainage or in standing water up to 70cm deep. *P. mauritianus*, on the other hand, occurs in riverine situations, often floodplains, preferably with well-drained, sand soils and permanently flowing

or frequently moving water. The horizontal rhizomes readily penetrate sand alluvial deposits, so that these plants are often the first perennials to re-colonize flood-disturbed river banks (Gordon-Gray and Ward 1971).

Dense stands of Brazilian pepper trees (*Schinus terebinthifolius*) together with some dune forest species occurred approximately 2km from the mouth. Brazilian pepper is an alien species introduced to South Africa as an ornamental shrub. The plant acclimates easily to a wide variety of soils and moisture levels, is salt tolerant, grows rapidly and forms dense forests that exclude all other plant life by producing a dense closed canopy. It infests thousands of hectares in Florida, USA displacing mangrove and other indigenous communities. It thrives on disturbed soils and in habitats that are created by drainage and farming (<http://aquat1.ifas.ufl.edu/mcplnt2b.html>, <http://edis.ifas.ufl.edu>). For some distance these trees occur behind a narrow band of *Phragmites australis* or interspersed with reed patches and thereafter they form dense stands at the waters edge. Sugarcane occurs behind this area. The abundance of the Brazilian pepper tree indicates that this area has probably been disturbed at some time in the past due to agriculture. Very large floods would deposit sediment in this floodplain area and it is not unusual for a meter of sand to be deposited over the floodplain vegetation which becomes rapidly colonized by opportunistic weed species.

Approximately 4km from the mouth, the banks are steep and are colonised by reeds, which extend only 2m inland. Common reed, *Phragmites australis* and Spanish reed, *Arundo donax* were found. *Arundo donax* is an introduced reed that is much taller than *Phragmites*. It occurs in cultivation and as a stray from cultivation and grows on river banks and other wet places. A variety of grasses occur on top of the bank (*Cynodon dactylon*, *Sporobolus africanus*) as well as a number of weed species (*Lantana camara*, *Sesbania punicea*).

3.2 NORTH BANK

In 2001 a large sedge marsh consisting of *Schoenoplectus scirpoides* (approximate area = 19.32 ha) was found at the mouth. Some signs of harvesting were evident (Plate 2). The material is used for thatching and to weave baskets and mats. These beds are flooded at high tide (Plate 3). In 1996 the estuary mouth had a completely different morphology and these sedge areas were absent. They have grown over a six year period to form an extensive bed. Orthophoto maps for 1992 also indicate the absence of this vegetated area.

In 1996 the estuary was visited after a flood. A variety of weeds (e.g. *Asclepias decipiens*, *Ageratum conyzoides*, *Senecio inaequidens*) were found growing amongst the debris deposited by the floods. Grasses, *Sporobolus* and *Dactyloctenium* occurred on the elevated bank and were interspersed with a few sedges. Directly behind the narrow grass banks (approximately 10 m in width) is the coastal forest. A small sedge marsh (*Schoenoplectus scirpoides*) occurred where a freshwater stream entered the river.

Approximately 1km from the mouth a narrow band of the rush, *Juncus kraussii* occurs. A steep grassy bank was sandwiched by coastal forest. Closer to the water a component of coastal forest is the brackwater mangrove *Barringtonia racemosa*. This is the only genus in South Africa and has the only species. It is a medium size tree (4-10m), found fringing coastal swamp forest, estuaries and rivers from the Natal south coast to Mozambique. Rare, scattered patches of swamp forest of which *Barringtonia racemosa* is a characteristic species are found where the water table is high and only plants tolerating the waterlogged conditions survive. Approximately 3km upstream from the mouth the banks are steep with little intertidal area. The steep banks are cultivated (Plate 4).

The vegetation found in the Thukela estuary was similar to that of other estuaries with floodplains in KwaZulu-Natal. Floodplain communities are characterized by a regular alternation of flood and dry phases with the result that their floral components are derived from both aquatic and terrestrial sources. Species composition is largely determined by the

interplay between topography and the hydrological regime and the ability of species to tolerate stresses and disturbances imposed by the hydrological regime. Species diversity is low but species composition can change rapidly in response to hydrology. Grasses and sedges such as *Vossia*, *Echinochloa*, *Paspalum vaginatum*, *P. maximum*, *Setaria sphacelata*, *Scirpus* spp and *Cynodon dactylon* are common. Species capable of morphological adaptations to increased water levels; *Cyperus* spp, *Schoenoplectus scirpoides*, *P. australis* and *P. mauritianus* are also characteristic (Breen *et al.* 1988).

4 BOTANICAL IMPORTANCE

A botanical importance rating system has been developed to summarize the botanical importance of an estuary (Coetzee *et al.* 1997; Colloty *et al.* 2001). Botanical importance is defined as the contribution of the flora to the conservation status of an estuary. Botanical importance was calculated as follows (Figure 3.1):

Botanical importance = Functional importance + Species richness + Community richness + Sum of habitat rarity scores of each plant community type present.

Functional importance was based on the area and number of different plant community types and their contribution in the form of energy input (i.e. primary productivity). The functional importance formula includes all estuarine plant community types namely; salt marsh, reeds and sedges, benthic microalgae (found in the intertidal sand and mudflats) and phytoplankton. The term plant community type is used as the plants do not exist as separate communities or populations. At times these plant community types are found as monospecific stands. The extent of the phytoplankton was calculated as the area covered by water on the slack low tide. This allowed for comparison with other plant community types without including intertidal communities twice. Average primary productivity values were calculated from available South African literature (Colloty *et al.* 2001).

Species richness was the number of plant species identified for a specific estuary and **community richness** was the number of plant community types.

For plant community type rarity a weight was assigned to the six least common community types found in South Africa. For example if that community type only occurs once, it receives a score of one. If a community type is found in 35 estuaries it receives a weight of 1/35. The weights of each community type found in each estuary are then summed to obtain a final score. An estuary will have a high score if it contains many community types that are rare. To obtain a plant community type rarity score the sum of weights was then applied to the ranges shown in Table 4.1.

Table 4.1 **Rarity weights and the respective community rarity scores for the botanical importance rating system**

Sum of weights	Plant community type rarity score
0-0.017	20
0.018-0.027	40
0.028-0.04	60
0.041-0.049	80
0.05-0.067	95
0.068-0.133	100

The Thukela Estuary had 4 of the plant community types used in the botanical importance rating system:

- Reeds and sedges (e.g. *Phragmites australis* and *Schoenoplectus scirpoides*).
- Swamp forest (*Barringtonia racemosa*, *Hibiscus tiliaceus*).
- Phytoplankton (water surface area).
- Benthic microalgae (exposed sand and mudbanks).

There were no salt marsh, mangrove, macroalgae or submerged macrophyte species. Submerged macrophytes were absent and this can probably be attributed to high water velocities (particularly during floods) and low water turbidity. There were no plants in the lower reaches of the Thukela River that indicate a persistent saline influence. True mangroves and salt marsh species were absent

The area covered by the different plant types was mapped using a Geographical information system (Table 4.2). The total area covered by reeds and sedges was 40.03ha. The area covered by intertidal sandbanks and wet river sand were assumed to support benthic microalgae, these habitats covered 20.55ha. The large area covered by dry river sand was assumed not to support benthic microalgae.

These dry sandy areas are characteristic of the Thukela system. Even after heavy rains the system drains quickly to revert to this condition within a few days.

The 1937 aerial photograph indicated that the sedge (*Schoenoplectus scirpoides*) area on the north bank (Plate 5) was absent. The south bank dune vegetation extended up the main river channel by approximately 1.5km. This has subsequently been replaced by cultivation. Behind the dune vegetation the coastal forest extended up the estuary for about 1.2km. This patch has also been lost to cultivation. However both these categories will not affect the botanical importance rating score as they are not estuarine plant types. The major change that affects the botanical importance rating is the loss of a large wetland area on the south bank, approximately 22ha of reeds and sedges and 1.5ha of swamp forest (*Barringtonia racemosa* and *Hibiscus tiliaceus*). The 1937 aerial photograph also showed very little intertidal sandbank area with the river draining far out into the sea beyond the breakers. The intertidal sandbank area was probably less than a hectare in total in 1937.

Table 4.2 Area covered by different plant types in 2001

Plant type	Area (ha)
Reeds	20.38
Sedges	19.65
Swamp forest	0.27
Water surface area	72.47
Intertidal sandbank	7.28
Wet river sand	13.27
Dry river sand	69.86

The components of the functional importance component of the botanical importance score is shown in Table 4.3. The final functional importance score was 65 (see Colloty *et al.* 2001 for details on the scoring method). The estuary contains approximately 11 estuarine species and thus the final species richness score was 60. The estuary contains 4 of the possible 9 different plant types and thus received a plant community richness score of 40. The estuary obtained a plant community type rarity score of 40 due to the presence of swamp forest. The sum of these four components is the botanical importance score (i.e. 65 + 60 + 40 + 40 = 205). The Thukela estuary has a botanical importance score of 205 out of a possible 400. Table 4 compares this score with other South African estuaries. A selection of estuaries, mainly those that occur in the subtropical zone have been included in this Table. Further details can be found in Colloty *et al.* (2001). The low score of the Thukela estuary is similar to that obtained for the larger temporarily open / closed estuaries in KwaZulu-Natal e.g. Mdloti and Mkomazi.

Table 4.3 Calculation of the functional importance score

Plant types	Area (ha)	Average productivity value (g m ⁻² y ⁻¹)	Functional importance score
Reeds and sedges	40.03	1 384	55 402
Swamp forest	0.27	1 890	510
Intertidal benthic microalgae	20.55	124	2 548
Phytoplankton	72.47	163	11 813
Functional importance score			70 273
Normalised score			3.5
Final score			65

Table 4.4 The botanical importance scores of some South African estuaries. The component scores of functional importance, species richness, community richness and habitat rarity are shown. The Thukela Estuary is indicated in bold

Estuary	Functional importance	Species richness	Community richness	Habitat rarity	Botanical Importance
St Lucia	100	100	100	100	400
Mngazana	85	100	100	100	385
Knysna	85	100	80	95	360
Keiskamma	85	100	80	95	360
Swartkops	75	100	80	95	350
Mlalazi	75	75	100	100	350
Mhlathuze	85	60	80	100	325
Siyaya	30	60	60	95	245
Mhlanga	75	40	20	95	230
Mdlotane	75	20	40	95	230
Nhlabane	30	60	40	95	225
Thukela	65	60	40	40	205
Mdloti	40	60	40	60	200
Mkomazi	30	80	40	40	190
Zinkwazi	65	40	20	60	185
Tongati	40	20	40	60	160

5 HABITAT INTEGRITY (Change over time)

Habitat integrity was determined by calculating the functional importance of an estuary in its past and present state. The area covered by the different plant community types was measured from the oldest available aerial photographs, maps or literature and compared with recent information. The difference in functional importance scores was calculated as a percentage and this was subtracted from 100 and expressed as deviation from the natural condition or as the habitat integrity of an estuary. All estuaries that have not changed were given a score of 100, while for other estuaries that have changed the percentage change is applied to the ranges shown in Table 5.1. Changes in scores over time, positive or negative are regarded as a deviation from the natural condition.

Table 5.1 The habitat integrity scores applied to the ranges for percentage deviation from natural scores

Percentage deviation from natural	Habitat integrity score
0	100
0.5-7.6	60
7.7-14	40
15-30	20
31-90	10

The area covered by sand and water area can vary on a daily basis in the Thukela Estuary, thus for the calculation of change over time the 1937 and 2001 values were kept the same (Table 4.2). A total of 22ha of reeds and sedges have been lost on the south bank, but the estuary has gained a sedge area of 19.32ha on the north bank, so the overall change in area covered by reeds and sedges is smaller than expected. A total area of 1.5ha of swamp forest has been lost since 1937. The estuary received a habitat integrity score of 20. Habitat integrity scores have been calculated for 124 South African estuaries (Colloty *et al.* 2001). The score obtained for the Thukela Estuary is similar to the Bira, Knysna, Mpako, Mtentu and Mngazi estuaries.

6 EFFECT OF PHYSICAL FACTORS ON THE MACROPHYTES

6.1 FLUSHING / FLOODING

The lack of natural vegetation can be related to anthropogenic impacts but is also probably due to the morphological and physical characteristics of the lower reaches of the river. It is a dynamic system characterised by violent floods. The frequency of these floods could prevent the encroachment of reeds into the river channel. The flooding frequency is likely to have kept the main channel largely free of vegetation and the greater part of the primary productivity in the estuary would have arisen from microalgae.

Table 6.1 The area covered by different plant community types, functional importance scores and percentage change over time

Habitat	1937	2001
Sand (intertidal benthic microalgae)	20.55	20.55
Water (phytoplankton)	72.47	72.47
Reeds and sedges	49.38	40.03
Swamp forest	1.77	0.27
Functional importance score	86 047	70 273
Difference		15 774
% Change		18
Habitat integrity score		20

A reduction in freshwater input coupled with high nutrient input could result in reed and sedge encroachment into the main channel. However this would be a dynamic process, the sedimentation study (Taljaard *et al.* 2002) predicts a deepening of the estuary in the future. A plume of sediment was deposited at the mouth of the Thukela after the 1996 floods. On the north bank of the estuary the sedge *Schoenoplectus scirpoides* has colonized this area. A large flood (1 in 5 year, $> 200 \text{ m}^3\text{s}^{-1}$) would remove these sedges and this indicates that the system has been stable over the last 6 years.

Lack of flushing due to closed mouth conditions may cause an accumulation of detritus, an increased oxygen demand and anaerobic conditions, impairing the biological functioning of the estuary. Anaerobic conditions also prevent the development of a population of secondary consumers which can utilise the excess detritus (Schleyer and Roberts 1987). Anoxia may not occur in the Thukela Estuary as it is probably well mixed by wind (Taljaard *et al.* 2002). However according to Basson and Beck (Taljaard *et al.* 2002) the estuary may deepen by 1 m in the future and under these conditions anoxia may become a problem.

6.2 WATER LEVEL

The dominant wetland species associated with the lower mouth reaches e.g. *Phragmites* and *Schoenoplectus* are adapted to waterlogged conditions. *Phragmites australis* has been found in standing water up to 70 cm deep. However, these plants are sensitive to prolonged submergence that could occur if the water levels rise to greater than 1 m. Submergence affects *P. australis* differently depending on season. In spring, new plants and shoots are establishing and submergence inhibits growth. Submergence during autumn would have a negative effect on plants, as this is when nutrients are remobilized for spring growth. Winter submergence is less severe than for the other seasons as this is when *Phragmites australis* dies back naturally. Mouth closure would mostly occur in winter (low flow periods) and would therefore not have a severe effect on the reeds unless submergence occurred for greater than 3 months.

Increased depth can produce a shift in reproductive strategies i.e. from vegetative to seed production (Grime 1979). Increased seed production ensures the rapid colonization of open mudflats when water levels decrease. Squires and Van der Valk (1992) have shown that tubers of *Scirpus maritimus* remained viable in sediments even when flooded by deep water for several years.

The limiting depth of emergent macrophytes appears to be approximately 2 m (Haslam 1971, Weisner 1991). Although *P. australis* has been reported to occur in water depths up to 4 m in Uganda (Haslam 1971) under these inundated conditions Squires and Van der Valk (1992) found that survival was only possible for one or two years. At these water depths, photosynthesis was reduced, oxygen transport to below ground parts became restricted and metabolic losses and rhizome mortality were experienced (Haslam 1971).

Seedling establishment is also adversely affected by water level fluctuations and inundation. Weissner *et al.* (1993) have found *Schoenoplectus scirpoides* growing on the waterside of *P. australis* presumably because of its ability to withstand deeper depths and greater wave action due to its leafless nature. The authors suggested that this zonation was due to the seedlings of *S. scirpoides* being more capable of establishing and developing under water. This supported the findings of Hellings and Gallagher (1992) who found that the buds and seeds of *P. australis* were sensitive to submergence.

6.3 SALINITY

There were no plants in the lower reaches of the Thukela Estuary that indicate a persistent saline influence. True mangroves and salt marsh species were absent. The vegetation present therefore reflects that of a river mouth. Trees such as brackwater mangrove (*Barringtonia racemosa*) and lagoon hibiscus (*Hibiscus tiliaceus*) indicate waterlogged conditions but these species would not tolerate prolonged saline conditions.

Cyperus, *P. pulchrum*, *Echinochloa*, *Leersia* and *P. mauritanus* are considered strictly freshwater species. *Typha capensis* extends into brackish conditions (3 – 5 ppt, Glen *et al.* 1995), whereas *S. scirpoides*, *Juncus kraussii*, *Cladium mariscus* and *Phragmites australis* occur over a wide salinity range but grow best at salinity less than 15 ppt (Howard-Williams 1979, Adams *et al.* 1999).

Open mouth conditions are important in the Thukela Estuary as saline water is introduced and the brackish plant communities are maintained. If the mouth closed and the estuary became fresh and nutrient rich then plants such as the bulrush (*Typha* spp.) and the aquatic weed, water hyacinth (*Eicchornia crassipes*) may become dominant during the fresher month. Both species currently occur in the Thukela Estuary.

6.4 WAVE ACTION

Wave action has an effect on growth and species distribution. Coops and Van der Velde (1996) showed that *Phragmites australis* was better adapted morphologically to wave action due to its higher bending stiffness and lower susceptibility to breaking. By contrast, water velocities associated with 0.23m waves were strong enough to uproot and fracture *Schoenoplectus scirpoides*.

7 EFFECT OF FUTURE RIVER INFLOW SCENARIOS ON THE MACROPHYTES

The report on the physical dynamics and water quality of the Thukela Estuary was studied (Taljaard *et al.* 2002) in order to assess the relative changes related to the future run-off scenarios.

The following scenarios were assessed:

- Scenario corresponding to (preliminary) River Ecological Reserve Category (ERC) A - [Scenario: River Category A]
- Scenario corresponding to (preliminary) River ERC B - [Scenario: River Category B]
- Scenario corresponding to (preliminary) River ERC C - [Scenario: River Category C]
- Scenario corresponding to (preliminary) River ERC D - [Scenario: River Category D]
- Worst case scenario 1 – [Scenario: Worst Case 1]
- Worst case scenario 2 - [Scenario: Worst Case 2]

Four different Abiotic States were derived for the Thukela Estuary, of which the occurrence and duration varies depending on river inflow rate (Table 7.1). There would be no significant changes in the macrophytes if the mouth closed for a few days and therefore State 2 and State 3 would be similar in terms of macrophyte response. State 1, closed mouth conditions, would have the greatest effect on the macrophytes.

Table 7.1 indicates the different MAR values for the different scenarios. The greatest differences between the three River Reserve scenarios (B, C, D) lies in their low flow characteristics and not in the high flows. This is consistent with what might be expected in terms of a Reserve at the outlet of a large catchment with distributed storage and abstractions; i.e. managed moderate to low flows and relatively unmanaged high flows (Hughes, 2002).

State 1 occurs presently for 0.6 % of the time (Table 7.3). For the river scenarios (River Category A-D), this state will not occur i.e. the mouth will not close. For the two worst case scenarios this state is expected to occur for 31.6 % of the time. There will be some reduction in the biomass of emergent reeds and sedges at the mouth. Freshwater species may displace brackish species.

State 2 and 3 occurred for 33.2 % of the time for the reference condition. This has increased to 48.2 % of the time for the present state i.e. the estuary has become more saline. The river scenarios category A and B would be similar to the present state whereas category C and D would occur for 63.1 and 68.7 % of the time respectively. The estuary would be more saline for these scenarios compared to the present state condition and river category A and B. Under these conditions the brackish reeds and sedges would flourish. For a third of the year the estuary would still be completely fresh and therefore no salt accumulation or hypersaline conditions unfavourable to macrophytes would occur. For the worst case scenarios the estuary would be in this state for 33 % of the time, less than the other scenarios as the estuary will also close for periods of time (Table 7.3).

The percentage of time that the estuary remains in State 4 (river dominated) will be fairly similar between the reference, present condition and river category A and B. For river category C and D and the two worst case scenarios, the percentage of time that the estuaries remains in State 4 is fairly similar (Table 7.3). For these scenarios the estuary receives enough river flow to maintain the system as a river mouth between the months of December to March. The detrimental effects of closed mouth conditions during some months would be counteracted by open mouth conditions during other months. Overall the estuary is less dynamic that it was in the past. Longer periods between high flushing flows would promote the growth of emergent reeds and sedges.

The greatest reduction in the highest average monthly flows is for the worst case scenario 2. There will be a 68 % reduction compared to a present 88 % reduction. The system will become more stable and growth of reeds and sedges will occur on the sand plume at the mouth of the estuary.

Table 7.1 Four different Abiotic States derived for the Thukela Estuary

State 1: Mouth closed, from weeks to a few months at a time	0 – 2 m ³ /s
State 2: Mouth open, occasional mouth closures of a few days	2 – 5 m ³ /s
State 3: Mouth open, saline intrusion	5 – 30 m ³ /s
State 4: Mouth open, river dominated	> 30 m ³ /s

Table 7.2 Mean Annual Run-off values for the different scenarios

Scenario	MAR (m ³ * 10 ⁶)	% MAR
Reference Condition	3753.6	100
Present Day (1995)	2756.4	73.4
Category A River	2494.8	66.5
Category B River	2258.4	60.2
Category C River	2056.8	54.8
Category D River	1915.2	51.0
Worst Case 1	1788.0	47.6
Worst Case 2	1669.2	44.5

Table 7.3 Percentage occurrence of States per scenario

Scenario	State 1 (%)	State 2 (%)	State 3 (%)	State 4 (%)
Reference Condition	0	0	33.2	66.8
Present State	0.6	6.2	42.0	51.0
River Category A	0	0.4	38.0	61.6
River Category B	0	0.4	48.8	50.8
River Category C	0	0.5	62.6	36.9
River Category D	0	0.7	68.0	31.3
Worst Case 1	31.6	8.9	24.4	35.1
Worst Case 2	31.6	8.9	24.9	34.6

The Estuarine Health Index scores are summarized for the physical parameters in Table 8 and for the macrophyte parameters in Table 7.3. Motivations for the macrophytes scores are provided in the templates of the main RDM report. Values highlighted in bold indicate where there has been a change from the previous scenario and there should now be some biological response.

8 CONCLUSION

According to Begg (1978) the flora of the Thukela Estuary has little of resource or ecological value due to sugar cane encroachment and eucalyptus plantations on the northern bank. This study confirms that observation. Aquatic or semi-aquatic vegetation (wetland areas) is sparse and the only vegetation of natural value remaining is the indigenous coastal dune forest and the small wetland area on the north and south bank. According to Begg (1978) the Hlogwene Forest, is a remnant of indigenous coastal dune forest that extends southwards in a narrow strip to the north bank of the Zinkwasi estuary. Conservation of the coastal forest together with stands of the brackwater mangrove *Barringtonia racemosa* is important as these areas contribute to the aesthetic appearance of the lower reaches of the Thukela River.

The river channel is also wide with relatively steep banks that restrict colonization by wetland species. In some areas reeds colonize the banks and are important as they protect banks from erosion and re-colonize rapidly after floods. The only area of any significant wetland vegetation is associated with the lower reaches of the Thukela River. This is a *Phragmites* dominated wetland on the south bank close to the mouth. This area must serve as an important habitat for faunal species especially birds. There is a sedge bed, *Schoenoplectus scirpoides* on the north bank. The wetland areas would act as a natural filter for the effluent from the catchment. The reeds and sedges would also be an important detritus source for the estuary and marine environment.

Mouth closure will limit the supply of detritus to the coastal zone, which could effect the offshore fishing industry as detritus is an important component of the offshore food-chain. The Thukela is one of the few estuarine systems along the KZ-Natal coast that fulfil this essential function.

If one excludes large estuarine lake systems such as St Lucia, most of KwaZulu-Natal's estuaries have surface areas of less than 100 ha. The Thukela is the largest River in KZ-Natal, it therefore has unique features worthy of conservation.

Table 8.1 Estuarine Health Index scores (physical/chemical components) for different scenarios

	Present	A	B	C	D	WC1	WC2
a. % similarity in period of low flows.	83	100	83	75	67	67	67
b. % similarity in the magnitude of major floods (e.g. 1:20, 1:50 and 1:100) in comparison with the reference condition.	93	73	73	73	73	73	73
Change in mean duration of closure over a 70 year period.	80	100	100	95	95	20	20
1. Change in the longitudinal salinity gradient (%) and vertical salinity stratification	60	100	80	70	60	40	40
2a. Nitrate and phosphate concentration in the estuary.	70	70	70	70	70	50	50
2b. Suspended solids in present in inflowing freshwater.	50	50	50	50	50	40	40
2c. Dissolved oxygen (D) in the estuary.	80	80	80	80	80	60	60
2d. Levels of toxins.	100	100	100	100	100	100	100
Resemblance of <u>intertidal sediment</u> structure and distribution to reference condition.							
% similarity in intertidal area exposed.	70	60	60	60	60	60	60
% similarity in sand fraction relative to total sand and mud.	70	60	60	60	60	60	60
Resemblance of subtidal estuary to reference condition: depth, bed or channel morphology.	90	75	75	75	75	75	75

Table 8.2 **Macrophyte Estuarine Health Index scores for different scenarios**

	Present	A	B	C	D	WC1	WC2
Species richness	80	75	75	75	75	65	65
Abundance	60	62	64	67	67	60	60
Community composition	80	80	80	78	78	70	70

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10 ANNEXURE 1

10.1 LIST OF PLANT SPECIES FOUND IN THE LOWER REACHES OF THE THUKELA RIVER

FAMILY	GROWTH FORM	HABITAT
<i>Maytenus heterophylla</i>	shrub	dune
<i>Maytenus procumbens</i>	shrub	dune
Anacardiaceae		
<i>Rhus chiridensis</i>	scrambling shrub	dune
<i>Rhus nebulosa</i>	scrambling shrub	dune
<i>Schinus terebinthifolius</i>	Brazilian pepper	tree riparian
Apiaceae		
<i>Centella asiatica</i>	creeping herb	damp places
Arecaceae		
<i>Phoenix reclinata</i>	palm	riparian
Asparagaceae		
<i>Asparagus falcatus</i>	herb/shrub	forest margin
Asteraceae		
<i>Ageratum conyzoides</i>	herb	dune/grassy banks
<i>Asclepias decipiens</i>		grassy banks
<i>Brachylaena discolor</i>	small tree	dune
<i>Berkheya erysithales</i>	robust herb	forest margin
<i>Chrysanthemoides monilifera</i>	shrub	dune
<i>Helichrysum asperum</i>	shrub	dune forest
<i>Senecio inaequidens</i>	herb	grassy banks
<i>Senecio latifolius</i>	robust herb	disturbed north bank
<i>Xanthium strumarium</i>	herb	grassy banks
Caesalpinaceae		
<i>Cassia</i> sp.	tree	riparian
Commelinaceae		
<i>Commelina africana</i>	creeper	dune forest
Convolvulaceae		
<i>Ipomoea cairica</i>	herbaceous climber	riparian/dune
<i>Ipomoea palmate</i>	creeper	dune forest
<i>Ipomoea purpurea</i>	creeper	dune forest
Cyperaceae		
<i>Cyperus brevis</i>	herb	damp areas
<i>Cyperus distans</i>	herb	damp areas
<i>Cyperus longus</i> var <i>longus</i>	herb	damp areas
<i>Schoenoplectus scirpoides</i>	herb	riparian
Euphorbiaceae		
<i>Bridelia micrantha</i>	tree	dune forest

Fabaceae

<i>Acacia karoo</i>	small tree	dune/riparian
<i>Canavalia ensiformis</i>		dune forest
<i>Dalbergia</i> sp.	small tree	dune forest
<i>Derris trifoliata</i>	woody climber	riparian
<i>Sesbania</i> sp.	shrub/small tree	riparian
<i>Tephrosia purpurea</i> subsp. <i>canescens</i>	herb	dune forest

Juncaceae

<i>Juncus kraussii</i>	rush	riparian
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Lamiaceae

<i>Leucas lavandulifolia</i>	shrub	grassy banks
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Lecythidaceae

<i>Barringtonia racemosa</i>	tree	riparian/estuarine
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Malvaceae

<i>Hibiscus tiliaceus</i>	tree	estuary margins
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Meliaceae

<i>Melia azedarach</i>	tree	riparian
<i>Trichilia drageana</i>	tree	riparian

Moraceae

<i>Ficus sur</i>	tree	riparian
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Poaceae

<i>Arundo donax</i>	tree/shrub	riparian
<i>Bambusa balcooa</i>	bamboo	riparian
<i>Cynodon dacylon</i>	grass	riparian
<i>Dactyloctenium australe</i>	herb	grassy banks
<i>Diheteropogon amplexus</i>	herb	riparian
<i>Echinochloa colona</i>	grass	riparian/wetland
<i>Eleusine coracana</i> subsp. <i>africana</i>	herb	riparian
<i>Eragrostis aspera</i>	grass	riparian
<i>Eragrostis ciliaris</i>	grass	grassy banks
<i>Panicum maximum</i>	grass	riparian
<i>Paspalum dilatatum</i>	herb	riparian
<i>Phragmites australis</i>	reed	riparian
<i>Sorghum halepense</i>	herb	riparian
<i>Sporobolus africanus</i>	grass	riparian
<i>Sporobolus virginicus</i>	grass	riparian

Rhamnaceae

<i>Scutia myrtina</i>	scrambling shrub	riparian
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Sapotaceae

<i>Mimusops caffra</i>	shrub/tree	dune
<i>Sideroxylon inerme</i>	tree	riparian/dune

Solanaceae

<i>Cestrum laevigatum</i>	robust shrub	riparian
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Strelitziaceae*Strelitzia nicolai*

shrub

riparian/dune

Thymeliaceae*Passerina rigida*

shrub

dune

Typhaceae*Typha capensis*

robust herb

riparian/wetland

Verbenaceae*Lantana camara*

shrub/creeper

riparian

11 ANNEXURE 2

11.1 PLATES



Plate 1 Distribution of vegetation along the south bank, indicating the location of reeds (*Phragmites australis*), sedges (*Schoenoplectus scirpoides*) and lagoon hibiscus (*Hibiscus tiliaceus*)



Plate 2 Harvesting of the sedge, *Schoenoplectus scirpoides*



Plate 3 **Inundation of the sedge area on the north bank near the mouth**



Plate 4 **Agricultural areas on the north bank of the estuary**



Plate 5

Sedge (*Schoenoplectus scirpoides*) area on the north bank

Appendix F

Invertebrates of the Thukela Estuary

Fiona MacKay (Macroinvertebrates)
Digby Cyrus
Hendrik Jerling* (Zooplankton)
Phinda Buthelezi (Macrocrustacea)

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CONTEXT OF STUDY

During 1997, the Department of Water Affairs commissioned an initial assessment of the Thukela Estuarine Freshwater Requirements (EFR) as part of the feasibility options for augmenting supplies to the Vaal River System. The Thukela Water Project Feasibility Study provided an overview of available data on the estuary in the form of several specialist reports from 1996-1998. The results of some brief sampling surveys served to identify future research needs in certain areas. In this regard, it was recommended that more long term studies of the macrobenthos be conducted. This was to provide some account of seasonal change and to identify if a freshwater, estuarine or intermediate faunal component represented the macrobenthos of the lower Thukela.

The study was initiated in autumn 1997 and spanned twelve consecutive months until March 1998 (Mackay and Cyrus 1998). Until that time, the only data available were limited to a number of once off surveys and historical eyewitness accounts. The earliest survey was conducted by Day (1981) whilst other available information of the biology of the lower reaches of the Thukela has only included a brief description of the area (Begg 1978; Cooper *et al.* 1993).

The Decision Support Phase of the Thukela Water Project has now required that limited additional investigations be conducted to support the original findings. These were conducted in low (winter 2001) and high flow (summer 2002) conditions. The original macrobenthic survey was deemed detailed enough to represent the context of the 'present state'. However, in August 2001 macrobenthic samples collected at several of the original sites gave some indication that the communities were significantly different from those during a comparable period in the 1997/8 study. The results of both these studies have been integrated and are presented as **Part 1: Macroinvertebrates** of this report.

During 1998/9 the mass migration of megalopae of the grapsid decapod, *Varuna litterata* was studied to determine recruitment period into the system (Mackay and Cyrus 1999; Mackay and Cyrus 2002). Little more data (if any), are available on other invertebrate components of the Thukela Estuary. To fulfil the EFR requirements of the Decision Support Phase limited investigations have been conducted on the Zooplankton (low and high flow conditions) and Macrocrustaceans (low and high flow conditions). These studies were conducted under requirements stipulated in the Intermediate Determination of an EFR study. The results are presented in **Part 2: Zooplankton** and **Part 3: Macrocrustaceans**.

PART 1: MACROINVERTEBRATES

1 INTRODUCTION

River mouths have not often been considered in estuarine classifications as the mixing zone of saline and freshwater generally occurs some distance out to sea. This is due to the strength of outflow in these generally shallow systems (Pritchard 1967; Reid and Wood 1976). This is the case of the Thukela Estuary where by virtue of its strong outflow for most of the year, it has little or no measurable variation of salinity within its banks and therefore is only classically estuarine for a short duration each year and is characterised by a strong estuarine component of fauna (Day 1981, Whitfield 1992). In this sense, the Thukela and the Orange on the west coast are both unique systems within South Africa's 2900km of coastline (Little 1984). Until 1997, the state of knowledge of the Thukela Estuary was extremely poor and this was especially true of its fauna.

The major factors known to determine macrobenthic community structure are divided into environmental and non-environmental. The former may have some effect on the communities studied in the lower reaches of the Thukela, with the proposed impoundment of the stretches of the river within the watershed. Physical and chemical environmental factors that may affect estuarine macrobenthos are salinity gradients, shelter from wave action, fluctuations in temperature and oxygen levels, the nature of the substratum and the input of detritus (Nichols 1970; Barnes 1974; Metzeling 1993).

Physico-chemical variables are direct factors influencing benthic organisms, as far as they affect the physiological processes of any life stage of an organism (Boesch *et al.* 1976). The components of estuarine fauna are separated by means of their tolerance to salinity, although they are also affected by the aforementioned factors. In tolerable salinity and temperature ranges, it is substratum type that becomes the determining factor in benthic distribution (Day 1981). Cooper *et al.* (1995), reason that in our local estuaries the fauna are influenced by the salinity characteristics, period of connection with the sea, turbidity (controlled by catchment geology and flow), substrate and availability of nutrients (controlled to a large extent by cycles of breaching and flushing). The substrates within estuaries are usually different from adjacent marine coasts, in that they usually have sandy and muddy components. This is typical of most southern African estuaries (Blaber 1980). Although nutritionally rich, these muds are difficult areas to colonise, as locomotion both through and over the substrate may be difficult. In addition, fine silt in suspension can clog the filtering mechanisms of many of the animals that use this as their method of feeding. Gray (1981), maintains that grain size and organic content are important for estuarine macrobenthos. Marine sediments and muds provide inhospitable habitats, thus medium and fine sands usually have an abundant benthic faunal assemblage. Almost all bottom-dwelling animals will live only on specific substrates, and depending on the grain size of the sediment, this may play a role in determining the dominant feeding type (Nichols 1970) and the formation of burrows, as the latter is dependant on whether the substrate is sand or mud (Blaber 1980). The nature of the substrata in any estuary is dependent on:

1. The dominant water mass (fresh or seawater).
2. The nature of offshore deposits.
3. The nature of the catchment drained by inflowing rivers.

In addition, anthropogenic activities may directly or indirectly affect the distribution of macrobenthos, in that one, more or a combination of the above factors may be altered through pollution, habitat modification or by poor agricultural practices.

2 STUDY SITE

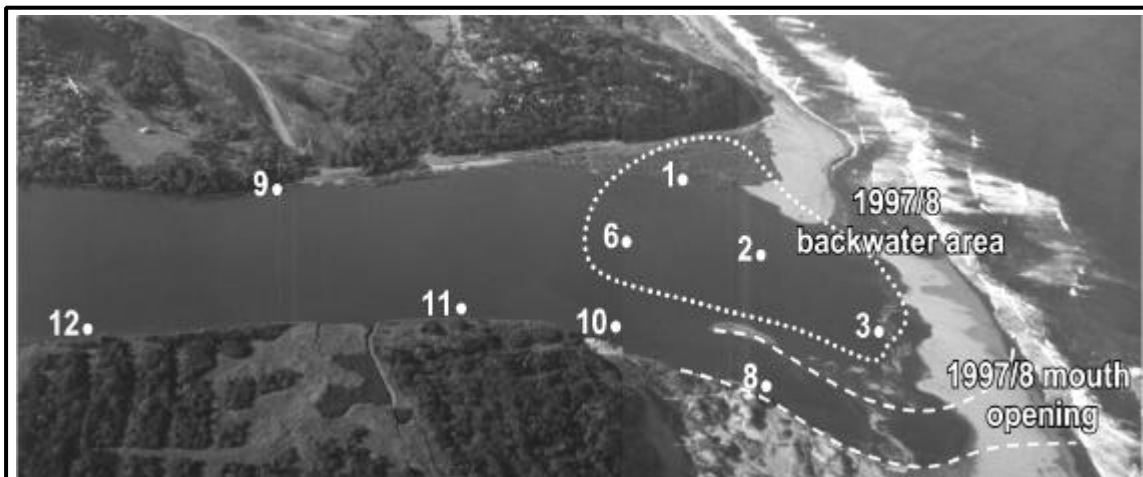
2.1 GENERAL

For the duration of the April 1997 to March 1998 study, the most striking observable feature of the Thukela Estuary was its physical variability. This was in terms of the emergence of sandbanks and new channels on a month to month basis, as well as the narrowing and widening of the sandspit lying perpendicular to the mouth that allowed the delta to continue to be closed off and become a tidally influenced backwater (Figure 2.1). Although the position of the mouth remained constant for the duration of the study, it became progressively narrower over the twelve-month period, while the south bank was continuously eroded, deposition was taking place on the extreme southern edge of the mouth. This eventually led to the outflow being forced in a right-angled northerly direction.

The area investigated extended 2km upstream from the mouth, included the river 'channel' and the tidally exposed backwater around the north bank of the mouth area (Figure 2.1). The initial survey in April 1997 revealed that there was very limited saline intrusion over any high tide and this did not extend beyond the 2km point upstream. This determined the uppermost site for the macrobenthic survey. Above this site the substrate was composed of very coarse river sand, which depending on river flow and state of the tide, became large exposed areas which were inaccessible for the purposes of sampling.

Conditions during the low flow survey in August 2001 were vastly different. The mouth had migrated to a northerly position, with the lower reaches of the original channel reduced to a pool on the southern spit. Reeds significantly covered the backwater area and coarser grained sediments replaced much of the original muddy substrate. Thus, two of the original sampling sites (3- backwater; 8- channel) were now permanently exposed and were excluded from the 2001 survey. An additional site further upstream was included to better represent the extent of saline intrusion and 'estuarine area'.

Fig 2.1 Map of Macroinvertebrate sampling sites used in 1997/8 (sites 1-3, 6, 8-10) and 2001 (sites 1-2, 6, 9-10, 12) surveys



3 METHODS

3.1 SITES

During April 1997, 11 sampling sites were identified from the study area (section 2.1), which would be suitable over the long term for the purposes of benthic invertebrate sampling. These samples were analysed, and from the results, seven sites were selected and sampled for the twelve-month duration of the project. These are further referred to as sites 1, 2, 3, 6, 8, 9, and 10. Of these, sites 8 and 10 were situated along the margin of the river channel along the south bank (Figure 2.1), site 9 was the furthest sampling site upstream and the remainder were situated within the backwater area. Sites 1 to 3 were the most stable in terms of sediment deposition and tidal flow, as well as being sheltered from heavy outflow conditions. Site 6 formed the interface of both of these situations and as a result had a varied substrate composition.

In August 2001, samples were collected at sites 1, 2, 6, 9, 10 and at a new station (12) further upstream (Figure 2.1).

3.2 COLLECTION

Standard estuarine macroinvertebrate sampling methods were employed:

Five random grab samples were collected at each site using a Zabalocki-type Eckman grab (uniformly samples 0.0236m² of the substratum to a depth of at least 4.5cm). The contents of each grab were emptied into separate buckets and a small amount of 10% formalin added to coerce invertebrates present to release their hold on any particulate matter. Each bucket was filled with water and the mixture thoroughly stirred. The suspended matter was then decanted through a 0.5mm mesh, and the process repeated five times. The remainder of the sample was then poured through a 1mm sieve that retained larger and heavier invertebrates such as bivalves. This method results in the extraction of >95% of the fauna present in each sample (Cyrus and Martin 1988). The fauna and debris retained were preserved in 10% formalin, and the vital dye Phloxine B added to aid in sorting and counting in the laboratory. Preserved samples were sorted, counted and identified to the lowest taxonomic level possible using a dissecting microscope. Taxon densities for each site were expressed as the mean number of individuals per square metre, of the five replicate samples taken at each site.

3.3 STATISTICAL ANALYSIS

To provide a clear spatial and temporal analysis of community change, data ($\sqrt{\sqrt{\quad}}$ transformed) were subject to multivariate methods of classification using the Primer statistical software package (Clarke and Warwick 1994). The analyses comprised the community classification method using Bray-Curtis similarity coefficients and ordination using non-metric multidimensional scaling (NMDS). This method uses some function of the dissimilarity measure between each pair of stations and reconciles the result on a two dimensional map. The calculation of the non-metric multidimensional scaling algorithm is an iterative process involving a number of random starts in order to obtain the best two-dimensional configuration. A stress value is then used to indicate the validity and usefulness of the configuration.

4 RESULTS AND DISCUSSION

4.1 PRESENT STATUS OF MACROINVERTEBRATES

A total number of 170 taxa were sampled from the Thukela Estuary from April 1997 to March 1998. The general impression was of a wide faunal assemblage with representatives from many taxonomic groups. Although truly estuarine taxa were sampled at times, the overall macrobenthic assemblage was one comprised of a dominance of freshwater taxa interspersed with estuarine invertebrates. The latter group were comparatively uncommon and generally limited to specific sampling sites. A list of the total taxa sampled from the Thukela is presented as Appendix A.1. For the purposes of further analysis, these taxa were then grouped according to their Order or even higher classifications, as many remained unidentifiable in the time span allowed for the duration of the project. This list is presented as Table 4.1 and includes 33 taxa with the inclusion of several developmental stages of certain taxa, where they were present in relatively large numbers and provided some source of food for the benthic feeding avifauna.

Table 4.1 Summary list of Macroinvertebrate taxa sampled in the Thukela Estuary from April 1997 to March 1998. Estuarine and freshwater dominated taxa are indicated

	Classification	Estuarine	Freshwater
1	Phylum Porifera (sponges)	X	
2	Phylum Cnidaria (coelenterates)	X	
3	Phylum Platyhelminthes (flatworms)		X
4	Phylum Nemertea (proboscis worms)		X
5	Phylum Nematoda (roundworms)		X
	Phylum Annelida (segmented worms)		
6	Oligochaeta		X
7	-Invertebrate eggs (oligochaete)		X
8	Polychaeta	X	
	Phylum Mollusca		
9	Gastropoda (snails)	X	
10	Bivalvia (mussels)		X
	Phylum Arthropoda		
	Class Crustacea		
11	Cladocera (water fleas)	X	
12	Ostracoda (shell shrimps)	X	
13	Copepoda	X	
14	Amphipoda (sand hoppers/beach fleas)	X	
15	Isopoda	X	
16	Tanaidacea	X	
17	Cumacea	X	
18	Mysidacea (opossum shrimps)	X	
	Decapoda		
19	-Macrura (shrimps/prawns)	X	
20	-Brachyura (crabs)	X	
21	Class Collembola (springtails)		X
	Class Insecta		
22	Ephemeroptera (mayflies)		X
23	Odonata (damselfly and dragonflies)		X
24	Hemiptera (bugs)		X

	Classification	Estuarine	Freshwater
25	Coleoptera (beetles)		X
26	-Coleoptera nymphs		X
27	-Coleoptera pupae		X
	Diptera (true flies)		
28	-Diptera larvae		X
29	-Diptera nymphs		X
30	-Diptera pupae		X
31	Trichoptera (caddis flies)		X
	Class Arachnida (spiders/mites)		
32	Acariformes		X
33	Aranea		X
TOTAL NUMBER OF TAXA		14	19

In August 2001, 41 taxa were collectively sampled from six sites. The faunal assemblage was vastly different from that described for 1997/8. The community was characterised by >95% estuarine fauna and only two insect taxa. The list of taxa, relative density per site and % contribution to the average density of the site are given in Table 4.2. The greatest contribution to all six sites was given by the estuarine polychaete, *Desdemona ornata*. This species is classified as endemic to the subtropical areas of South Africa (Day 1981) and is relatively common in the smaller, temporarily open estuaries of the north coast of KwaZulu-Natal. *Desdemona ornata* is not an opportunistic species and therefore its presence and numbers did not signify a system under stress. The typical first order opportunists in the estuarine environment are *Capitella* spp. polychaetes. These were limited to site 6 and only represented 9% of the abundance at the site.

The primary difference between the two sampling periods was the change from an oligochaete-dominated community in 1997/8 to a polychaete-dominated community (11 taxa) in 2001.

Macroinvertebrate abundance varied significantly over the study period and peaked at ~13200 invertebrates m² during August 1997 (winter). Figure 4.1 is a plot of the monthly average density m² (+/- SE) for all sites sampled in 1997/8 and 2001. The lowest densities were recorded during autumn 1997 (April) with <1500 invertebrates m⁻² over seven sampling sites. The reason for this could perhaps be attributed to flow conditions prior to this. In early 1996, the mouth was situated adjacent to the northern bank (i.e. in its current, 2002 position) and from that time, it migrated southwards. Such a change would almost certainly involve some scouring in the area around the mouth and result in the suppression of benthic populations. It is possible that the macroinvertebrate community was at a stage of re-establishment when the 1997/8 study commenced.

August 2001 abundance was significantly different from a comparable period in the 1997/8 study. However, although the mean density was lower (5026 macroinvertebrates m⁻²) it was not significantly different to samples collected in 1997/8 apart from late autumn/early winter samples (April-June 1997; Figure 4.1).

Fig 4.1 Average Macroinvertebrate density (m⁻²), monthly from April 1997 to March 1998 and during low flow condition in August 2001. Mean densities and standard errors of the mean are indicated

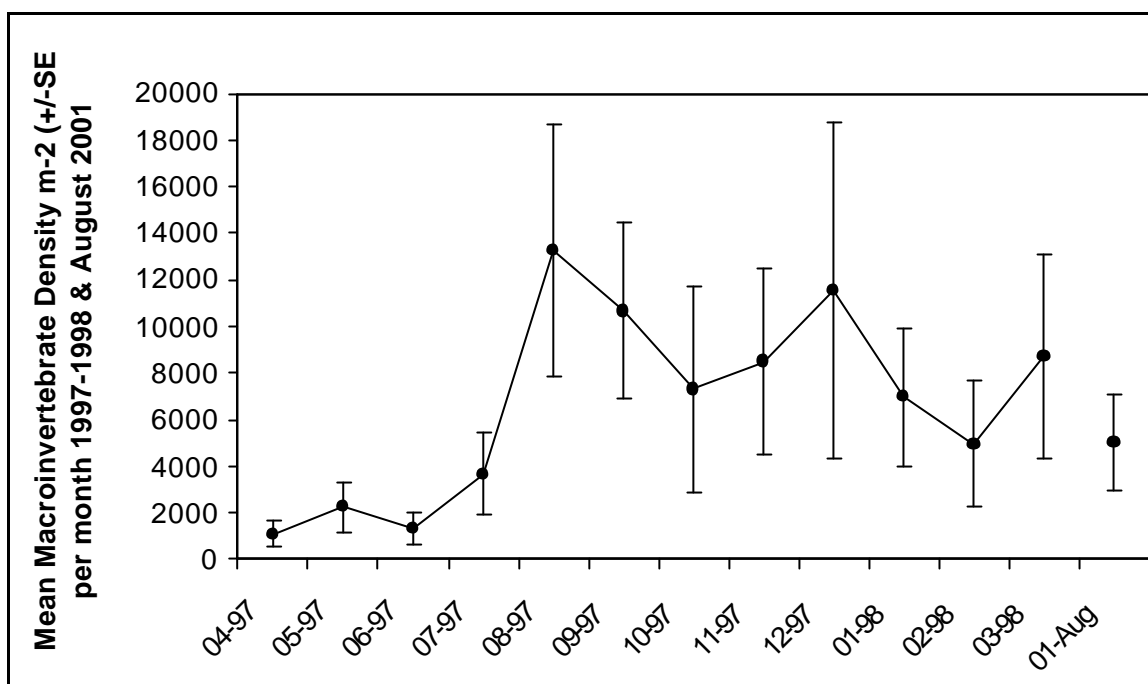


Table 4.2 List of Macroinvertebrates sampled in the Thukela Estuary in August 2001 with % contributions of each taxon to the average density per site

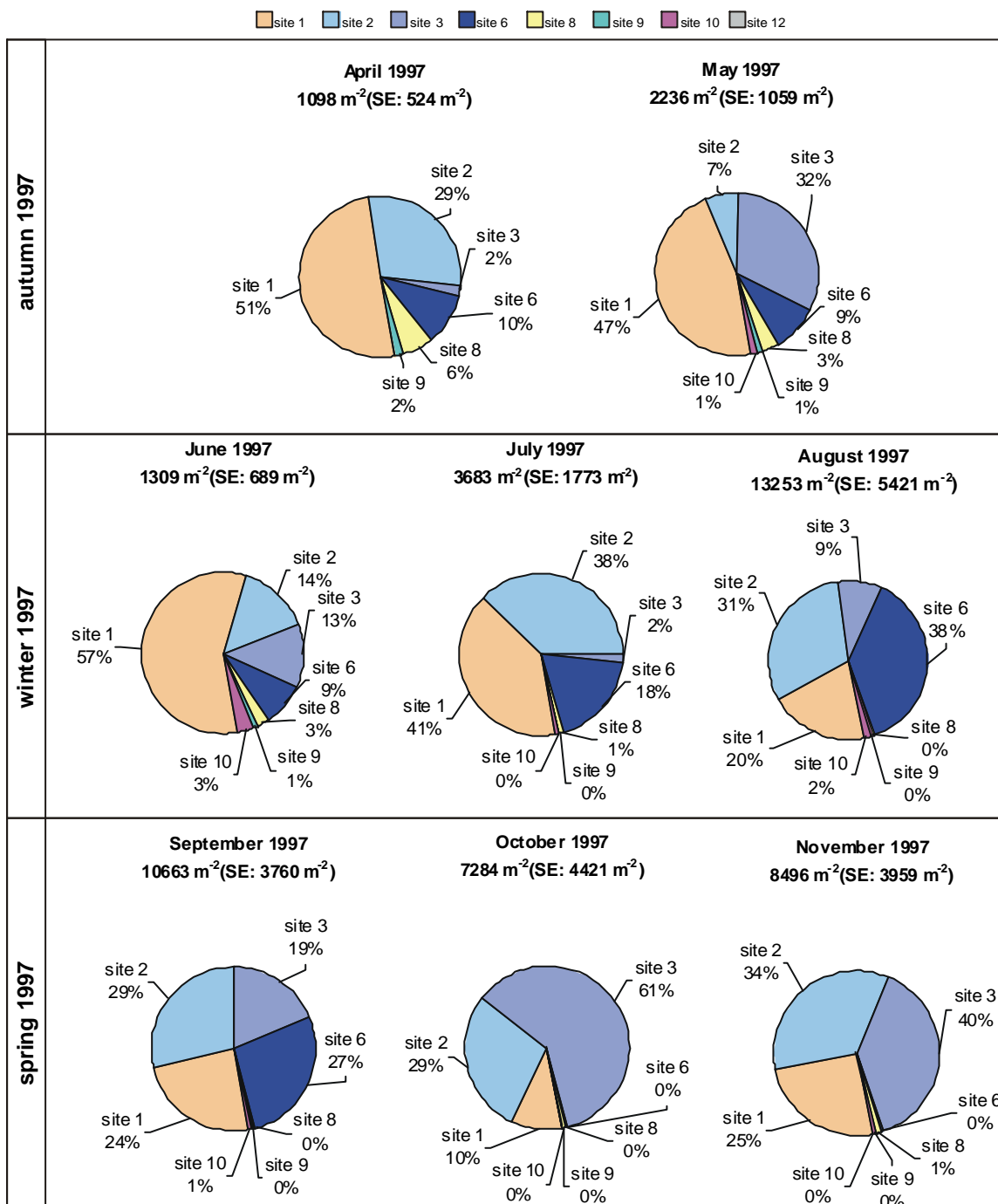
	1		2		6		9		10		12	
	av den	% cont	av den	% cont	av den	% cont	av den	% cont	av den	% cont	av den	% cont
Phylum Annelida												
Oligochaeta sp. 1					8	3						
Polychaeta												
<i>Desdemona ornata</i>	126	71	10349	91	118	40	4805	95	2100	82	9836	92
<i>Dendronereis arborifera</i>			8	0			25	1	101	4	8	0
<i>Scolelepis squamata</i>					8	3			8	0		
<i>Prionospio pinnata</i>	8	5	176	2	8	3	17	0	8	0	25	0
<i>Prionospio sexoculata</i>			101	1							25	0
<i>Capitella capitata</i>					25	9						
<i>Malacoceros indica</i>					8	3						
<i>Glycera natalensis</i>					17	6						
<i>Nephtys sphaerocirrata</i>					8	3						
<i>Prionospio saldanha</i>					34	11						
<i>Ceratonereis keiskamma</i>											17	0
Phylum Arthropoda												
Crustacea												
Amphipod sp. 1									8	0	34	0
Amphipod sp. 2											17	0
<i>Grandidierella bonnieroides</i>											67	1
<i>Erichthonius brasileinsis</i>											8	0
<i>Corophium triaenonyx</i>											8	0
<i>Apeudes digitalis</i>									8	0		

	1		2		6		9		10		12	
	av den	% cont	av den	% cont	av den	% cont	av den	% cont	av den	% cont	av den	% cont
<i>Gastrosaccus psammodytes</i>					34	11						
<i>Corycaeus sp.(cyclopoida)</i>											25	0
<i>Centropages sp.(calanoida)</i>									8	0	59	1
<i>Upogebia sp.</i>			50				67	1	109	4	25	0
<i>Upogebia capensis</i>							8	0				
<i>Varuna litterata</i>											8	0
<i>Scylla serrata</i>											8	0
Brachyura sp. 1			8	0			8	0				
Brachyura sp. 2 (megalop)											17	0
Brachyura sp. 3											8	0
Insecta												
Insect sp. 1									8	0		
Tabanidae sp larvae											8	0
Arachnida												
Pycnogonid sp. 1							8	0				
Phylum Echinodermata												
Ophiuroidea sp.											8	0
Phylum Mollusca												
Nudibranch sp 1											17	0
<i>Nassarius sp.</i>											34	0
Gastropod sp.											8	0
<i>Dosinia sp. 1</i>					8	3	34	1	0			
<i>Dosinia hepatica</i>			8	0			17					
Gastropod sp. 1	42	24					17	0	168	7	328	3
Bivalve sp.											8	0
Phylum Bryozoa												
Bryozoa sp.			655	6	8	3	34	1	34	1	67	1
Bryozoa sp. 1			8	0	8	3					42	0
Total	176	100	11365	100	294	100	5040	100	2562	100	10718	100

In terms of percentage contribution of each site to the total abundance per month, site 1 was characterised by the most abundant macroinvertebrate communities until July 1997 (Figure 4.3). Later winter and spring 1997 densities at other sites in the backwater (sites 2 and 3; Figure 2.1) increased significantly. Over all seven sampling sites, sites 1, 2 and 3 contributed most greatly towards the total abundance. This was generally consistent throughout the year, and overall site 2 had the highest densities in the area (Figure 4.2 and 4.3).

Fig 4.2

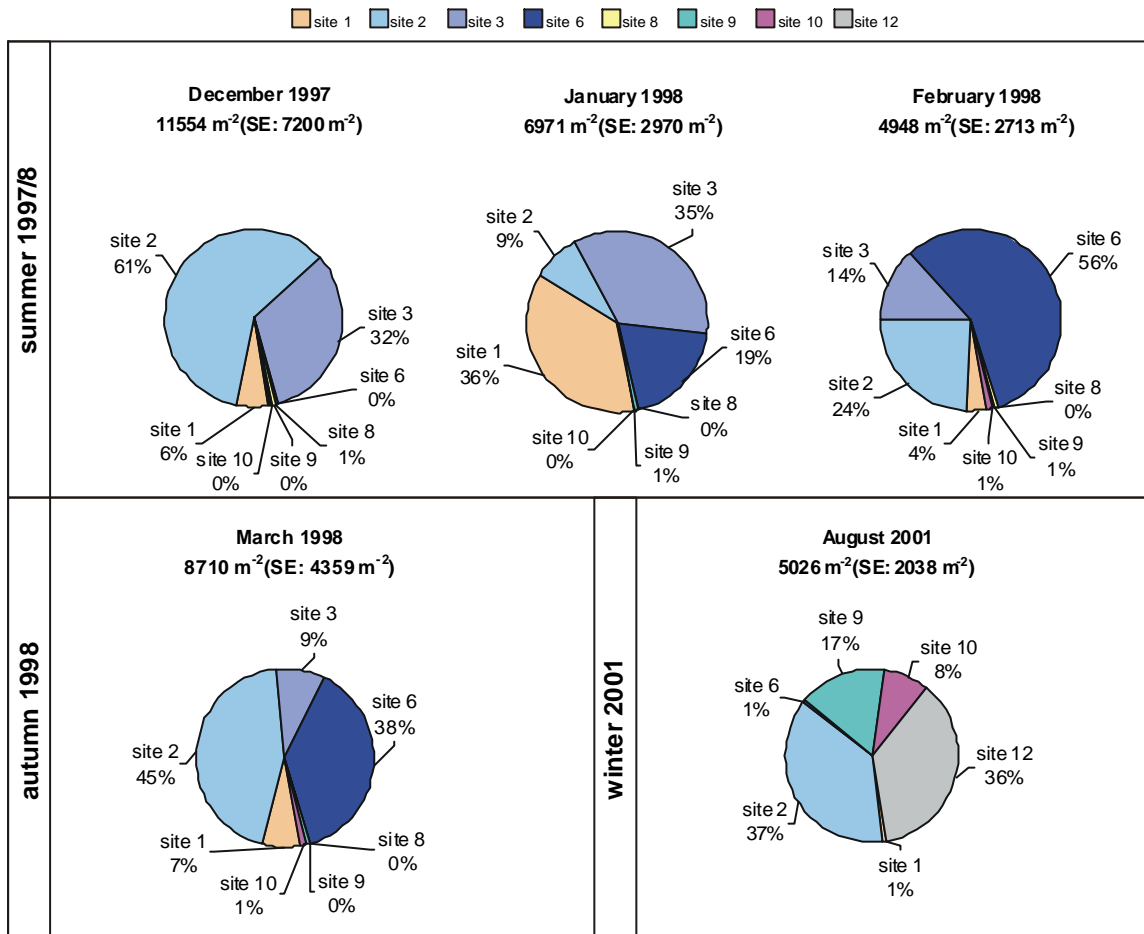
Seasonal Macroinvertebrate densities (m⁻²) from April 1997 to November 1997. Percentage contributions of site densities per month are given. Mean densities and standard errors means are indicated



While dominance of site 1 decreased in summer 1997/8, there was a corresponding increase in numbers at site 6 until March 1998 (Figure 4.3). The fauna associated with this site were primarily freshwater in origin (oligochaetes and insects), although there were several estuarine taxa present on occasion. In contrast to the 1997/8 survey, the percentage contribution of six sites in August 2001 indicated that >60% of the abundance was in the middle reaches of the system (1.25 - 1.85km upstream) in the River-Estuary Interface (REI) area.

Fig 4.3

Seasonal Macroinvertebrate densities (m^{-2}) from December 1997 to March 1998 and August 2001. Percentage contributions of site densities per month are given. Mean densities and standard errors means are indicated



4.2 MACROINVERTEBRATE COMMUNITY ANALYSIS

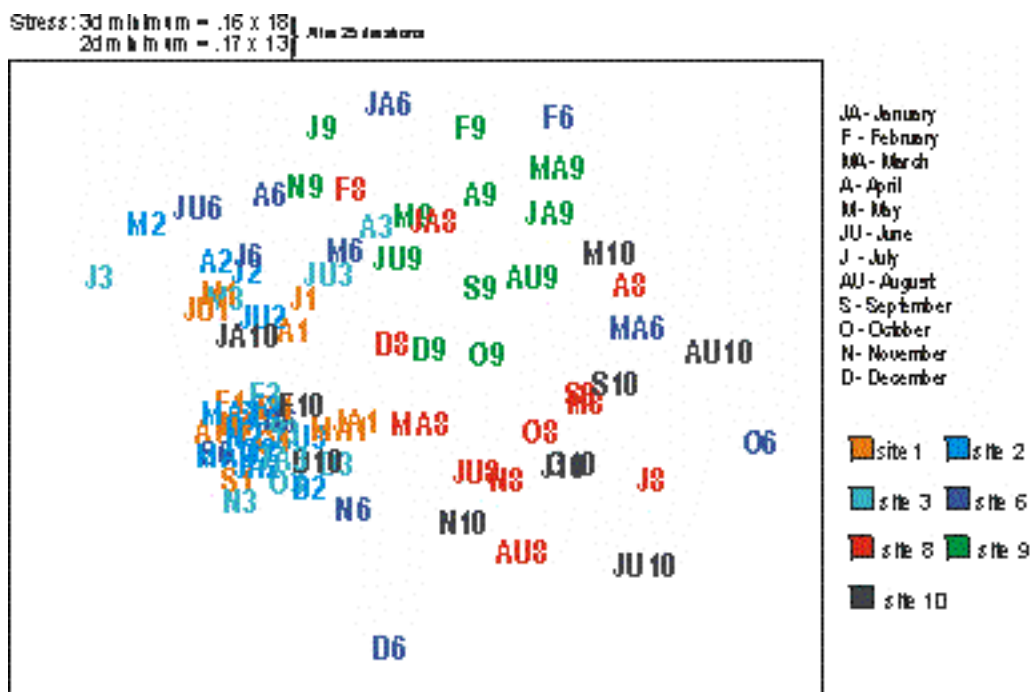
Bray-Curtis similarity matrices and hierarchical cluster (group average linkages) dendrograms were calculated for each sampling site and month and for each taxon sampled throughout the year, to investigate relationships between samples and taxa. The matrices were then used as an input to a non-metric multidimensional scaling ordination (NMDS), to confirm relationships between samples and the macrobenthos. Sample relationships are given by the dendrogram and NMDS plots in Figures 4.4 - 4.5 and 4.10 and macrobenthic taxon relationships are given by the NMDS plot in Figures 4.6 - 4.7 and 4.11).

4.2.1 Relationships between Samples

Cluster analysis identified three main groups at a 75% level of similarity (Mackay and Cyrus 1998). These were approximately clearly divided as sampling sites within the backwater area and those within the channel. At this level of classification, site 9 was intermediate between these two groups of fauna but was more closely related to samples from sites 1, 2, 3 and 6 (Figure 4.4). The NMDS plot (stress value indicated a fairly good ordination and representative of the data) clearly indicated the tight cluster of samples from sites 1, 2 and 3 (more closely related) and the larger spread of samples from site 9 (Figure 5). Samples from sites 8 and 10 were indistinguishable as discreet clusters and were therefore similar in either species composition or abundance. Further analysis showed that in 1997/8, the macroinvertebrates of the Thukela Estuary were not as temporally separate as they were spatially different - this was in the absence of definite clusters of seasonal groups (Mackay

and Cyrus 1998). The changing habitat (flow, salinity regime and nature of the substrate) is therefore more important in terms of assemblages and numbers than that of any seasonal effect on these fauna.

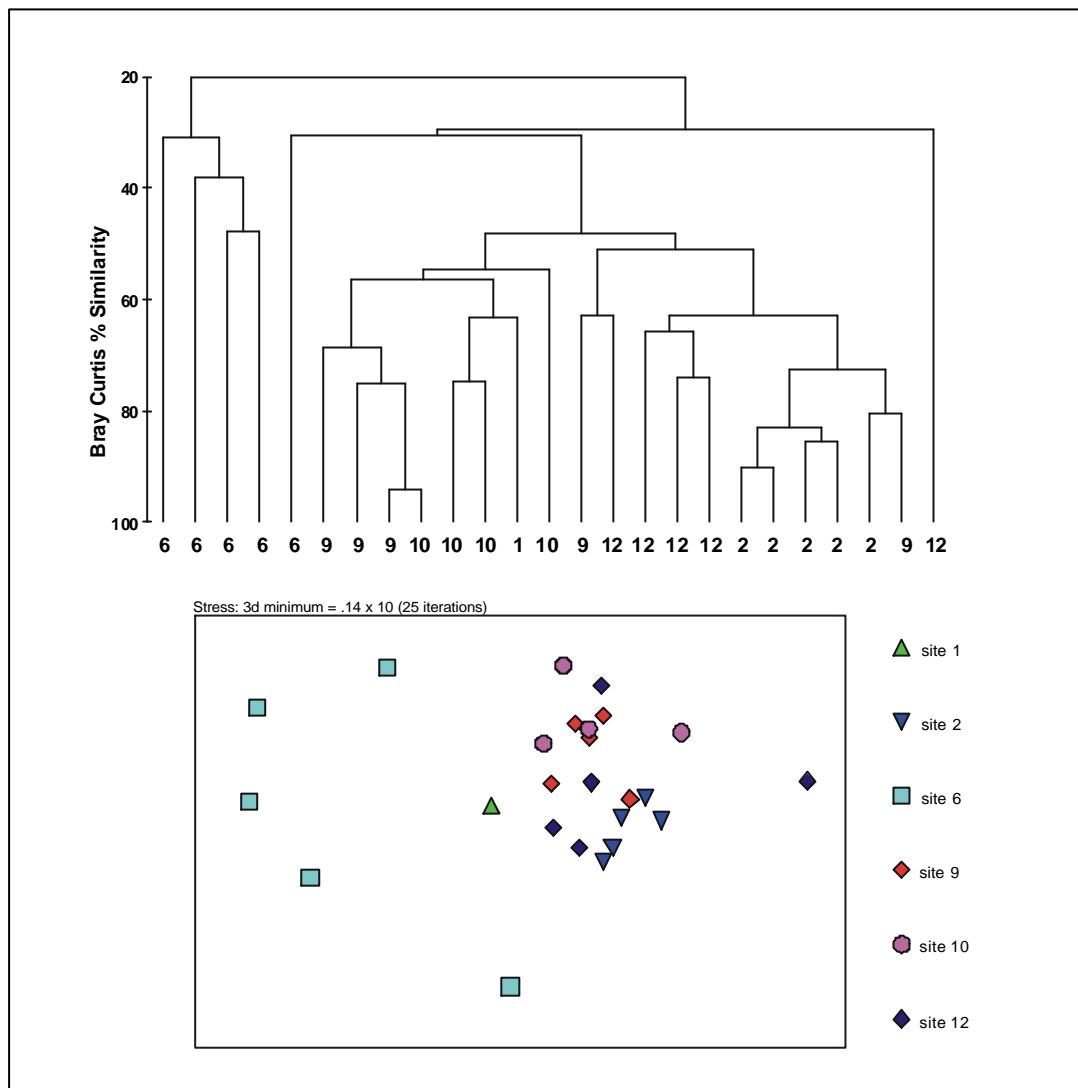
Fig 4.4 Result of nonmetric multidimensional scaling (NMDS) ordination of macroinvertebrate samples collected at seven sites from April 1997 to March 1998. Samples are shaded according to sampling site and month



August 2001 samples showed a different pattern when subject to the same suite of analyses. Bray Curtis similarity indicated that site 6 was highly variable in terms of species composition, abundance or both these parameters and highly 'patchy'. Replicate samples were only comparable at a 30% level of similarity (Figure 4.5). At 55% similarity, sites 9 and 10 were similar as were sites 12 and 2.

Ordination of the replicate samples (five per site) showed the clear variability of site 6 (presented by its spatial separation) and the similarity of all other sites. However, the other sites could be separated to some degree as: sites (9 and 10) and (12 and 2). Only one replicate sample at site 1 contained macroinvertebrates (Figure 4.5).

Fig 4.5 Bray-Curtis cluster analysis and NMDS ordination of macroinvertebrate samples collected at six sites in August 2001



When data from both studies were combined and plotted as an NMDS ordination, August 2001 samples were clearly different from 1997/8 samples. The ordination was plotted according to season (temporal relationships) and site (spatial relationships) (Figure 4.6). The six sites sampled in winter 2001 were not similar in species assemblage and/or abundance to samples collected in winter 1997/8. None of the six sites sampled in 2001 were comparable to samples collected at the same sites on 12 occasions between April 1997 and March 1998.

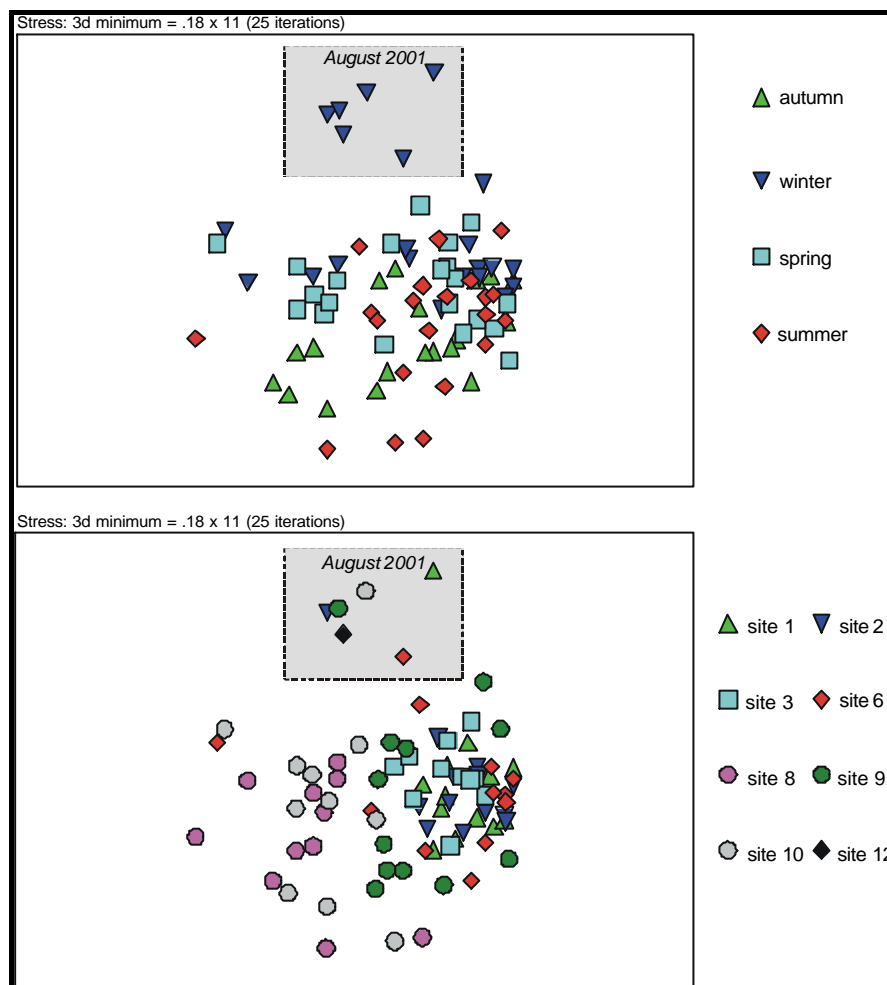
The collective data (1997/8 and 2001) were then reclassified into higher taxonomic groups (Level of Class) and then coded according to their freshwater (blue square), estuarine (green triangle) or marine origin (blue triangle) (Figure 4.7). A clearer pattern of the association of fauna from the three different environments was evident. The tolerance of freshwater or marine conditions by some estuarine organisms was also clear in the NMDS ordination.

4.2.2 Relationships between Taxa

The inverse analysis of these data (on taxa rather than samples) showed undefined relationships between taxa in 1998/7 (Mackay and Cyrus 1998). The lack of relationship between taxa (estuarine or freshwater taxa grouped together) was attributed to the inconsistency of the physical environment within the estuary. During periods of high flow,

there were large numbers of insects while during low flow conditions crustaceans and other organisms were able to colonise estuarine areas, albeit for a short duration.

Fig 4.6 NMDS ordination of macroinvertebrate samples collected at seven sites from April 1997 to March 1998 and six sites in August 2001. Samples are shaded according to season and site



4.3 MACROINVERTEBRATE SPECIES ANALYSIS

4.3.1 Measures of Similarity and Dissimilarity

The program SIMPER in Primer v5 (Clarke and Warwick 1994) was used to determine intrasite relationships between species and the dissimilarity of sites (in terms of species assemblages). The program is based on the calculation of similarity percentages, which are in respect of contributions to average similarity within a group and average dissimilarity between groups (Clarke and Warwick 1994). In this case, groups were taken as sampling sites. Table 4.3 shows the results of species contributions presented as dissimilarities of species assemblages between sampling sites.

Table 4.3 Percentage dissimilarity of species assemblages between eight sampling sites (1997/8 and 2001 data). Dissimilarities <75% are highlighted

Site	% Dissimilarity between sampling sites							
	1	2	3	6	8	9	10	12
1		56.07	56.54	68.22	98.39	91.97	98.36	99.46
2			60.24	70.41	99.18	94.25	98.84	92.53
3				68.74	97.08	84.24	96.54	99.36
6					94.65	85.29	94.15	99.43
8						90.29	81.46	99.62
9							87.09	94.52
10								93.33
12								

These results substantiate those obtained through cluster analysis and nonmetric multidimensional scaling. Sites 1, 2 and 3 were relatively similar to each other in terms of species present, hence low percentage dissimilarities (highlighted). Site 6 was more similar to sites within the backwater area (sites 1 to 3), than those situated within the channel (1997/8 condition) or estuarine area (2001 condition). Sites 8, 9, 10 and 12 were highly dissimilar to each other and to those within the backwater. The reasons for this may be that sites 1, 2 and 3 were characterised by large numbers of oligochaetes, oligochaete eggs, brachyurans (juvenile) and dipteran larvae (particularly chironomids). Site 6 also had large numbers of the above taxa, but was more variable in terms of the influence of a larger number of estuarine taxa. This was further evidence of the greater instability of habitat at this site than at sites 1, 2 and 3. When data from both surveys were combined, species at sites 8-10 and 12 were primarily estuarine but at a lower abundance than sites 1-3 and 6.

Using this same program (SIMPER), the contribution each species made to the average similarity within a site was calculated. The more abundant a species within a site, the more it contributed to the intrasite similarity and typified a site (Clarke and Warwick 1994). Data for the 1997/8 survey are presented separately to the combination of 1997/8 and 2001 data, to illustrate the vastly different communities (Figure 4.6). Sites 1, 2 and 3 had relatively high percentages of similarity between species (>50%), indicating that throughout the year a fairly similar species assemblage colonised those areas (Table 4.4). The opposite may be said of site 10, where fluctuations in what was sampled throughout the year were reflected in a low intrasite percentage similarity (29.47%).

Table 4.4 Percentage similarity of species assemblages at each of seven sampling sites in the Thukela Estuary (1997/8 data). Percentage similarities >50 are highlighted

Site	% Similarity within a sampling site
1	57.27%
2	57.08%
3	54.23%
6	41.41%
8	35.36%
9	41.23%
10	29.47%

Percentage similarity of species assemblages for 1997/8 and 2001 data were low (all <45%). Thus, no species could be said to typify a site and it was concluded that the assemblages were highly variable at each site and each sampling period (Table 4.5).

Fig 4.7

NMDS ordination of macroinvertebrate taxa (Inverse analysis) collected at six sites in August 2001. Bottom figure depicts the same ordination but taxa are shaded according to freshwater, estuarine or marine origin

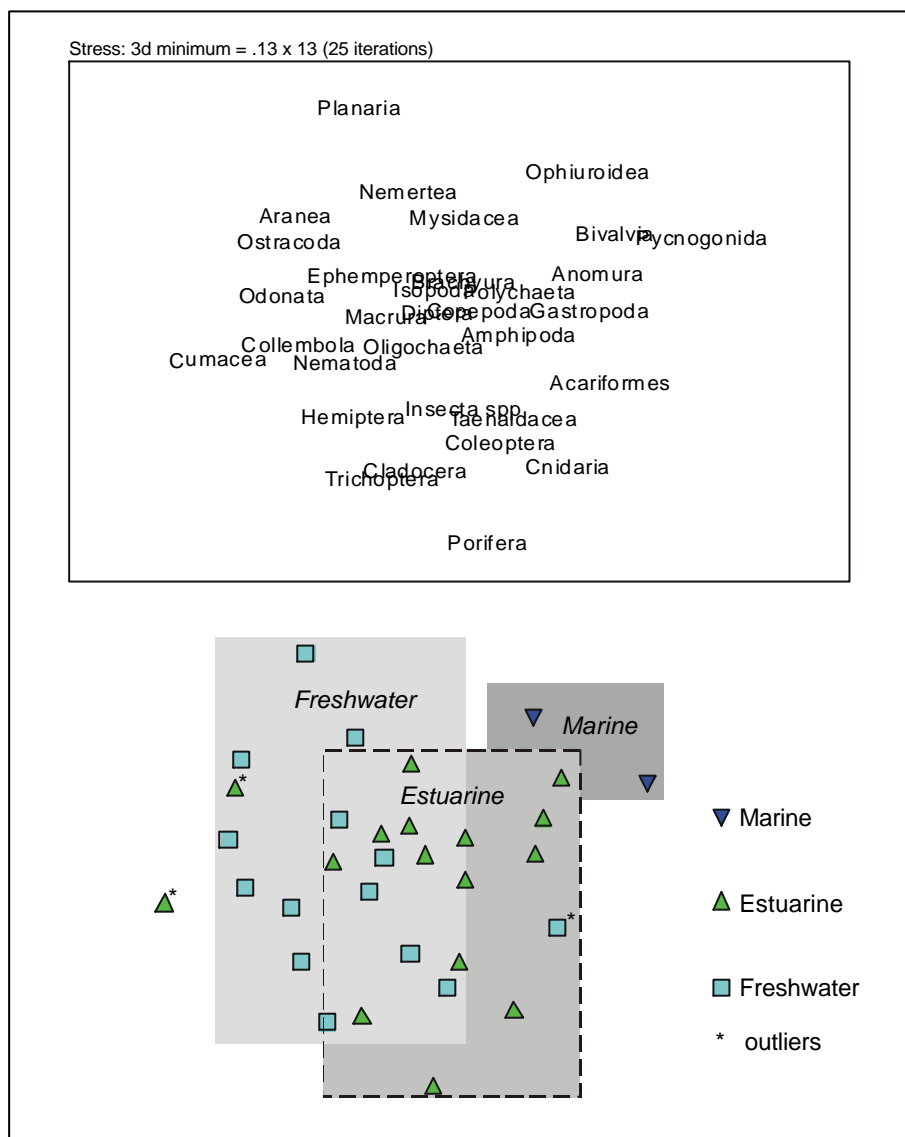


Table 4.5 Percentage similarity of species assemblages at each of eight sampling sites in the Thukela Estuary (1997/8 and 2001 data). Percentage similarities >50 are highlighted

Site	% Similarity within a sampling site
1	44.99%
2	39.94%
3	38.79%
6	20.90%
8	21.80%
9	36.85%
10	17.30%
12	too few samples

Tables 4.6 and 4.7 are the results of the above similarities broken down from sites 1 and 10 (1997/8 data), and represent the greatest and least intrasite percentage similarity of contributing species. The overall similarities were 57.27% at site 1 and 29.47% at site 10 (Table 4.4).

Table 4.6 The importance rating of each species, presented as a percentage of the total contribution at site 1 from 1997/8

Taxon	Average Abundance (m ²)	Average similarity	Percentage contribution	Cumulative percentage contribution
Oligochaeta	4474	36.8	64.23	64.23
Brachyura	12	2.7	4.68	92.64
Polychaeta	7	2.3	4.03	96.67
Macrura	3	0.5	0.90	97.57
Isopoda	3	0.5	0.79	98.36
Diptera (larvae)	6	0.4	0.75	99.11
Copepoda	2	0.2	0.29	99.39
Mysidacea	4	0.1	0.24	99.64
Hemiptera	5	0.1	0.18	99.82
Amphipoda	1	0.1	0.18	100.00

At site 1, >90% cumulative percentage was achieved by the first two taxa listed (Oligochaeta and Brachyura). The remaining taxa, which were primarily estuarine in origin, contributed approximately equally to the overall similarity at this site. At site 10, the first seven taxa contributed to >90% cumulative percentage similarity (Table 4.7). The species assemblage consisted of an even contribution of insects and crustaceans. These results were reasonable evidence for the spread of sampling points in the NMDS plots (Figure 4.4) and further indicated that samples from site 10 bore no relationship to those from the backwater (sites 1, 2 and 3). This was in terms of either abundance or species composition.

Table 4.7 The importance rating of each species, presented as a percentage of the total contribution, at site 10 in the Thukela Estuary

Taxon	Average Abundance (m ²)	Average Similarity	Percentage contribution	Cumulative percentage contribution
Isopoda	57	7.4	25.08	25.08
Oligochaeta	11	5.4	18.46	43.54
Macrura	99	4.9	16.67	60.21
Brachyura	11	3.0	10.02	70.23
Ephemeroptera	5	2.3	7.68	77.91
Diptera (larvae)	11	2.2	7.35	85.26
Mysidacea	5	1.5	5.03	90.29
Diptera (nymphs)	137	1.4	4.74	95.03
Copepoda	4	0.6	1.89	96.93
Diptera (pupae)	5	0.2	0.69	97.61
Oligochaeta (eggs & larvae)	15	0.2	0.67	98.28
Amphipoda	2	0.2	0.65	98.93
Nematoda	5	0.2	0.61	99.54

Tables 4.8 and 4.14 are the results of the above similarities broken down from sites 1 - 3, 6, 8-10 and 12 using combined 1997/8 and 2001 data. All sites located in the former backwater (sites 1 - 3,6) were >95% characterised by one taxon – oligochaete worms (Tables 4.8 - 4.11). This taxon was indicative of the freshwater influence of the lower Thukela for the majority of the time. At sites with an estuarine influence, the cumulative percentage contribution to 95% was spread among several taxa including Macrura, Brachyura and Isopoda) (Tables 4.12 - 4.14).

Table 4.8 The importance rating of each species, presented as a percentage of the total contribution at site 1, in the Thukela Estuary (1997/8 & 2001 data)

Taxon	Average Abundance (m ²)	Average similarity	Percentage contribution	Cumulative percentage contribution
Oligochaeta	4130	44.73	99.44	99.44

Table 4.9 The importance rating of each species, presented as a percentage of the total contribution at site 2, in the Thukela Estuary (1997/8 & 2001 data)

Taxon	Average Abundance (m ²)	Average similarity	Percentage contribution	Cumulative percentage contribution
Oligochaeta	8199	39.80	99.67	99.67

Table 4.10 The importance rating of each species, presented as a percentage of the total contribution at site 3, in the Thukela Estuary (1997/8 & 2001 data)

Taxon	Average Abundance (m ²)	Average similarity	Percentage contribution	Cumulative percentage contribution
Oligochaeta	3746	38.23	98.55	98.55

Table 4.11 The importance rating of each species, presented as a percentage of the total contribution at site 6, in the Thukela Estuary (1997/8 & 2001 data)

Taxon	Average Abundance (m ²)	Average similarity	Percentage contribution	Cumulative percentage contribution
Oligochaeta	4928	20.02	95.78	95.78

Table 4.12 The importance rating of each species, presented as a percentage of the total contribution at site 8, in the Thukela Estuary (1997/8 & 2001 data)

Taxon	Average Abundance (m ²)	Average similarity	Percentage contribution	Cumulative percentage contribution
Isopoda	102	9.57	43.90	43.90
Mysidacea	69	5.19	28.83	67.73
Brachyura	31	2.30	10.55	78.28
Diptera	18	1.52	6.99	85.26
Oligochaeta	8	1.30	5.94	91.21

Table 4.13 The importance rating of each species, presented as a percentage of the total contribution at site 9, in the Thukela Estuary (1997/8 & 2001 data)

Taxon	Average Abundance (m ²)	Average similarity	Percentage contribution	Cumulative percentage contribution
Oligochaeta	97	29.94	81.24	81.24
Macrura	16	3.32	9.00	90.24

Table 4.14 The importance rating of each species, presented as a percentage of the total contribution at site 10, in the Thukela Estuary (1997/8 & 2001 data)

Taxon	Average Abundance (m ²)	Average similarity	Percentage contribution	Cumulative percentage contribution
Isopoda	46	5.82	33.61	33.61
Macrura	99	5.25	30.33	63.94
Oligochaeta	11	2.08	12.02	75.96
Diptera	27	1.51	8.71	84.67
Ephemeroptera	5	0.98	5.65	90.31

4.3.2 Species Defining the Present State

As clear differences were established between the two surveys (Figure 4.6) and between sites in the most recent study (Figure 4.5), the species responsible for these differences were investigated. The original ordinations were used with a specific symbol (bubble plot) superimposed to describe each selected species. The species were plotted in proportion to the relative abundance at each sampling site, during each month. This process was repeated for each species sampled. Only those that represented definite patterns are presented in Figure 4.8 (combined 1997/8 and 2001 data) and Figure 4.9 (2001 data only).

The most obvious difference between the two surveys was the presence of some keystone estuarine species in the August 2001 survey. These were the polychaete *Desdemona ornata*, the anomuran *Upogebia sp.* and several gastropod species (Figure 4.8). Where *D. ornata* occurred in high numbers in August 2001 (sites 2 and 12), numbers were few of *Upogebia sp.* and visa versa. Nematoda, Oligochaeta, the isopod *Excirrollana natalensis*, the burrowing mud crab *Paratyrodiplox blephariskios* and Chironomidae dipterans characterised the 1997/8 survey and did not occur in August 2001. Whilst the oligochaetes and mud crabs were limited to the backwater area (muddy substrate), the Nematoda and Chironomidae were less specific in their distribution and occurred in all regions of the estuary during 1997/8.

Figure 4.9 presents superimposed plots of the four most abundant species sampled in 2001 (in order of importance). Each species is also presented in terms of its percentage contribution to the mean density per site. *Desdemona ornata* was clearly a significant species throughout the Thukela in the low flow conditions of August 2001. The separation of site 6 from the other sites was most certainly due to the low abundance of fauna sampled. In 2001, site 6 was situated in the main outflow channel of the estuary.

Fig 4.8 NMDS ordination of macroinvertebrate samples (combined 1997/8 & 2001 data), with characteristic species superimposed

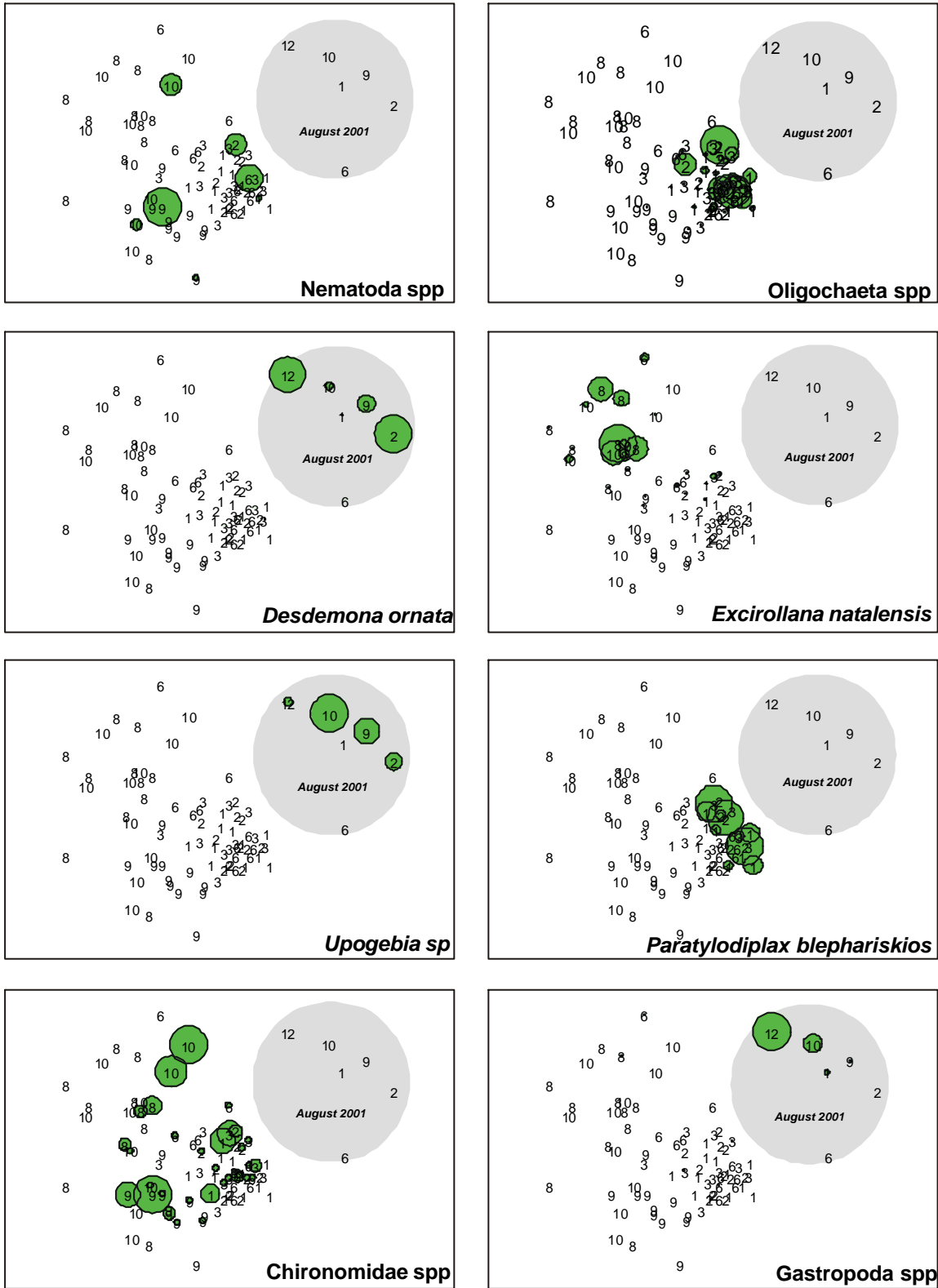
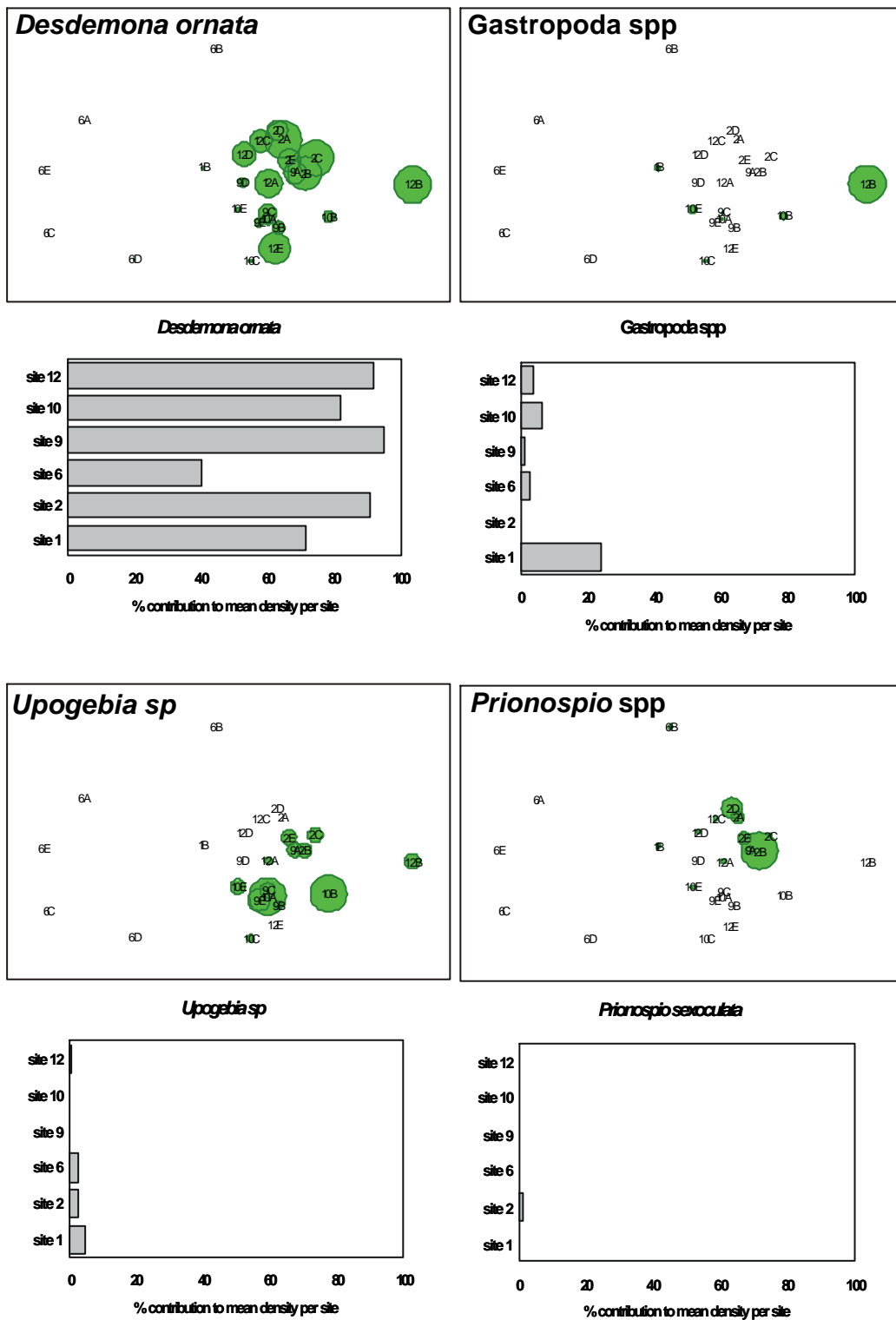


Fig 4.9 NMDS ordination of macroinvertebrate samples (2001 data) with most abundant species superimposed. Percentage contribution of each species is given below the appropriate plot



4.4 COMPARATIVE INDICES

Diversity indices were used to describe species-abundance relations, in place of distribution models. The major criticisms of these indices, that they confound a number of variables (species richness, evenness and the homogeneity of sampling area) and are not easy to interpret, was acknowledged. For this reason, multivariate analyses were used together with the indices to characterise the macroinvertebrate communities. The indices used were:

Richness:

$$\text{Margalef's index: } D_{Mg} = (S - 1)/\ln N$$

Where S = number of species recorded, and N = total number of individuals summed over all S species.

Diversity:

Shannon's Index - based on theory of Shannon and Weaver (1963)

$$H' = - \sum_{i=1}^{S^*} p_i \ln p_i$$

Where p_i = proportion of individuals found in the i th species (N_i/N).

The number of taxa (S') and abundance of macroinvertebrates (m^{-2}) are plotted monthly per site in Figures 4.10 and 4.11, respectively.

The numbers of taxa per site were variable on a monthly scale. Generally, more taxa were present in the estuarine/REI (sites 8-10, 12) (Figure 4.10). The monthly abundance (m^{-2}) per site gave a comparatively reverse situation. Significantly fewer numbers were present in the REI zone than the backwater sites (sites 1-3, 6). The richness and diversity indices calculated for site and month were slightly misleading in that they showed greater richness in the REI zone, but there is a high diversity associated with this (Appendix A-2). Diversity increased with increasing saline influence (sites 8-10, 12). The high variability associated with site 6 was evident in the low index results for 1997/8. This changed in August 2001 where it was the most diverse site (although exceptionally low in abundance).

4.5 ENVIRONMENTAL FACTORS INFLUENCING MACROINVERTEBRATES OF THE THUKELA ESTUARY

4.5.1 1997/8 Survey

Variability within the Thukela Estuary, and the fact that it arises primarily from riverine rather than marine influence, gives rise to a number of changes within the system in any given year. After the 1997/8 survey it was concluded that the high sediment loads that travel along the system with constant deposition of fine particles and organic matter around the backwater area, played a major role in determining what was able to settle in that environment (Mackay and Cyrus 1998).

In 1997/8 the sediments at sites 1 and 2 ranged between mud and muddy sand (90% <63 μ m; 95% < 125 μ m) (Mackay and Cyrus 1998). Both sites were areas of high organic input from the upper reaches of the system. Further along the backwater towards the channel, (site 6, Figure 2.1) the substrate was more variable, ranging from very coarse sand to mud (2000 μ m – 63 μ m). At site 9, sediments from upstream influenced the nature of the substrate. Coarser sediments from the marine environment and low levels of organic detritus distinguished those sites directly adjacent to the mouth of the system (Mackay and Cyrus 1998). The various soft

bottoms, such as gravel, sand and mud show differences in biota and analysis of the nature of substrates with regard to particle size are important in describing the ecology of benthos. Morgans (1956) noted that two features of soft substrata affect benthos, texture and dead organic matter. Examples of this importance may be reflected in the fact that some macroinvertebrate species are tubicolous and require a particular substrate with which to construct their burrows. Areas with large amounts of detritus may also support a greater number and abundance of species (Cyrus and Martin 1988).

Fig 4.10 Number of taxa sampled per site (S') during 1997/8 and 2001 surveys

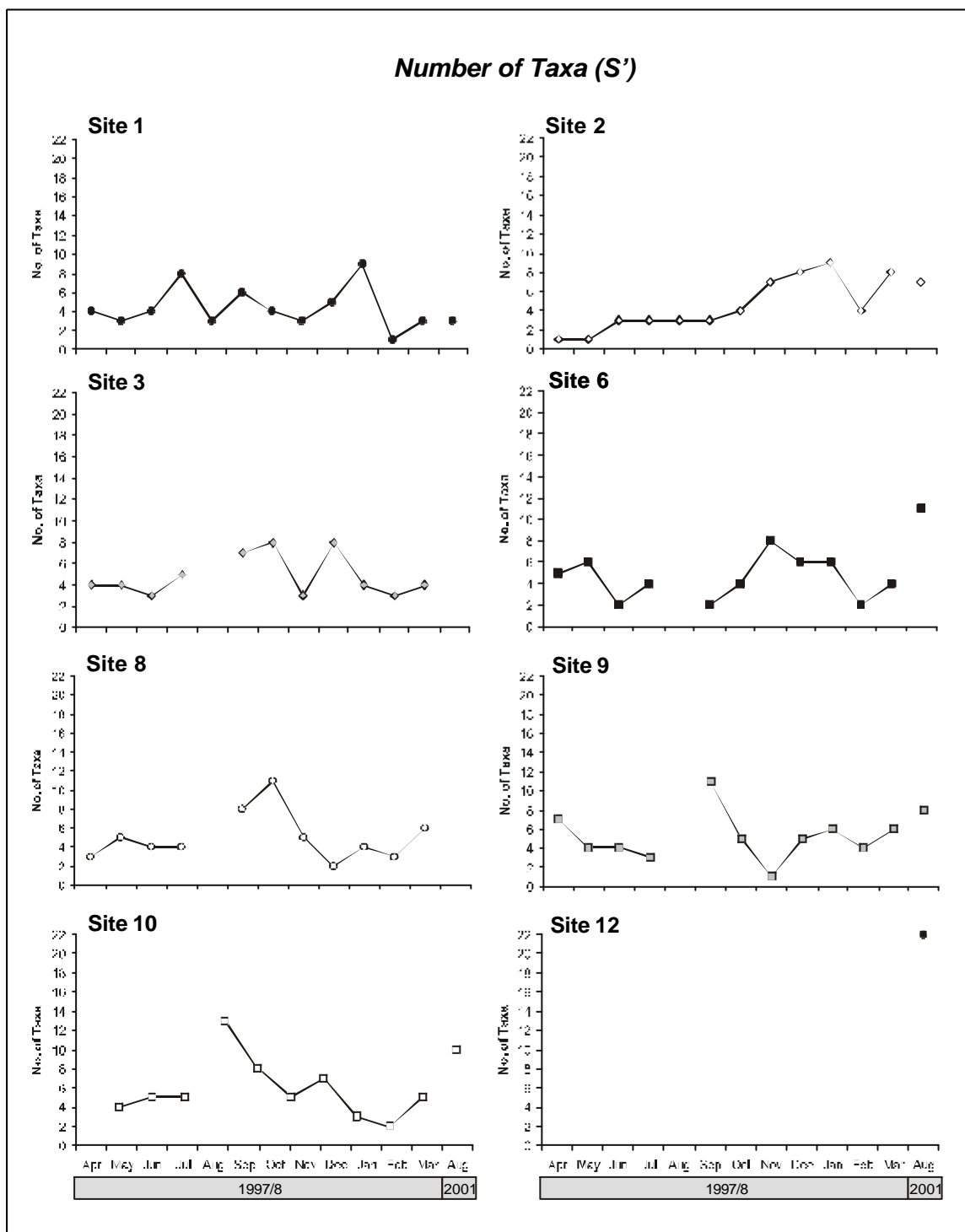
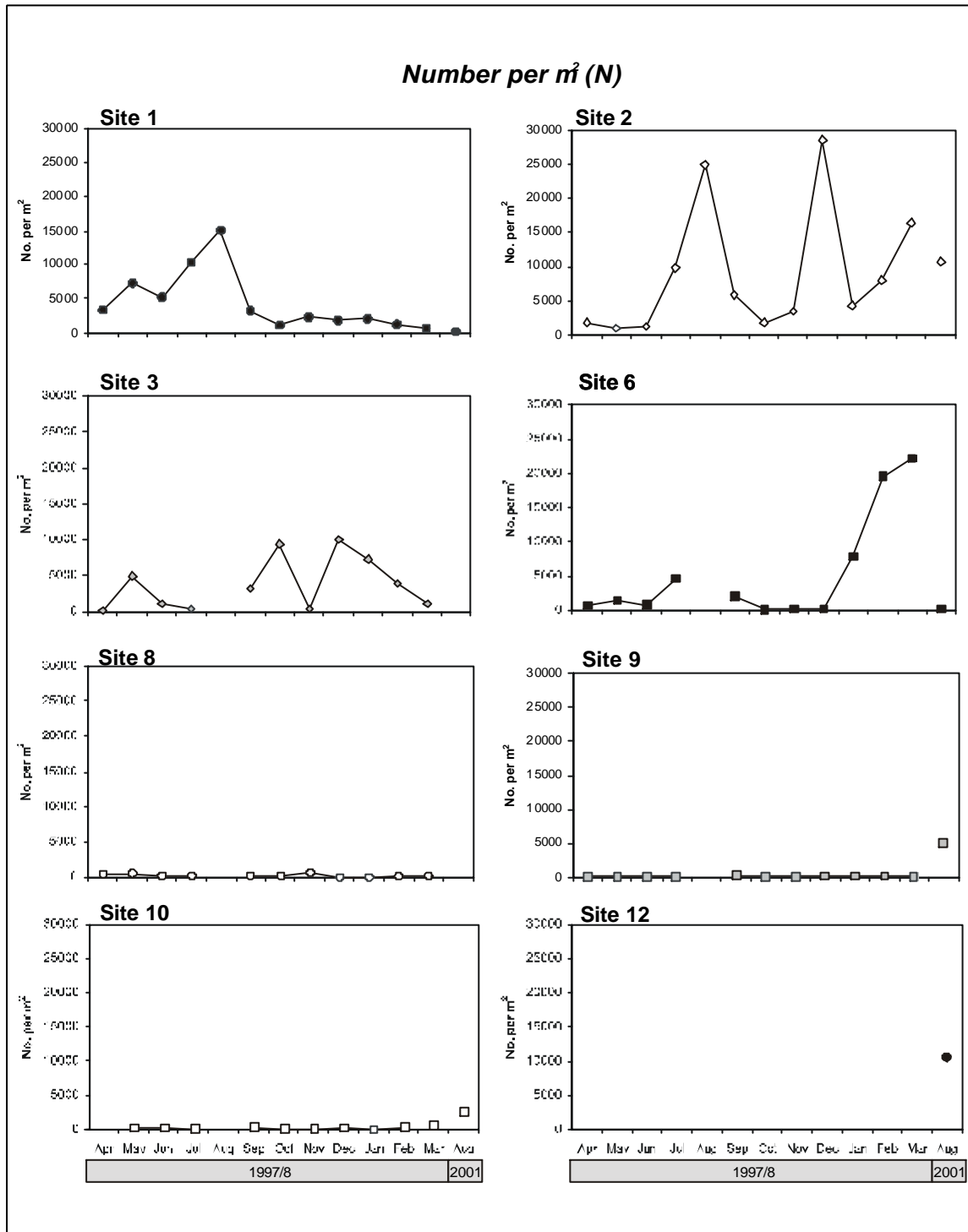


Fig 4.11 Abundance per m² per site (N) during 1997/8 and 2001 surveys

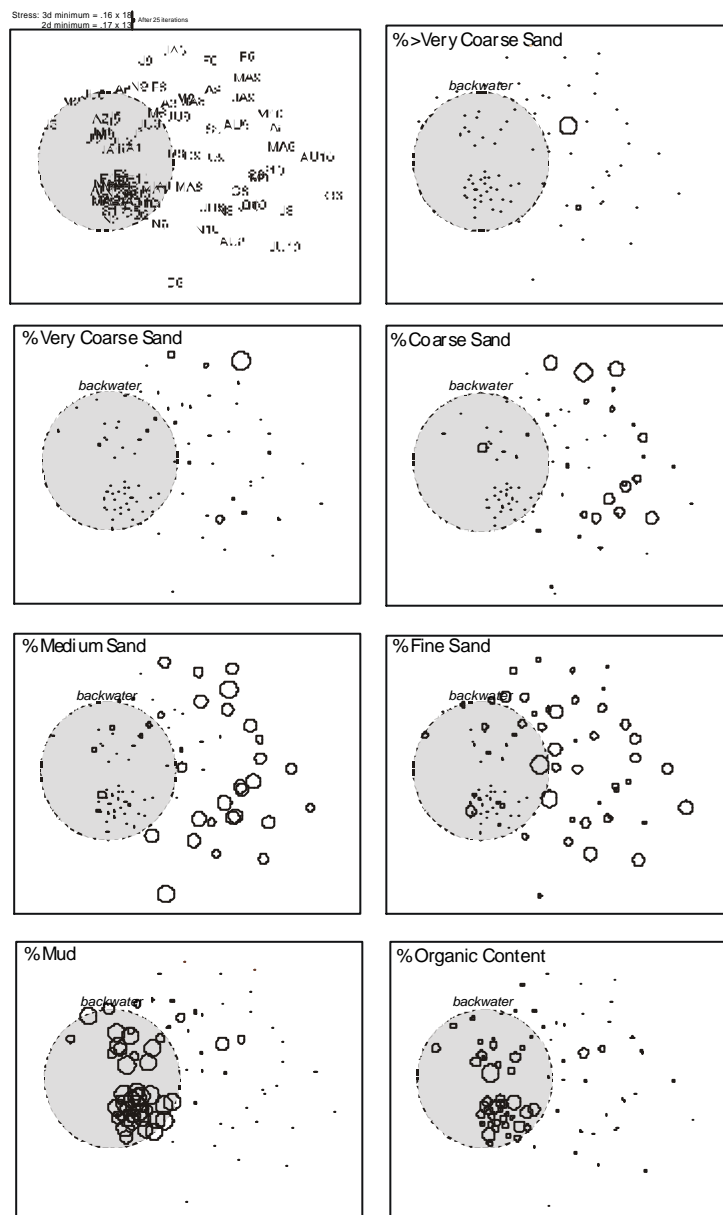


The strong interrelationship between certain physico-chemical parameters, which are usually 'cause and effect' type situations where a change in a certain parameter causes either a direct or indirect effect on another has the potential to also influence macroinvertebrate distribution. One physico-chemical parameter cannot be considered solely accountable for affecting the nature of the benthos (Mackay and Cyrus 2001). Appendix A - 3 lists several other environmental factors that were measured in the Thukela Estuary from April 1997 to March 1998.

As it is common to link environmental parameters to population distribution through multivariate analyses, the biotic sample NMDS plot (Figure 4.4) was used as a template on which various measurements of abiotic variables were superimposed (listed in Appendix A -

3). A specific symbol was used to describe each physico-chemical parameter, and these were plotted in proportion to the measurement at each sampling site, during each month. Due to the interrelationship of TDS, conductivity and salinity, these plots all presented a similar picture (variable distribution and symbol size throughout the plot) and were therefore at that time, not significant biotic determinants (Mackay and Cyrus 1998). This was also true of pH. However, the cluster group of sites 1 - 3 in the backwater (Figure 4.4) had relatively higher turbidity levels than at any other site. The highest macroinvertebrate densities occurred at sites 1 - 3. Therefore turbidity was not a limiting factor to distribution and fauna that occurred there were in fact tolerant of high levels (particularly during high flow conditions: <600 NTU in January 1998, Appendix A - 3). Sediment characteristics superimposed in the same manner, revealed that finer sand, mud and organic content of substrate may have had a part to play in the distribution of macroinvertebrates in 1997/8 (Figure 4.12).

Fig 4.12 NMDS plot of monthly macroinvertebrate samples (1997/8) with grain size categories and percentage organic content of sediments superimposed

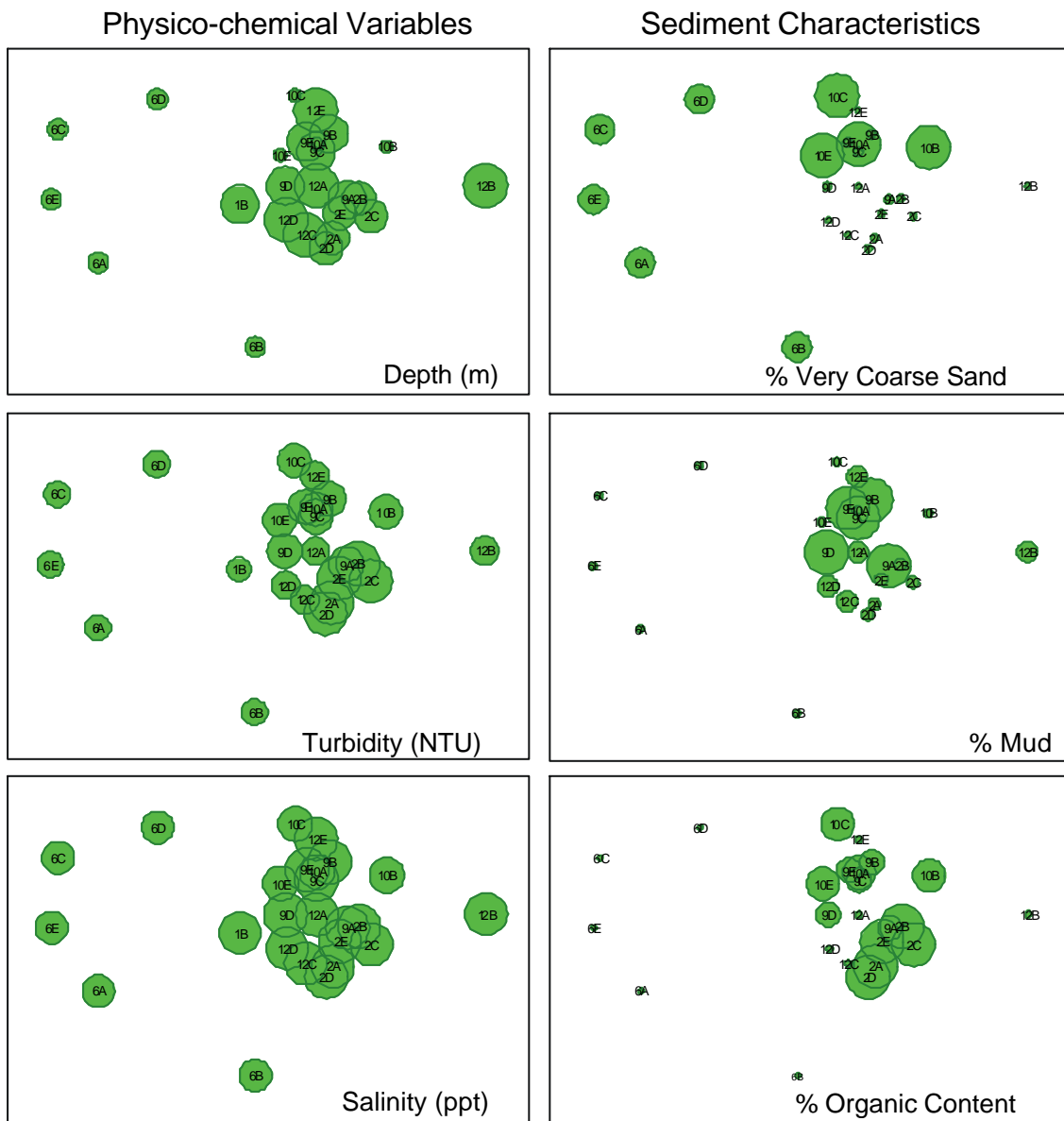


4.5.2 August 2001 (low flow) Survey

The groups identified in the NMDS ordination of August 2001 samples (Figure 4.5) were superimposed with a suite of physico-chemical measurements and sediment characteristics. During 2001, the environmental forcing factors responsible for the separation of site 6 from the other sites was a combination of % Mud and % Organic Content of the sediments and sampling depth. Site 6 was <0.5m (Appendix A - 4).

The low % Very Coarse Sand at sites 2 and 12 was responsible for the separation of this group from the others at a 55% level of Bray Curtis Similarity (Figure 4.5). The salinity distribution at all six macroinvertebrate sites was uniform in August 2001. However, a comparison of 1997/8 and 2001 salinity data (Appendices A3-4) show that the clear separation of the two surveys was based on differences in salinity (Figure 4.6). In August 2001, the level of outflow was considerably lower than the previous survey (<6 m³.s⁻¹) and the system was subject to a far greater marine influence. The macroinvertebrate populations at that time were typically estuarine.

Fig 4.13 NMDS plot of macroinvertebrate samples (2001) with certain physico-chemical variables and sediment characteristics superimposed



4.6 HISTORICAL INFORMATION ON MACROINVERTEBRATES OF THE THUKELA

The earliest survey was conducted by Day (1981) who found limited numbers of *Dotilla fenestrata*, *Sesarma eulimene* and juvenile *Palaemon pacificus*. Adams *et al.* (1997) sampled *P. pacificus* in addition to the polychaete *Scolelepis squamata*, the mysid *Gastrosaccus longifissura* and an isopod, *Eurydice* sp. These early surveys stated that the estuarine macrobenthic community was poorly represented and only few individuals were recorded. The reason given was the variability related to the frequent shift between river and estuarine conditions near the mouth. The recent surveys indicate that the macroinvertebrate community of the Thukela although not as diverse and abundant as many other estuaries, is clearly not as depauperate as had previously been documented.

Due to the paucity of historical information concerning the macroinvertebrates of the Thukela, it is only possible to clearly characterise its current state. The Reference state would most certainly have been dominated by freshwater fauna that were tolerate of high flows and the variability associated with seasonal changes to flow and saline intrusion.

The results of the current surveys have therefore shown that although the macroinvertebrates of the system were not as rich or abundant in estuarine species as other local systems, they were not entirely depauperate. The macroinvertebrates support an important wading bird population (Mackay and Cyrus 1998). The number of benthic invertebrate feeding birds associated with the Thukela Estuary is greater than any other group that utilises the system. The dominance of freshwater macrobenthos throughout the lower or 'estuarine' part of the system, evidently points to this being the major food source for benthic invertebrate feeding water birds.

Overall, the macroinvertebrate community was entirely dominated by a freshwater component of which no more than five key species contributed to over 75% of the total abundance. Species abundance distribution plots confirmed this, in that there were large numbers of taxa that were only sampled on one occasion, and others that were constantly sampled in large numbers. The most abundant taxa throughout the estuary were the oligochaete annelid worms. With regard to both the freshwater and estuarine components, no unusual species were sampled that would not otherwise have been found in their corresponding riverine or estuarine/marine systems.

4.7 EFFECTS OF FLOW REDUCTION

The August 2001 survey gave a clear indication of the resulting macroinvertebrate community, should flow be reduced for sustained periods. Initially, the dominant freshwater fauna would be reduced and perhaps disappear as tidal influence increases. Ultimately, this could result in an increase in salinity of the lower reaches of the system. The secondary response would be an increase in the current numbers of estuarine species, which would eventually replace the freshwater species in dominance. Therefore, although there may not be a vast reduction in current densities, the species composition and assemblages in the system would change entirely. The system could then be expected to have similar fauna common to other local estuaries.

As the Thukela closes for longer periods and has limited exchange with the marine environment, the physical-chemical processes within the system would then be more greatly influenced by the river and become more fresh in its abiotic characteristics. Despite this, it is not likely that the macrobenthos would immediately return to its current state (dominated by freshwater species), as many systems that are periodically closed along the Zululand coast and subject to freshwater conditions, still retain a fully dominant assemblage of estuarine species.

The estuary is an important conduit for crab and prawn developmental stages (Mackay and Cyrus 1999, Mackay and Cyrus 2002). If the mouth were to close during low flow conditions it is probable that the lifecycle of this, and other species that use the system for the same purposes, would be interrupted.

5 CONCLUDING STATEMENTS

These surveys have given an indication of the abiotic and biotic variability associated with the Thukela Estuary. Although it is referred to as an estuarine system, due to the volume of its outflow the Thukela has a significant dominance of freshwater characteristics. Its general physico-chemical state (apart from the August 2001 low flow study) tended towards one that is closer to riverine than estuarine conditions, and the associated benthic fauna were primarily freshwater invertebrates that are also found in other local rivers. There were, however, areas within the system (and during August 2001) that allowed the influx of estuarine organisms when there was a reduction in river outflow.

The general impression of the Thukela is that it is unlike any other system provincially, or even nationally. This estuary is the only system in the province, and one of only two in the country, classified as a true river mouth. The results of the current study must also be used in conjunction with historical accounts of the fauna to reassess the state of the Thukela. The system's ecological importance has probably increased in the light of the numerous anthropogenic changes that have impacted on other systems.

Prior to assessing the management options of the Thukela, it must be decided if its current condition, classified as a river mouth, is of national significance. If this is affirmative, then future flow regimes will have to be altered to accommodate this. However, if it is decided that its current condition is not worthy of preservation, then the outcome of proposed operating rules should be monitored and its transition into an estuary be documented. This would facilitate management decisions to allow optimal estuarine conditions to be attained in the future.

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1 INTRODUCTION

Because of their links with freshwater and marine environments, estuaries characteristically support a wide variety of marine, estuarine and freshwater holo- and meroplanktonic animals. The dominance of any of these components depends on the characteristics of the estuary, which often vary spatially and temporally within the same estuary. This variation is linked to environmental fluctuations that may be of a short term, periodic nature such as tidal cycles, medium term seasonal cycles, or longer-term events such as wet and dry cycles, ranging from a few years to decades.

The Thukela is regarded as a river mouth according to the classification by Whitfield (1992) with a strong freshwater component. As fast flowing rivers do not sustain any significant plankton communities the Thukela can be expected to be virtually devoid of zooplankton assemblages. However, the estuary is also known to go through periods of low flow conditions when zooplankton communities may be established. Very little information is however available on zooplankton of the estuary. Apart from unpublished, once-off, samples collected by John Grindley during the late 1960's (Begg 1978) no other data are available on the zooplankton component of the Thukela. This paucity of zooplankton data also applies to the other river mouth estuaries in southern Africa.

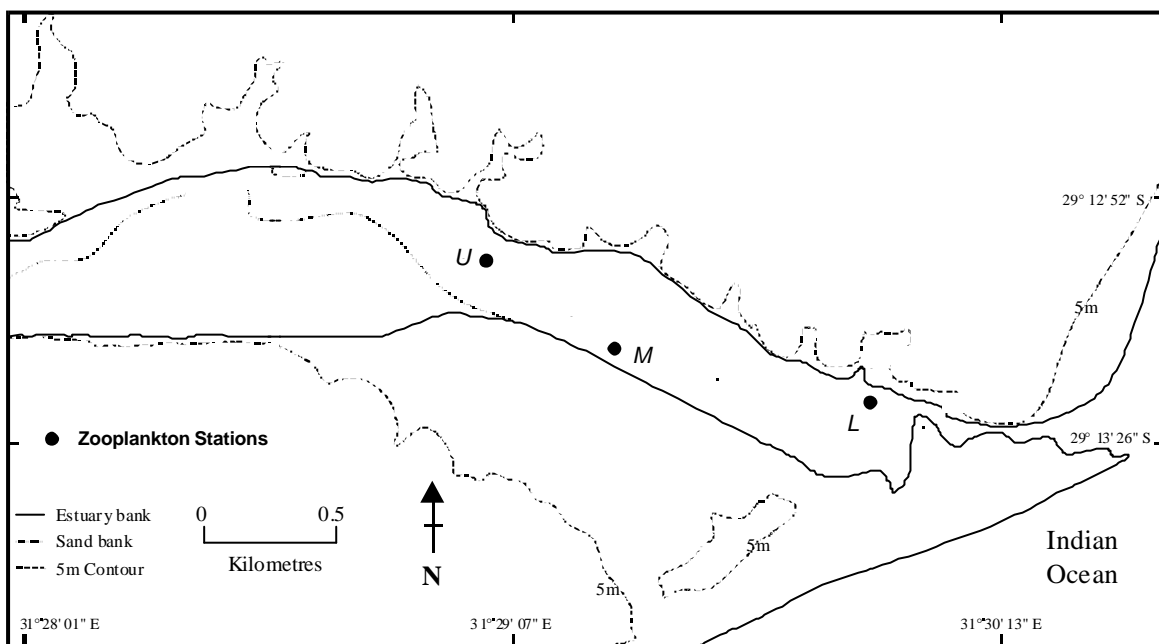
The present study on the zooplankton community was commissioned as part of the estuarine reserve determination for the Thukela. Only two sampling sessions were allowed and represent, at best, snapshot views of conditions during one low and one high river flow event. All results and conclusions drawn from the results must therefore be viewed with this limitation in mind.

2 METHODS

Zooplankton samples were collected at three stations (Figure 2.1) in the Thukela estuary during August 2001 and February 2002. These sampling sessions coincided with low and high river flow conditions respectively. Mid-water samples were collected after dark with a small river boat equipped with a double, modified bongo type plankton net to collect duplicate samples simultaneously. Each net was fitted with 200 μ m mesh and had a mouth diameter of 300mm. A flow meter was fitted in one net to quantify the volume of water sampled. Tows were restricted to 3 minutes at a slow speed to prevent excessive clogging. Samples were preserved in c. 10% formalin. Plankters were later identified and quantified in the laboratory.

A Hydrolab H₂O water quality multiprobe linked to a Surveyor 3 display logger was used to measure physico-chemical environmental variables during each sampling session.

Fig 2.1 Zooplankton sampling stations in the upper (U), middle (M) and lower (L) Thukela Estuary



3 RESULTS AND DISCUSSION

Physico-chemical data reflect the low and high flow conditions during the two sampling sessions (Table 3.1). The system was entirely fresh with substantially higher turbidity levels during the February sampling session whereas marine conditions dominated the August session. Some stratification was evident during the latter with less saline water floating on top of denser seawater. Temperatures show winter/early spring and summer conditions during the low and high flow sessions respectively.

Abundances of zooplankton taxa recorded during the two sampling sessions are indicated in Table 3.2. A total of 53 taxa were identified. Although plankton identification was attempted to as low a taxon level as was practically feasible some plankton were grouped into higher taxa and these groupings often represent more than one species, e.g. cnidarians, polychaetes and insects. As is typical for estuarine and coastal marine waters the zooplankton was dominated by copepods. The vast majority of taxa and also highest densities were recorded during the low flow sampling session. This relatively high diversity, in terms of species number, is typical of a marine zooplankton community compared to the relatively low numbers of species present in systems dominated by estuarine zooplankton. The number of species recorded is comparable to that recorded for the Mhlathuze estuary which also became mainly marine dominated since construction of the harbour (Jerling, 1998/1999).

Coastal marine zooplankton dominated the low flow sampling session at all three stations (Figure. 3.1). Intrusion of marine water at the upper sampling station was confirmed by the salinity data (Table 3.1). The term "coastal marine" as used in this report refers to the predominantly stenohaline component of the plankton and was distinguished from primarily euryhaline taxa, which are indicated in Table 3.2 with the abbreviation M/E (marine/estuarine). Typical examples of the stenohaline component includes the cladoceran *Pseudevadne* sp., copepods such as Calanidae, *Temora* spp., Poecilostomatoida and *Macrosetella* sp. the prawn *Lucifer* spp. and hyperid amphipods (Table 3.2). Some of the taxa indicated as M/E may include both marine and estuarine species, e.g. the polychaetes.

Table 3.1 Surface (S) and bottom (B) physico-chemical data recorded at three stations (upper, middle and lower) in the Thukela estuary during zooplankton sampling sessions in August 2001 (Low flow) and February 2002 (High flow)

		Low Flow			High Flow		
		Upper	Middle	Lower	Upper	Middle	Lower
Depth (m)		1.3	2.6	1.5	1	1.9	1.9
Temp. (°C)	S	22.07	21.74	20.55	27.56	27.24	27.19
	B	21.66	21.46	21.04	27.57	27.27	27.2
Turbidity (NTU)	S	6.86	6.39	5.43	176.6	170.1	164.6
	B	5.77	7.43	5.44	154.5	161.1	175.5
Oxygen (mg/l)	S	5.07	5.4	5.67	6.75	6.94	6.76
	B	5.08	5.31	5.42	6.76	7.21	6.79
Salinity (ppt)	S	4.6	8.8	13.5	0.1	0.1	0.1
	B	31.9	35.8	34.2	0.1	0.1	0.1
pH	S	7.73	7.73	7.78	7.81	7.95	7.87
	B	7.84	7.89	7.88	7.81	7.95	7.88

Fig 3.1 Taxa recorded at three sampling stations in the Thukela estuary during low flow conditions

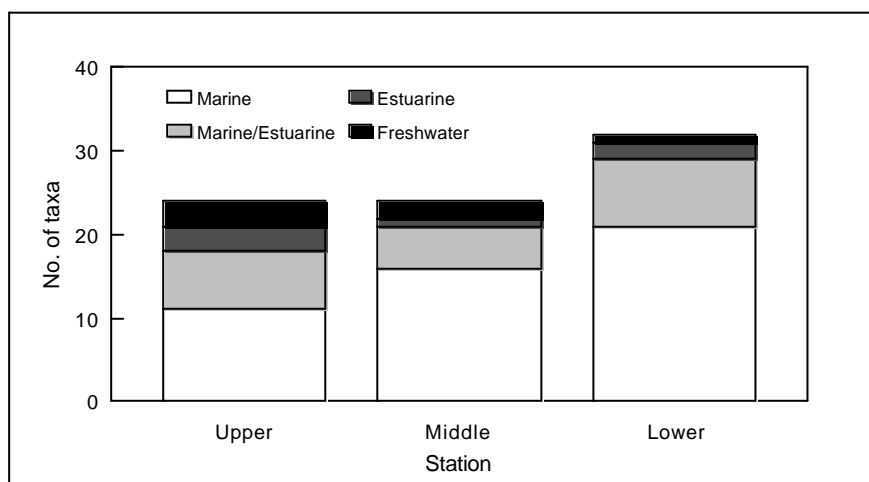


Table 3.2 Abundance (average numbers.m⁻³) of zooplankton taxa recorded from sampling stations in the upper, middle and lower reaches of the Thukela estuary during high and low river flow conditions. M = marine, M/E = marine/estuarine, F = freshwater

	Type	Low Flow			High Flow		
		Upper	Middle	Lower	Upper	Middle	Lower
Cnidaria	M		0.5	7.3			
Polychaeta							
Polychaete larvae	M/E	0.8	1.6	37.3			
Unidentified polychaetes	M/E	0.8	0.2	6.2			
Oligochaeta	F	17.4	0.8		2.4	0.4	
Cladocera							
Pseudevadne sp.	M	3.3	39.2	373.5			
Daphnidae.	F	0.8			1.0	0.4	
Copepoda							
Calanoida							
Acartia natalensis	E	15.0	18.0	33.2			
<i>Acartia</i> sp			2.5				
Calanida unidentified	M	0.1	2.6	114.8			
<i>Clausocalanus</i> sp.	M	5.1	23.7	591.3			
<i>Centropages</i> sp	M			6.2			
<i>Eucalanus</i> sp.	M	1.0	1.6	42.9			
<i>Euchaeta</i> sp.	M		1.5	44.3			
Paracalanidae	M/E	34.4	100.6	809.2			
Pontellidae	M			7.3			
Pseudodiaptomus hessei	E	3.2					
<i>P.nudus</i>	M		1.6	41.5			
<i>Temora stylifera</i>	M	0.1	0.2	4.3			
<i>Temora turbinata</i>	M	0.5	3.7	400.4			
<i>Tropodiaptomus</i> sp.	F				0.4		
Poecilostomatoida							
<i>Sapphirina</i> sp.	M		0.2	4.1			
Oncaeidae	M	5.5	29.4	788.4			
Corycaeidae	M	19.0	71.1	1504.3			
Cyclopoida							
<i>Halicyclops</i> sp.	E	2.4					
<i>Oithona</i> sp. copepodites	M/E	30.0	50.7	269.7			
<i>Mesocyclops</i> sp.	F	0.8					
Unidentified freshwater cyclopoid	F				0.4	1.4	
Harpacticoida							
Unid. harpacticoids		25.3	7.4	31.1			
<i>Peltidium</i> sp.	E			0.1			
<i>Macrosetella</i> sp.	M	4.7	0.8	41.5			
Unidentified copepodites		58.5	123.5	643.2			
Copepod nauplii		12.3	22.1	114.1			
Cirripedia							
Nauplii	M/E	28.5	54.8	207.5			
Cyprid larvae	M/E	0.8		300.9			
Mysidacea							
<i>Gastrosaccus</i> spp.	M/E	0.9		1.3			
Tanaidacea		0.1					
Isopoda							
<i>Cirolana</i> sp.	M/E			0.1			
Amphipoda							
Unidentified amphipods			0.2	7.3			

	Type	Low Flow			High Flow		
		Upper	Middle	Lower	Upper	Middle	Lower
Hyperideia	M	0.1	0.2	2.3			
Decapoda							
<i>Lucifer spp.</i>	M			1.2			
Megalopa		0.2	0.2	1.1			
Penaeid larvae		0.1	0.4	9.3			
Carid larvae		0.2	0.6	7.3	15.1	19.6	15.1
<i>Upogebia sp.</i> decapodids		5.0	1.1	5.2			
Brachyuran zoea		0.1	0.9	23.5	1.0		
Mollusca							
Pteropods	M			5.2			
Mollusc larvae		4.7	12.3	321.6			
Unidentified insect larvae	F	0.2	0.4	1.0	19.8	8.7	15.9
Cyphonautes larvae	M		4.9	45.6			
Chaetognaths	M	7.9	8.2	30.1			
Larvacea (Appendicularia)	M			0.2			
Fish eggs		20.6	8.2	211.6			
Fish larvae		0.4	0.2	0.5			2.0

Abundances were, overall, slightly higher but still within one order of magnitude of that recorded in the Mhlathuze estuary for the same month (August) (Jerling 1998/1999, unpublished data). In general zooplankton densities show strong seasonal fluctuations and in the Mhlathuze the August samples still reflect relatively low winter abundances, which, for some taxa, increase substantially during spring. If, however, river inflow increases dramatically, as is often the case with the Thukela, the community would instead be decimated.

During the August sampling typical estuarine species such as the calanoids *Pseudodiaptomus hessei* and *Acartia natalensis* were present but in low numbers. *P. hessei* was only recorded at the upper station. *A. natalensis* were recorded at all three stations but in much lower densities than in systems with healthy estuarine zooplankton communities (Jerling and Wooldridge 1995). It is also possible that a true estuarine community occurred higher up in the Thukela, above the present upper sampling station, during low flow conditions.

A few freshwater species such as insect larvae, a daphnid cladoceran and the cyclopoid *Mesocyclops* were recorded, mostly at the upper station. These plankters were probably associated with freshwater flowing in over the salt wedge as indicated by the vertical salinity stratification measured at all three stations during August (Table 3.1).

The high flow sampling session coincided with the tail-end of a flooding event and it comes as no surprise that very few zooplankters were recorded. Some carid and insect larvae (mostly chironimids, black flies and baetids) were recorded (Table 3.2). Samples collected during high flow were also loaded with fluvial detritus. High flow conditions were probably the norm in the past and also the reason why Grindley, based on samples collected during the 1960's, referred to the zooplankton of the Thukela as "barren" (Begg 1978). Under these conditions the estuarine community would probably be situated offshore, if occurring at all.

Noteworthy is the presence of carid larvae during the high flow conditions. Although not yet classified with absolute certainty all indications are that the larvae are that of the freshwater prawn *Macrobrachium*. An interesting aspect of their live cycle and one that is of relevance is that larvae of these prawns need salinities of between 8 and 20 ppt, depending on the species, to complete their development (Bickerton 1989).

3.1 NATIONAL AND REGIONAL IMPORTANCE

As a river mouth the zooplankton community of the Thukela is probably almost non-existent for large parts of the year. Even during low flow conditions, on a national scale, the zooplankton densities of the Thukela are impoverished. By comparison, e.g., the dominant calanoids in the Sundays estuary often exceeded densities of 10000m^{-3} and sometimes reached numbers above 100000m^{-3} (Jerling and Wooldridge 1995). The dominant copepods in the Thukela estuary barely reached densities of 1000m^{-3} . As secondary producers in the water column of estuaries, the zooplankton supports many juvenile and adult fish species. A lower zooplankton stock density would thus also support a lower zooplanktivorous fish stock.

3.2 CURRENT FORCING FACTORS

The most important physical factor influencing the zooplankton community in the Thukela is the high river flow. This prevents the establishment of any proper estuarine plankton community.

3.3 FUTURE IMPACTS

A reduction in freshwater inflow would probably enhance conditions for the establishment of a zooplankton community in the estuary. Depending on the level and duration of flow reduction as well as water quality such a community could consist of anything between marine dominated, estuarine or even freshwater assemblages. The latter would only occur if the mouth remains closed for prolonged periods and the system eventually turns fresh.

3.4 CURRENT DATA GAPS

As a system that is presumably lacking a proper zooplankton community during its natural high flow state the relevance of filling current data gaps for this specific estuary may be debatable. However, with reference to future flow reductions the gaps in our knowledge of the flow requirements of potential zooplankton communities in the Thukela estuary are largely common problems applicable to all our estuaries. Critical gaps exist in our knowledge of the taxonomy, biology and ecology of our estuarine zooplankton. For example, positive, routine identification of many of our estuarine meroplankton is not possible. We still have little knowledge of their biological and ecological functioning or their requirements in terms of chemo-physical conditions. What would the correct timing be, in terms of zooplankton requirements, for water releases simulating flood events? We will only be able to answer these types of questions once we have an understanding of the biology and ecology of the organisms using the estuary, either as a permanent residence, a nursery area or a passage to freshwater or marine systems.

Other important gaps are related to proper scientific investigations and long term monitoring. We are dealing with systems that not only undergo medium term seasonal fluctuations but also longer-term wet and dry cycles. This study, which is based on only two sampling sessions, illustrates this point. The bottom line is that we have insufficient data to make any conclusive inferences with sufficient confidence.

4 REFERENCES

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1 INTRODUCTION

Estuaries have been shown to be important ecosystems because they provide shelter and nursery grounds to many species of commercial importance. They also form an important link between the riverine and marine environments. However, increased human activities such as river impoundment, agriculture activities, sewage disposal and interbasin transfer pose some threat to estuaries through their effects on biota and water quality. A review of the status of South African estuaries has shown that there is deterioration in estuaries with regard to their function as nursery grounds for many marine fish and invertebrate species (Forbes, Demetriades and Cyrus 1996). This deterioration has resulted from increased sedimentation, dredging, and industrial and agricultural pollution (Forbes, Demetriades and Cyrus 1996).

The Thukela Estuary is classified by Begg (1978) as a river mouth because during high flows the estuary becomes fresh to sea and mixing happens offshore (Day 1981). During long period of drought, sandbars develop in the Thukela Estuary mouth, resulting in the constriction in the tidal inlet. As a result the connection between the estuary and the sea becomes disturbed (or less efficient). However, during wet season river floods erode sediment that have accumulated and helps to maintain the estuary mouth open. The proposed damming of the Thukela Estuary would result in reduced discharge that might change the natural behaviour of this system. This study investigates the present status of the macrocrustaceans and possible impacts of reduced freshwater discharge on the macrocrustaceans of the Thukela Estuary. This includes determining species composition, species abundant, diversity and changes in community structure with special attention given to the low flow and high flow in the estuary.

Very limited information is available on the macrocrustaceans especially penaeid prawns and *Macrobrachium* species in the Thukela Estuary. Studies conducted on the east coast of KwaZulu-Natal include a report on the biology of the *Macrobrachium* spp. of the St. Lucia estuary (Bickerton 1989), records of *Macrobrachium* spp from the lake Cubhu (Schoonbee et al 1989) and St. Lucia and Richards Bay penaeid prawns (Forbes and Benfield 1985, Fielding et al. 1990). All these studies have demonstrated the importance of these estuaries as nursery areas and breeding grounds for many decapod shrimps.

2 METHODS

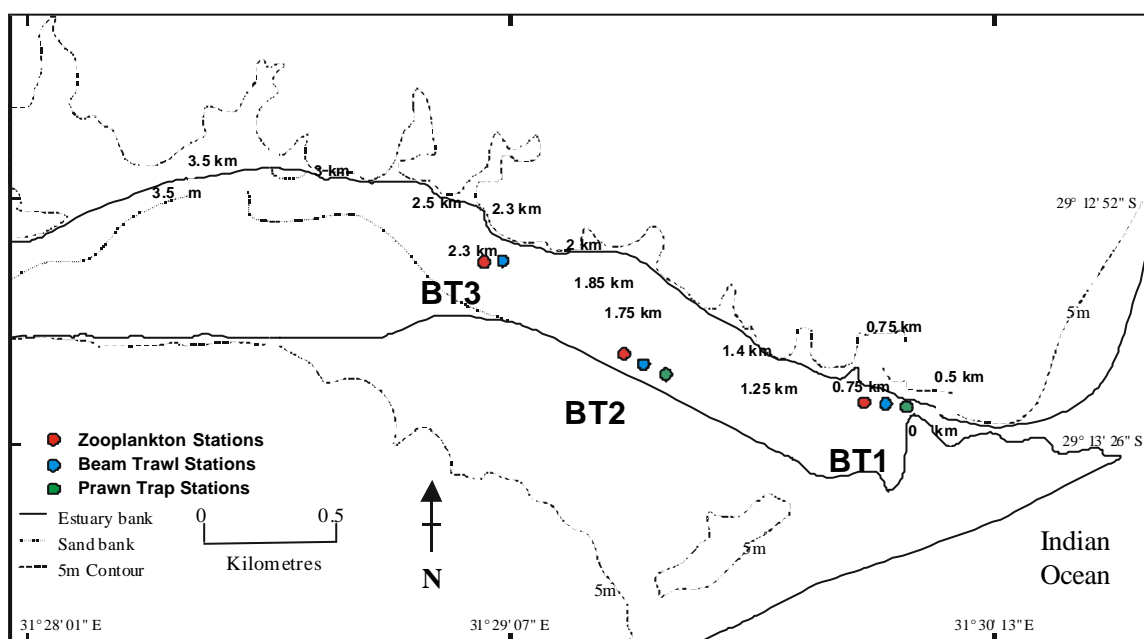
2.1 SAMPLING SITES

Macrocrustacean sampling sites are shown in Figure 2.1. Beam trawl sampling sites (BT1-BT3) represented the lower, middle upper reaches of the estuary. Prawn traps were only deployed at two of the beam trawl sampling sites (BT2 & BT3).

2.2 SAMPLING METHODS

The macrocrustacea survey was conducted in the estuary during both high and low tides in winter (August 2001 - period of low flow) and summer (February 2002-period of high flow). Macrocrustaceans were sampled at three sites (BT1, BT2 and BT3 in Figure 2.1) using beam trawl technique and at two sites (BT2 and BT3) using fish baited prawn traps. At each sampling site beam trawling and overnight trapping were conducted ensuring that the same habitat was sampled by each of the two techniques. During each sampling the trawled distance and trawling time for the beam trawling technique and the time of deploying and taking out of traps were noted. Prawn traps were deployed at Site 2 and 3, with seven traps being put at each site. Samples were preserved on site with 4 % formaldehyde and brought to the laboratory for identification and counting. Visual observations of sampling sites were made to determine the habitat preference of species collected. In addition, physico-chemical variables such as salinity, temperature, pH, conductivity, TDS and dissolved oxygen were measure *in situ* using the Multiprobe Hydrolab Datasonde. Turbidities were measured in the laboratory using a Hatch turbidimeter.

Fig 2.1 Beam Trawl and Prawn Trap sampling stations relative to Zooplankton stations in the upper (U), middle (M) and lower (L) Thukela Estuary



In the laboratory, specimens were identified to the lowest possible taxon with the aid of keys by Barnard (1950), Kensley (1972), Day (1969) and following description provided by Bickerton 1989, measured and their sex identified. A representative (reference) collection of the penaeid prawns were provided to Mr HFB Champion, with *Macrobrachium* spp obtained will be provided to Professor LB Holthuis for confirmation of the species. Beam trawl catches were expressed as numbers per 100 m² of trawled distance. Prawn trap catches were express as catch per unit effort (CPUE) in terms of numbers in a prawn trap per hour. Biotic and physico-chemical data were subjected to multivariate and univariate statistical analyses using the PRIMER software package. Hierarchical clustering (Bray-Curtis similarity)

was performed on double square root transformed biotic data. Indicator and discriminating species of sample groups obtained from these analyses were determined using the SIMPER routine. Correlation between biota and physico-chemical variables was determined using BIOENV procedure to investigate which of physico-chemical variables was influential in structuring the community. Diversity (Margalef's species richness and Shannon-Wiener diversity) indices based on \log_e were calculated using PRIMER software and mean (± 1 standard error) plotted for each index. Significance of any difference between flows, tides and sampling sites was determined using ANOSIM, Tukey's One-way ANOVA and two-sample t-test at 95% significant level where appropriate.

3 RESULTS AND DISCUSSION

3.1 BEAM TRAWLS

A total of nine taxa were collected including four *Macrobrachium* spp. (*Macrobrachium equidens*, *M. lepidactylus*, *M. rude*, *Macrobrachium* sp.), a sesamid crab, three penaeid prawn species (*Penaeus japonicus*, *P. canaliculatus* and *Metapenaeus monoceros*) and the mudprawn *Upogebia capensis* (Table 3.1). Macrocrustaceans collected during the low flow period included both juvenile males and females (3-15 mm CL) of species *P. japonicus*, *M. monoceros*, *U. capensis*, *P. canaliculatus*, *Sesarma* sp. and *Macrobrachium rude*. Beam trawl catches were dominated by *P. japonicus* at sites BT2 and BT3. No animals were caught at site BT1. However, during the high flow taxa the highest density was recorded at site BT1 by *M. equidens*.

Table 3.1 Mean densities (ind/100m²) of macroinvertebrate taxa collected in the Thukela Estuary during low (August 2001) and high (February 2002) flows at sites BT1-BT3

	Low flow			High flow		
	BT1	BT2	BT3	BT1	BT2	BT3
<i>Penaeus japonicus</i>		0.64	0.6			
<i>Metapenaeus monoceros</i>		0.032	0.77			
<i>Upogebia capensis</i>			0.43			
<i>Penaeus canaliculatus</i>			0.07			
<i>Sesarma</i> sp.		0.032	0.07			
<i>Macrobrachium rude</i>			0.03			
<i>Macrobrachium equidens</i>				0.65	0.16	
<i>Macrobrachium lepidactylus</i>					0.16	
<i>Macrobrachium</i> sp. (Juvenile)				0.15	0.16	

Differences in macrocrustacean abundance was statistically analysed using a two sample t-test for differences in mean densities during low and high flow. No significant difference was recorded ($p>0.05$). Differences between sampling sites were also tested using One-way ANOVA. Significant differences were only recorded between sites 'no catch' and 'catch' sites.

3.1.1 Macrocrustacean Community Structure

Temporal and spatial changes in macrocrustacean community structure are shown in Table 3.1 and Figure 3.1. Hierarchical clustering revealed three distinct macrocrustacean assemblages at a similarity level of 55% based high and low flows. Further analysis showed that these groups were divided into subgroups at 25%. This separation was due to the state of tide at the time of sampling (ebb or flood) (Figure 3.1). However, results from analysis of similarities (ANOSIM) between flows ($R=1$; $p=0.333$), tides ($R=-0.063$; $p=0.556$) and sampling sites ($R=0.125$; $p=0.156$) indicated that there were no significant differences between these catches.

Group 1 includes samples collected during high flow (February 2002). Samples in this group were from Sites BT1 and BT2 during high and low tides. The high flow assemblage was divided into two groups (Group 1a and 1b). Group1a occurred mainly at Site BT1 during high tide and at Site BT2 during high and low tides. This group was, however, dominated by samples collected during the high tide. The high flow assemblage was characterised by the presence of *M. equidens*, *M. lepidactylus* and *Macrobrachium* sp. Another group of samples was identified during the high flow survey at Site BT1 and BT2 at low and high tides, and included species separated based on low density (one individual of *M. lepidactylus*).

During the low flow conditions (August 2001), the assemblage depicted by Group 3 was restricted to Sites BT2 and BT3. This group was further being divided into two subgroups. Group 3a included macrocrustacea from Sites BT2 and BT3 during low tide and high tide, and Group 3b included macrocrustacea from Sites BT2 and BT3 during the low tide only. The low flow assemblage was primarily dominated by *P. japonicus*, *M. monoceros*, *Sesarma* sp., *P. canaliculatus* and *Upogebia capensis*.

SIMPER analysis (calculation of similarity percentages for samples that are spatially or temporally separated) also showed that the low flow and high flow faunal assemblages were 100% dissimilar. The difference between these assemblages was due to the fact that taxa such as *P. japonicus*, *M. monoceros*, *Sesarma* sp., *P. canaliculatus* and *U. capensis* were recorded during the low flow only. *Macrobrachium equidens*, *M. lepidactylus*, and *Macrobrachium* sp. were recorded during the high flow period (Table 3.2).

Table 3.2 Average abundance of macrocrustaceans collected by beam trawl

	Low flow	High flow
<i>Penaeus japonicus</i>	6.21	
<i>Macrobrachium equidens</i>		3.60
<i>Metapenaeus monoceros</i>	3.99	
<i>Macrobrachium lepidactylus</i>		0.82
<i>Macrobrachium</i> sp.		1.56
<i>Sesarma</i> sp.	0.49	
<i>Penaeus canaliculatus</i>	0.33	
<i>Upogebia capensis</i>	2.17	

Diversities (mean±1SE) reflect variations in the beam trawl community with regard to flow and sites (Figure 3.2 a - d). During low flow, diversities increased between Sites BT1 and BT3 reflecting an increased number of species from 0 at Site BT1 to 6 at Site BT3. Densities also followed a similar increase between Sites BT1 and BT3. During high flow diversities changed slightly at Sites BT1 and BT2 followed by a remarkable decline at Site BT3. At Site BT3 no macrocrustaceans were recorded. Diversities during high flow reflect a relatively stable community at Site BT1 and BT2, but with densities being decreased between Site BT1 and BT3. The higher densities recorded during low flow are due to relatively high numbers of *P. japonicus*, *M. monoceros* and *U. capensis*.

It is well known that penaeid prawns migrate to breed offshore and return as post larvae to inshore and estuary nursery areas where larval development takes place. In estuaries, post larvae grow rapidly to juveniles, which again grow to become large enough to migrate to the sea (de Freitas 1984). The occurrence of juvenile forms of *P. japonicus* and *M. monoceros* mainly at Site BT1 (near the mouth) is believed to be due to their eminent migration out to sea (offshore) where they grow to adults. The genus *Macrobrachium* was poorly represented during the low flow (*M. rude* single record or one individual) compared with three species recorded during high flow (*M. equidens*, *M. lepidactylus* and *Macrobrachium* sp.). *Macrobrachium* species were present mainly as gravid females and juveniles in the lower reaches of the estuary (Site BT1 and BT2). The presence of gravid females and juveniles of *M. equidens* and *M. lepidactylus* indicated the low salinity conditions and high freshwater inflow into to the estuary.

Physico-chemical variables such as temperature, salinity and rainfall play an important role in the distribution and providing suitable conditions for larval development. High temperatures have stimulatory effects on *Macrobrachium* species and act a cue for initiation of the reproduction cycle of some *Macrobrachium* species (Bickerton 1989). Rainfall reduces salinity and results in suitable conditions for larval development. Bickerton (1989) suggests

that species such as *M. rude* use floods to be washed downstream prior to the breeding season. During this study, the relationship between macroinvertebrate community and physico-chemical variables was investigated as stated in the methods section. The physico-chemical variables such as turbidity (NTU), conductivity (mS/cm) and TDS (g/l) were most influential in shaping the macrocrustacean community structure in the Thukela Estuary, with a maximum Weighted Spearman's correlation (ρ_w) of 0.726 being obtained. Both conductivity and TDS were very low during the high flow, whilst turbidity levels were very high (Table 3.3). The two flow conditions were characterised by different physico-chemical conditions and thus different communities. Low flow was typified by estuarine taxa such as *P. japonicus*, *P. canaliculatus*, *U. capensis* and high flow typified by freshwater/brackish water species such as *M. equidens*, *M. lepidactylus*, *Macrobrachium* sp. (juvenile) and the presence of insect larvae.

Table 3.3 Ranges of physico-chemical variables measured at Sites BT1-3 during low flow (August 2001) and high flow (February 2002)

	Low flow	High flow
Temperature (°C)	20.06-21.66	26.97-27.57
Turbidity (NTU)	4.45-9.82	122.3-161.1
Oxygen (mg/l)	5.06-6.22	6.76-7.21
Oxygen (%)	60.3-83.2	86.2-92.3
Conductivity (mS/cm)	10.63-54.2	0.152-0.161
Salinity (ppt)	6.8-35.9	0.1
TDS (g/l)	6.5-33.9	0.083-0.1
pH	7.5-7.86	7.79-7.95

3.2 PRAWN TRAPS

Table 3.4 shows changes in the macrocrustacea community structure and CPUE recorded during this study using prawn traps. Seven macrocrustacea taxa were collected these were dominated by three species of the genus *Macrobrachium*. These species included *Macrobrachium rude* (dominated by males), *M. equidens* and *M. scabriculum* in order of importance. Adult gravid females dominated both *M. equidens* and *M. scabriculum* mainly during high flow (summer). Juveniles were identified to genus level only. Other macrocrustaceans taxa recorded include *Macrobrachium idae*, *Macrobrachium* sp.1 and *Varuna litterata*. Highest numbers of macrocrustacea were sampled during summer (high flow) at Sites BT2 and BT3, with *M. equidens* recorded during low flow period at Site BT2 only.

Table 3.4 CPUE of macrocrustaceans collected using prawn traps during low flow (August 2001) and high flow (February 2002) at Sites BT1-3

Flow	Site	No. prawn traps	Taxa	Count	Gravid females	Carapace range (mm)	CPUE	Total per site	Total per flow
Low flow	2	7	<i>Macrobrachium equidens</i>	1		15	0.01	0.01	0.01
	3	7		0			0		
High flow	2	7	<i>Macrobrachium scabriculum</i>	15	present	11-24	0.15	0.42	0.96
			<i>Varuna litterata</i>	6		11-27	0.06		
			<i>Macrobrachium rude</i>	13		22-26	0.13		
			<i>Macrobrachium</i> sp.1	1		30	0.01		
			<i>Macrobrachium idae</i>	1		22	0.01		
	3	7	<i>Macrobrachium equidens</i>	6	present	12-22	0.06	0.54	
			<i>Varuna litterata</i>	4		15-25	0.06		
			<i>Macrobrachium lepidactylus</i>	2		30-34	0.03		
			<i>Macrobrachium rude</i>	18	present	21-25	0.25		
			<i>Macrobrachium equidens</i>	10	present	14-20	0.14		
			<i>Macrobrachium</i> sp.	4		5-9	0.06		

Since the reproduction success of the genus *Macrobrachium* depends on the availability of conditions suitable for larval and juvenile development (Rajyalakshmi 1980: in Bickerton 1989), migration of adults to the estuary for breeding coincides with periods of high water temperatures and the wet season (Bickerton 1989). The increased CPUE of *Macrobrachium* species in the Thukela Estuary in summer can be explained by such migrations. In addition, salinity levels during high flow were very low (0.1 ppt) accompanied by high turbidities indicating the increased inflow of freshwater. *Macrobrachium* species such as *M. rude* depend on floods for their migration. Floods wash them downstream to areas where salinity would be favourable for larval development (Bickerton 1989). During this study, increased flow of water also played a role in the increased CPUE in summer. However, low CPUE recorded during low flow is attributed to high salinities (34-35.9 ppt) and low temperatures measured in the estuary, resulting in unsuitable conditions for larval development.

3.3 MACROCRUSTACEANS IN THE THUKELA ESTUARY

3.3.1 Penaeid prawns

Most penaeid prawn species migrate to spawn offshore, followed by post larval migration to inshore areas and estuarine waters to utilize these habitats as nursery areas. After a period of approximately six months of development penaeid prawn species (as juveniles) migrate offshore again where maturation and spawning takes place. In the southern African east coast, penaeid prawns form a valuable crustacean resource trawled on the Thukela Banks and off St. Lucia (de Freitas 1989). This resource consists of five main species, namely the white prawn *Penaeus indicus*, the tiger prawn *P. monodon*, the zebra prawn *P. semisucaltus*, the bamboo prawn *P. japonicus* and the brown prawn *Metapenaeus monoceros*. During the study the penaeid prawn species recorded included *P. japonicus*, *M. monoceros* and *P. canaliculatus*. These species were mainly dominated by *P. japonicus*, which was also abundant in the beam trawls during the low flow period.

3.3.2 *Penaeus japonicus* and *Penaeus canaliculatus*

According to Day 1981, *Penaeus japonicus* and *P. canaliculatus* are endemic to Indo-West Pacific marine waters. *Penaeus japonicus* is nocturnally active, and prefers sandy mud and often lies half buried on sheltered sandbanks. It has been reported to utilize Richards Bay harbour as a nursery area. During this study, *P. japonicus* juveniles were recorded in winter (low flow) at Sites BT2 and BT3 close to the estuary mouth and were found to prefer muddy substrates where there are reeds and sedges. *Penaeus canaliculatus* is usually netted on sand banks in estuaries (Day 1981) and was recorded in the fine sand substratum in the Thukela Estuary (this study).

3.3.3 *Metapenaeus monoceros*

Metapenaeus monoceros is endemic to Indo-West Pacific marine waters and has been reported to be common at low salinities (de Freitas 1980). It was recorded in high numbers on the Thukela Banks between May 1976 and April 1977 due to low salinity conditions (de Freitas 1980). Juveniles of this species are distributed in estuaries and sheltered bays (Day 1981). In the Thukela Estuary (this study) *M. monoceros* was found in similar substrates to *P. japonicus* and *P. canaliculatus*.

3.3.4 *Macrobrachium* spp.

Macrobrachium species prefer a variety of habitat conditions ranging from freshwater to brackish and can be categorised into two ecological groups (Bickerton 1989). These groups include continental species with life cycles completed in freshwater and species that require an estuarine or marine habitat for development (Bickerton 1989). The species recorded during this study were mainly those that require an estuarine or marine habitat for larval development. Adults of the *Macrobrachium* species that require brackish water for larval development migrate to the estuarine environment to breed. In southern Africa, *Macrobrachium* species have been shown to utilize estuaries as both nursery and habitat environments. The following *Macrobrachium* species were recorded in the Thukela Estuary: *M. equidens*, *M. Lepidactylus*, *M. scabriculum*, *M. rude* and *M. idea*, and were mainly dominated by *M. rude* and *M. equidens*. *Macrobrachium* species such as *M. rude*, *M. lepidactylus* and *M. scabriculum* enter estuaries to breed when salinities are suitably low, usually after summer floods in KwaZulu-Natal (Bickerton 1989) which corresponded with high numbers of *Macrobrachium* species being caught during the period of high flow (summer) in the Thukela Estuary (this study).

3.4 THE IMPORTANCE OF THE THUKELA ESTUARY FOR MACROCRUSTACEANS

In southern Africa, estuaries, bays, lagoons and harbours have been shown to be important nursery areas and breeding habitats for many invertebrate species. Marine, freshwater and estuarine invertebrate species such as penaeid prawns, caridean shrimps and sesarmid crabs require estuarine environmental conditions for larval development. Adults of these species migrate to spawn at sea (offshore) and return as post larvae to the estuary to make use of food resources and conditions provided by this environment. This is followed by emigration offshore as juveniles or sub-adults. Most caridean shrimps migrate from freshwater to estuarine environment to breed and larval development takes place there followed by the return to freshwater by juveniles.

Along the southern African east coast, estuaries are very important for penaeids that constitute a valuable crustacean resource mainly at Thukela and St. Lucia Banks. KwaZulu-Natal estuaries have also been shown to be important penaeid habitats, particularly at St. Lucia and Richards Bay. These two estuaries are reported to be the main source of the

penaeid fisheries for the Thukela Banks (Forbes and Benfield 1985). The importance of the Thukela Estuary for the penaeids and *Macrobrachium* species has not been historically reported in the literature. However, many penaeid prawns of commercial importance such as *Penaeus japonicus*, *Metapenaeus monoceros* and *P canaliculutus* and *Macrobrachium* species have been recorded in the lower reaches of the Thukela Estuary (this study). This perhaps indicates that the Thukela Estuary could serve as an important nursery area for penaeid prawns and both nursery and spawning habitat for *Macrobrachium* species. However, this remains speculative as the current study did not provide sufficient data to corroborate this idea.

3.5 POSSIBLE IMPACTS OF FRESHWATER REDUCTION ON MACROCRUSTACEAN SPECIES

Salinity has been shown to be the most important factor in the larval development of many *Macrobrachium* species (Cort 1983). High salinities in the estuary might reduce the immigration of *Macrobrachium* spp. into the estuary. Reduced freshwater inflow can also cause the formation of sandbars, causing the closure of the mouth. Larva and post larva of species such as *Varuna* spp. and penaeid prawns would not be able to migrate into the estuary. Since the *Macrobrachium* spp. of south east Africa move between freshwater, rivers and swamps and estuarine and brackish habitats, it is important that this migration is not hindered (Bickerton 1989). The maintenance of these prawns depends on recruitment of juveniles from saline breeding and nursery areas, and permanent exclusion of the critical stages of the reproductive cycle from such areas by natural or man-made obstructions, will result in localized extinction of this species (Bickerton 1989).

Fig 3.1 Bray Curtis Dendrogram of Macrocrustaceans sampled at Sires BT1-3 during low (August 2001) and high flow (February 2002). Symbols: LF= low flow, HF= high flow, 1-3 sites, = low tide, h= high tide

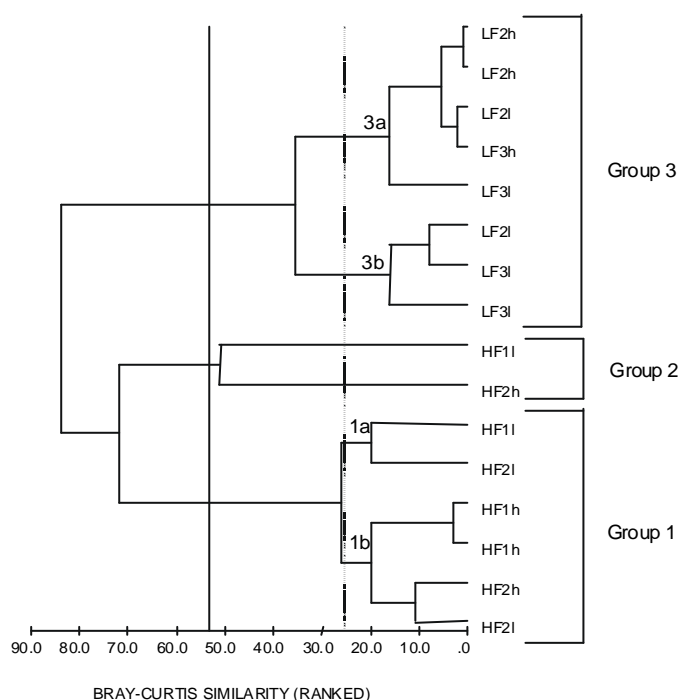
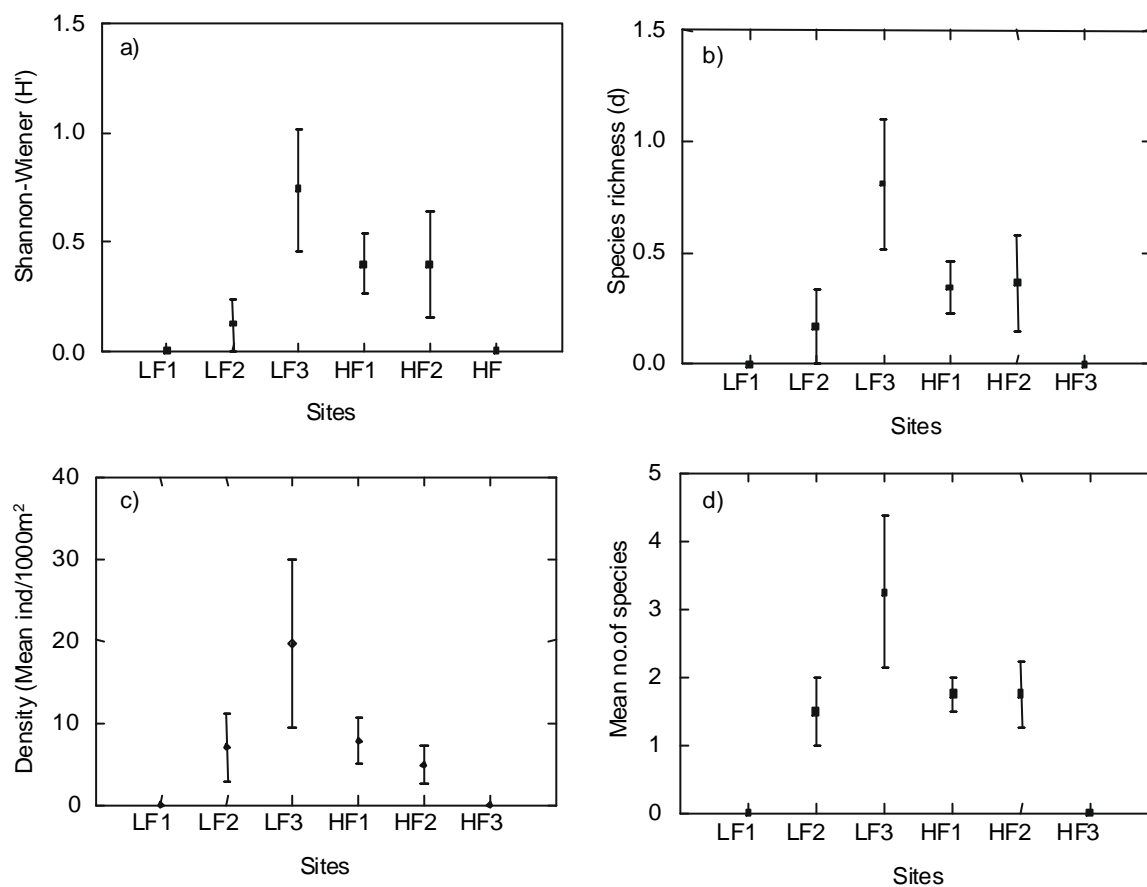


Fig 3.2 Diversity Indices (mean + 1 standard error) for Macrocrustaceans sampled at Sires BT1-3 during low (August 2001) and high flow (February 2002). Symbols: LF= low flow, HF= high flow, 1-3 sites



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1 APPENDIX A: MACROINVERTEBRATES

1.1 APPENDIX A1: MACROINVERTEBRATE ABUNDANCE APRIL 1997 – MARCH 1998

No	Species	1997									1998		
		Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1	Cnidarian sp. T1	8	0	0	0	0	0	0	0	0	0	0	0
2	Cnidarian sp. T2	8	0	0	0	0	0	0	0	0	0	0	0
3	Cnidarian sp. T3	0	0	0	0	0	0	0	8	0	0	0	0
4	Porifera sp. T1	8	0	0	0	0	0	0	0	0	0	0	0
5	Planaria sp. T1	0	0	0	0	0	0	0	8	0	0	0	0
6	Nemertea sp. T1	0	0	0	17	0	0	17	0	0	0	0	0
7	Nemertea sp. T2	0	0	0	8	0	0	0	0	0	0	0	0
8	Nematode sp. T1	0	0	8	0	0	8	0	0	0	0	0	0
9	Nematode sp. T2	0	0	0	0	21	17	0	0	50	17	0	0
10	Nematode sp. T3	0	0	0	0	11	50	0	0	0	25	0	0
11	Nematode sp. T4	0	0	0	0	8	0	0	0	0	0	0	0
12	Nematode sp. T5	0	0	0	0	0	17	0	0	0	0	0	0
13	Oligochaete spp.	987	2089	1222	3606	11770	2060	1754	902	5743	3053	4692	5755
14	Polychaete sp. T1	0	0	25	0	0	0	0	0	0	0	0	0
15	Neridae sp. T1	8	0	0	0	0	0	0	0	0	0	0	0
16	Ceratonereis keiskamma	0	8	0	0	11	0	101	17	118	0	8	8
17	Dendronereis arborifera	0	0	0	0	0	0	0	0	0	0	0	0
18	Prionospio pinnata	0	0	0	0	11	0	0	0	0	8	0	0
19	Prionospio sexoculata	0	0	0	0	0	0	0	0	8	0	0	0
20	Capitella capitata	0	0	0	0	0	0	0	0	8	0	0	0
21	Scolecopsis squamata	0	0	0	0	0	0	8	0	0	0	0	0
22	Desdemona ornata	0	59	25	101	61	25	0	0	0	0	0	8
23	Sabella fusca	0	0	0	0	0	0	0	0	8	0	0	0
24	Ostracod sp. T1	0	0	0	0	0	0	0	0	0	0	0	0
25	Ostracod sp. T2	0	0	0	0	0	25	0	0	0	0	0	0
26	Cladocera sp. T1	8	0	0	0	0	0	0	0	0	0	0	0
27	Cladocera sp. T2	0	0	0	0	0	8	0	0	0	8	0	0
28	Cladocera sp. T3	0	0	0	0	0	0	0	0	0	0	0	0
29	Argulus sp. T1	0	0	0	0	0	0	8	0	0	0	0	0
30	Argulus sp. T2	0	0	0	0	0	0	8	0	0	0	0	0
31	Copepod sp. T1	0	0	8	8	0	0	0	0	0	0	0	0
32	Copepod sp. T2	0	0	0	8	0	8	0	0	0	0	0	0
33	Copepod sp. T3	0	0	0	8	0	0	8	0	0	0	0	0
34	Copepod sp. T4	0	0	0	17	0	0	0	0	0	0	0	0
35	Calanoidea sp. T1	0	0	0	17	0	17	0	0	0	0	0	0
36	Calanoidea sp. T2	0	0	0	8	0	8	0	0	0	0	0	0
37	Cyclopoidea sp. T1	0	0	0	8	0	0	8	0	0	0	0	0
38	Cyclopoidea sp. T2	0	0	0	0	0	25	0	8	0	0	0	0
39	Gammarid sp. T1	0	0	0	0	8	0	0	8	0	0	0	0
40	Grandidierella sp. T1	0	0	0	0	0	17	34	0	17	0	8	0
41	Corophium triaenonyx	0	8	0	0	0	0	0	8	17	8	8	17
42	Isopod sp. T1	0	0	0	0	0	34	0	0	0	0	0	0
43	Isopod sp. T2	0	0	0	0	0	8	0	0	0	0	0	0
44	Excirrollana natalensis	277	437	403	76	176	109	92	311	92	8	0	42
45	Leptanthura laevigata	0	0	0	0	0	0	0	0	8	0	0	0
46	Taenaid sp. T1	0	0	0	0	0	0	0	0	0	19	0	8

No	Species	1997									1998		
		Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
47	Taenaid sp. T2	0	0	0	0	0	0	0	0	0	8	0	0
48	Apseudes digitalis	0	0	0	0	8	0	0	0	0	0	0	0
49	Iphinoe sp. T1	0	0	0	0	0	0	0	0	8	0	0	0
50	Gastrosaccus longifissura	0	218	67	176	0	0	101	344	0	0	0	0
51	Mesopodopsis africanus	0	8	0	0	0	0	50	0	0	0	0	0
52	Penaeid sp. post larva T1	8	0	0	0	0	0	0	0	0	0	437	42
53	Prawn post larva T2	0	8	0	0	0	0	0	0	0	0	0	0
54	Prawn post larva T3	0	0	0	0	0	0	0	0	0	0	0	0
55	Prawn post larva T4	0	0	0	0	0	8	0	0	0	0	0	0
56	Prawn post larva T5	0	0	0	0	0	8	17	0	17	0	0	0
57	Prawn post larva T6	0	0	0	0	0	0	0	0	101	8	0	0
58	Prawn post larva T7	0	0	0	0	0	0	0	0	0	25	0	8
59	Prawn post larva T8	0	0	0	0	0	0	0	0	0	0	0	42
60	Prawn post larva T9	0	0	0	0	0	0	0	0	0	0	0	8
61	Prawn post larva T10	0	0	0	0	0	0	0	0	8	0	0	0
62	Carid sp. T1	17	210	0	0	0	0	0	0	0	0	17	521
63	Carid sp. T2	0	8	0	0	0	0	0	0	0	11	8	0
64	Carid sp. T3	0	0	0	0	0	0	0	0	0	8	0	0
65	Macrobrachium sp. JT1	25	0	0	0	0	0	0	0	0	19	0	0
66	Macrobrachium sp. JT2	25	0	0	0	0	0	0	0	0	0	8	0
67	Macrobrachium sp. AT1	0	0	0	0	0	0	0	0	0	0	0	8
68	Macropetasma africanum	0	0	0	0	0	0	0	0	0	0	0	8
69	Brachyura megalop T1	168	34	17	8	0	8	0	0	0	0	0	0
70	Brachyura megalop T2	17	0	0	0	0	8	0	8	0	0	0	0
71	Brachyura megalop T3	0	0	0	0	8	25	0	0	0	0	8	160
72	Brachyura megalop T4	0	0	0	0	0	0	0	17	0	0	0	17
73	Brachyura megalop T5	0	0	0	0	0	0	0	8	0	0	0	0
74	Brachyura megalop T6	0	0	0	0	0	0	0	0	8	0	0	0
75	Brachyura megalop T7	0	0	0	0	0	0	0	0	0	0	0	8
76	Brachyura megalop T8	0	0	0	0	0	0	34	0	0	0	0	0
77	Brachyura late megalop T1	0	0	0	0	0	0	0	0	8	0	0	0
78	Sesarma sp. T1	0	0	8	0	0	0	0	0	0	0	0	0
79	Portunis sp. T1	0	8	0	0	0	0	0	0	0	0	0	0
80	Paratyloidiplax blephariskios	8	0	0	17	0	25	0	17	34	48	34	0
81	Macrophthalmus boscii	0	0	0	8	0	50	0	17	0	0	0	0
82	Varuna litterata	0	0	0	0	0	8	0	0	0	0	0	0
83	Insecta sp. AT1	0	0	0	0	25	0	0	0	8	0	0	0
84	Insecta sp. AT2	0	0	0	0	8	0	0	0	0	0	0	0
85	Insecta sp. PT1	0	0	0	8	0	0	0	0	0	0	0	0
86	Insecta sp. PT2	0	0	0	0	0	8	0	0	0	0	0	0
87	Diptera sp. NT1	17	0	0	0	67	0	0	0	0	0	0	0
88	Diptera sp. NT2	0	0	0	0	389	59	8	0	0	0	0	0
89	Diptera sp. NT3	0	0	0	0	8	0	0	0	0	0	0	0
90	Diptera sp. NT4	0	0	0	0	288	8	0	0	0	0	0	0
91	Diptera sp. NT5	0	0	0	0	8	0	0	0	0	0	0	0
92	Diptera sp. NT6	0	0	0	0	294	160	0	0	0	0	0	0
93	Diptera sp. NT7	0	0	0	0	8	0	8	0	0	0	0	0
94	Diptera sp. NT8	0	0	0	0	34	0	0	0	0	0	0	0
95	Diptera sp. NT9	0	0	0	0	59	0	0	0	0	0	0	0
96	Diptera sp. NT10	0	0	0	0	8	0	0	0	0	0	0	0
97	Diptera sp. P/NT1	0	0	0	0	0	0	0	0	0	0	0	0

No	Species	1997									1998		
		Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
98	Diptera sp. PT1	0	0	0	0	8	0	0	0	0	0	0	0
99	Diptera sp. LT1	0	0	0	0	0	0	0	0	0	0	0	0
100	Diptera sp. LT2	8	0	0	0	0	0	0	0	0	0	0	0
101	Anthomyiidae sp. LT1	0	0	0	0	0	0	8	0	0	0	0	0
102	Psychodidae sp. LT1	0	0	0	0	0	0	17	0	0	0	0	0
103	Simuliidae sp. LT1	0	0	0	0	0	0	0	0	34	0	0	25
104	Ceratopogonidae sp. LT1	0	0	8	0	0	0	0	0	0	0	0	0
105	Ceratopogonidae sp. LT2	0	0	0	8	0	0	0	0	0	8	0	8
106	Ceratopogonidae sp. LT3	0	0	0	0	11	8	8	0	0	0	0	0
107	Ceratopogonidae sp. LT4	0	0	0	0	0	0	0	0	0	42	0	0
108	Ceratopogonidae sp. LT5	0	0	0	0	0	0	0	0	0	8	0	0
109	Ceratopogonidae sp. LT6	0	0	0	0	0	0	0	0	0	8	0	0
110	Ceratopogonidae sp. PT1	0	0	0	0	0	0	0	0	0	8	0	8
111	Chironomid sp. LT1	25	0	0	8	8	34	8	8	92	76	0	76
112	Chironomid sp. LT2	8	0	0	0	0	0	0	0	0	0	0	0
113	Chironomid sp. LT3	0	0	8	0	0	0	8	0	0	0	0	0
114	Chironomid sp. LT4	0	0	0	0	17	0	0	17	0	0	0	0
115	Chironomid sp. LT5	0	0	0	0	8	0	0	0	0	0	0	0
116	Chironomid sp. LT6	0	0	0	0	8	8	0	0	0	0	0	0
117	Chironomid sp. LT7	0	0	0	8	0	0	0	0	0	0	0	0
118	Chironomid sp. LT8	0	0	0	0	0	0	0	0	0	36	25	8
119	Chironomid sp. PT1	0	0	0	0	8	17	8	0	0	0	0	0
120	Chironomid sp. PT2	0	0	0	0	76	0	8	0	0	0	0	0
121	Chironomid sp. PT3	0	0	0	0	8	0	0	0	0	0	0	0
122	Chironomid sp. PT4	0	0	0	0	8	0	0	0	0	0	0	0
123	Chironomid sp. NT1	0	0	0	0	378	25	17	8	0	8	0	0
124	Culicinae sp. LT1	0	0	0	0	8	0	0	0	0	0	0	0
125	Culicinae sp. PT1	0	0	0	0	0	0	8	0	0	0	0	0
126	Tipulidae sp. LT3	0	0	0	0	11	0	0	0	0	0	0	0
127	Tipulidae sp. LT4	0	0	0	0	8	0	0	0	0	0	0	0
128	Tipulidae sp. LT5	0	0	0	0	0	8	0	0	0	0	0	0
129	Trichoptera sp. LT1	0	0	0	0	0	8	0	0	0	0	0	0
130	Ephemeroptera sp. LT1	0	0	8	0	0	0	0	0	0	0	0	0
131	Ephemeroptera sp. LT2	0	0	0	0	0	0	0	0	8	0	0	0
132	Ephemeroptera sp. NT1	0	0	0	0	0	0	0	0	0	0	0	0
133	Ephemeroptera sp. Imago T1	0	0	0	0	8	0	0	0	0	0	0	0
134	Baetidae sp. LT1	0	8	0	0	0	0	0	0	0	0	0	0
135	Baetidae sp. LT2	0	0	8	0	0	25	0	0	17	8	0	8
136	Baetidae sp. LT3	0	0	0	0	0	0	8	0	0	0	0	17
137	Baetidae sp. LT4	0	0	0	0	0	0	8	0	0	0	0	0
138	Baetidae sp. LT5	0	0	0	0	0	0	0	0	0	11	0	0
139	Trychorythidae sp. T1	0	0	0	0	0	0	0	0	17	11	0	0
140	Odonata sp. NT1	0	0	0	0	0	0	0	0	0	0	0	0
141	Gomphid sp.LT1	0	0	0	0	0	8	0	0	0	0	0	0
142	Gomphid sp.LT2	0	0	0	0	0	8	0	0	0	0	0	0
143	Gomphid sp.LT3	0	0	0	0	0	8	0	0	0	0	0	0
144	Gomphid sp.LT4	0	0	0	0	0	0	0	0	8	8	0	0
145	Coleoptera sp. NT1	0	0	0	0	0	0	8	0	17	0	0	0
146	Coleoptera sp. PT1	0	0	0	0	0	0	0	0	0	11	0	0
147	Elmidae sp. T1	0	0	0	0	0	0	0	0	0	8	0	0
148	Corixidae sp. T1	0	0	0	0	8	0	0	0	0	17	0	0

No	Species	1997									1998		
		Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
149	Corixidae sp. T2	0	0	0	0	0	25	0	0	0	0	0	0
150	Corixidae sp. T3	0	0	0	0	0	17	0	0	0	0	0	0
151	Corixidae sp. T4	0	0	0	0	0	8	0	0	0	0	0	0
152	Plea sp. T1	0	0	0	0	0	0	0	0	0	0	0	8
153	Dytiscidae sp. T1	0	0	8	0	0	0	0	0	0	0	0	0
154	Hypogastrus sp. T1	0	0	0	8	0	0	0	0	0	0	0	0
155	Isotomidae sp. T1	0	0	0	0	11	0	0	0	0	17	0	0
156	Isotomidae sp. T2	0	0	0	0	59	0	0	0	8	0	0	0
157	Acariformes sp T1	0	0	0	0	0	0	0	8	0	0	0	0
158	Acariformes sp T2	0	0	0	0	0	0	8	0	0	0	0	0
159	Aranea sp. T1	8	0	0	0	0	0	0	0	0	0	0	0
160	Aranea sp. T2	0	8	0	0	0	0	0	0	0	0	0	0
161	Aranea sp. T3	0	0	0	0	11	8	0	0	0	0	0	0
162	Aranea sp. T4	0	0	0	0	8	0	0	0	0	0	0	0
163	Gastropod sp. T1	0	0	8	0	0	0	0	0	0	0	0	0
164	Gastropod sp. T2	0	0	0	0	21	0	0	0	0	0	0	0
165	Gastropod sp. T3	0	0	0	0	0	8	8	8	0	0	0	0
166	Gastropod sp. T4	0	0	0	0	0	0	0	8	0	0	0	0
167	Gastropod sp. T5	0	0	0	0	0	0	8	8	0	0	0	0
168	Corbiculidae sp. T1	0	0	0	0	0	0	0	0	0	0	0	8
169	Spheridae sp. T1	0	0	0	0	0	0	0	0	0	0	0	17
170	oligochaetae eggs	8	0	0	8	1167	8461	5437	7472	5707	3845	175	2798
	TOTAL	1646	3111	1831	4139	15147	11495	7831	9218	12169	7403	5428	9641

1.2 APPENDIX A-2: SPECIES RICHNESS (D) AND SHANNON WEINER DIVERSITY (H') MEASURED MONTHLY AT EACH SITE IN 1997-8 AND AUGUST 2001

Site	1997																		1998						2001		
	April		May		June		July		August		September		October		November		December		January		February		March		August		
	d	H'	d	H'	d	H'	d	H'	d	H'	d	H'	d	H'	d	H'	d	H'	d	H'	d	H'	d	H'	d	H'	d
1	0.370	0.081	0.225	0.018	0.350	0.045	0.756	0.067	0.208	0.013	0.617	0.202	0.425	0.217	0.258	0.048	0.533	0.161	1.042	0.278	0.000	0.000	0.305	0.130	0.387	0.727	
2	0.000	0.000	0.000	0.000	0.278	0.076	0.218	0.014	0.198	0.006	0.231	0.022	0.397	0.107	0.736	0.116	0.683	0.058	0.957	0.164	0.333	0.043	0.721	0.044	0.647	0.186	
3	0.612	0.822	0.353	0.082	0.283	0.085	0.660	0.712			0.744	0.181	0.765	0.116	0.340	0.297	0.760	0.120	0.337	0.027	0.242	0.031	0.423	0.125			
6	0.613	0.442	0.689	0.449	0.150	0.059	0.355	0.050			0.130	0.026	0.650	0.837	1.366	1.329	0.976	1.079	0.558	0.074	0.101	0.007	0.300	0.013	1.778	1.899	
8	0.331	0.820	0.635	0.903	0.549	0.938	0.575	0.862			1.282	1.629	1.885	2.102	0.627	0.955	0.354	0.693	0.803	1.332	0.408	0.602	0.967	1.409			
9	1.278	1.818	0.620	0.953	0.694	1.215	0.420	0.509			1.705	1.396	0.867	1.234	0.000	0.000	0.723	0.578	0.904	1.485	0.557	0.740	1.084	1.633	0.822	0.235	
10			0.557	0.912	0.715	0.550	0.839	1.376			2.000	2.113	1.618	2.043	0.839	0.994	1.106	1.372	0.569	1.040	0.175	0.127	0.614	0.761	1.149	0.712	
12																										2.266	0.423

1.3 APPENDIX A-3: MONTHLY PHYSICO-CHEMICAL CHARACTERISTICS MEASURED AT EACH MACROINVERTEBRATE SAMPLING SITE FROM 1997-8

Month	Site	Depth (m)	pH	TDS (g/l)	Salinity	Conduct. (mS/cm)	Temp. (°C)	Oxygen (mg/l)	Turbidity (NTU)
Apr-97	1	0.2	7.89	6.010	5.1	9.470	28.48	5.66	65
	2	0.3	8.48	1.090	0.1	7.740	23.07	7.22	100
	3	0.3	8.49	0.690	0.0	1.800	22.65	7.34	100
	6	0.8	8.54	0.724	0.6	1.104	23.09	7.21	89
	8	0.8	8.58	0.499	0.4	0.830	24.19	7.46	120
	9	0.4	8.53	0.134	0.1	0.210	23.24	7.85	94
May-97	1	0.2	8.12	4.090	3.5	6.390	23.64	8.95	100
	2	0.3	8.38	3.490	2.9	5.310	21.21	9.87	90
	3	0.2	8.76	0.719	0.6	1.123	20.83	9.95	36
	6	0.7	8.80	0.582	0.5	0.914	20.84	10.44	69
	8	1.2	8.70	1.080	0.9	1.640	20.50	11.45	40
	9	0.7	8.29	0.153	0.1	0.238	18.79	10.88	40
Jun-97	10	1.0	8.52	0.439	0.4	0.686	19.21	11.12	43
	1	0.2	8.09	0.516	0.4	0.806	17.31	8.50	93
	2	0.5	7.82	0.756	0.8	1.830	15.25	9.24	53
	3	0.5	7.82	0.756	0.8	1.830	15.25	9.24	53
	6	1.1	7.84	0.201	0.0	0.314	15.39	9.64	36
	8	1.3	7.72	0.602	0.5	0.944	15.67	9.38	49
Jul-97	9	0.6	7.73	0.393	0.3	0.520	15.53	9.36	58
	10	0.9	7.68	0.554	0.5	0.867	15.57	9.35	50
	1	0.2	6.98	1.500	1.2	2.220	16.55	9.27	93
	2	0.9	8.57	23.800	21.6	37.300	20.39	8.21	12
	3	1.0	8.51	28.900	30.6	47.200	20.69	7.80	12
	6	0.8	8.50	31.100	31.1	47.200	20.55	7.35	15
Aug-97	8	0.6	8.45	1.460	1.1	2.440	17.84	9.01	17
	9	0.9	8.91	0.287	0.2	0.452	19.41	9.80	16
	10	1.1	8.66	0.556	0.5	0.951	17.98	9.42	18
	1	0.4	8.70	0.628	0.5	0.976	22.21	10.62	50
	2	0.7	8.69	0.751	0.6	1.168	20.75	9.54	49
	3	0.8	8.57	0.845	0.7	1.306	20.54	9.58	46
Sep-97	6	1.1	8.32	1.160	0.9	1.780	20.26	9.55	44
	8	1.1	8.21	0.250	0.3	0.392	19.38	9.52	58
	9	0.9	8.56	0.223	0.2	0.348	20.21	9.47	49
	10	1.1	8.49	0.302	0.2	0.473	20.16	9.62	49
	1	0.7	8.52	0.393	0.3	0.620	24.70	8.05	120
	2	0.8	8.53	0.255	0.2	0.399	22.88	8.35	125
Oct-97	3	0.8	8.44	0.452	0.3	0.668	22.69	8.52	125
	6	1.0	8.42	0.495	0.4	0.798	24.21	8.30	120
	8	0.8	8.52	0.624	0.2	0.411	22.20	8.65	125
	9	0.9	8.39	0.204	0.2	0.374	22.72	8.25	125
	10	1.1	8.65	0.248	0.2	0.386	22.53	8.71	125
	1	1.0	8.73	1.410	1.3	2.270	21.48	7.31	50
Nov-97	2	1.1	8.54	9.900	8.7	16.400	21.42	6.87	46
	3	1.0	8.61	10.100	15.4	30.000	21.42	7.12	41
	6	0.7	7.90	27.300	25.2	41.500	21.46	7.15	34
	8	0.8	7.99	1.030	0.9	1.650	21.35	6.81	55
	9	0.9	8.01	0.405	0.3	0.638	21.04	7.22	73
	10	1.2	8.15	0.507	0.4	7.400	21.31	6.97	52
Nov-97	1	0.2	8.12	3.280	2.8	5.110	31.17	10.65	115
	2	0.4	8.14	1.380	1.2	2.160	24.85	8.35	77
	3	0.2	8.04	1.260	1.1	1.970	25.48	7.79	73
	6	0.8	8.12	0.577	0.4	0.898	25.02	7.66	90
	8	1.0	8.08	2.640	2.2	4.110	26.70	7.76	45

Month	Site	Depth (m)	pH	TDS (g/l)	Salinity	Conduct. (mS/cm)	Temp. (°C)	Oxygen (mg/l)	Turbidity (NTU)
	9	1.2	7.96	1.840	1.6	2.650	24.26	7.45	120
	10	1.3	7.96	2.850	2.5	4.410	25.69	7.78	49
Dec-97	1	0.3	8.28	1.340	1.1	2.080	31.40	7.04	72
	2	0.6	8.14	0.201	0.2	0.328	27.38	6.71	74
	3	0.8	8.07	0.434	0.4	0.608	25.90	6.49	72
	6	0.5	8.13	0.128	0.1	0.200	26.58	7.20	75
	8	1.2	8.27	0.134	0.1	0.215	26.76	7.63	75
	9	1.0	7.97	0.127	0.1	0.199	24.69	7.01	78
	10	1.4	8.18	0.125	0.1	0.195	25.15	7.51	75
Jan-98	1	0.9	8.32	0.440	0.4	0.702	30.32	6.07	630
	2	0.8	8.29	0.124	0.1	0.193	28.32	6.69	800
	3	0.7	8.23	0.156	0.1	0.255	27.73	6.92	800
	6	0.8	8.23	0.116	0.1	0.182	27.70	6.81	790
	8	0.9	8.20	0.115	0.1	0.180	27.75	7.23	810
	9	1.4	8.23	0.116	0.1	0.181	27.29	6.97	820
	10	1.1	8.29	0.113	0.1	0.178	27.95	6.93	810
Feb-98	1	0.5	7.68	3.460	3.3	5.710	25.77	6.69	150
	2	0.6	7.76	0.654	0.5	1.003	26.29	7.10	250
	3	0.5	7.84	0.621	0.5	0.945	26.52	7.84	250
	6	0.4	8.23	0.141	0.1	0.220	27.98	7.54	250
	8	0.8	8.29	0.177	0.7	0.427	28.34	7.66	230
	9	0.8	7.96	0.141	0.1	0.221	27.68	7.39	260
	10	1.9	7.95	0.142	0.1	0.221	27.37	7.57	260
Mar-98	1	0.5	7.91	2.020	1.7	3.120	32.04	6.32	180
	2	0.4	8.01	0.140	0.1	0.213	28.90	7.11	260
	3	0.6	8.32	0.140	0.1	0.220	28.31	7.05	250
	6	0.3	8.16	0.126	0.1	0.196	27.66	7.77	255
	8	1.1	8.11	0.175	0.1	0.273	27.37	7.63	275
	9	0.9	8.30	0.126	0.1	0.195	26.86	7.83	290
	10	1.2	8.32	0.130	0.1	0.204	27.79	7.68	260

1.4 APPENDIX A4: PHYSICO-CHEMICAL CHARACTERISTICS MEASURED AT EACH MACROINVERTEBRATE SAMPLING SITE IN AUGUST 2001

	Site	Time	GPS	Depth (m)	Temperature		Turbidity		Oxygen		Oxygen		Conductivity		Salinity		TDS		pH	
					(oC)		(NTU)		(mg/l)		(%sat)		(mS.cm)		(ppt)		(g/l)		log	
					SURFACE	BOTTOM	SURFACE	BOTTOM	SURFACE	BOTTOM	SURFACE	BOTTOM	SURFACE	BOTTOM	SURFACE	BOTTOM	SURFACE	BOTTOM	SURFACE	BOTTOM
21-Aug-01	1	9H30	S29°13'30.5" / E31°30'00.1"	1.5	20.55	21.04	5.43	5.44	5.67	5.42	67.6	75.0	28.60	51.90	13.5	34.2	14.7	33.1	7.78	7.88
21-Aug-01	2	12H30	S29°13'30.5" / E31°30'00.1"	1.3	21.37	21.21	4.31	9.88	4.83	5.54	62.1	77.4	36.10	53.40	21.7	35.4	22.30	34.20	7.79	7.92
21-Aug-01	6	12H05	S29°13'32.3" / E31°29'52.5"	0.8	20.59	20.85	6.95	5.98	4.44	4.78	52.0	61.5	11.75	42.30	7.1	26.8	7.55	23.80	7.67	7.78
21-Aug-01	9	13H20	S29°13'30.5" / E31°30'00.1"	1.5	21.71	20.95	7.48	7.89	4.70	4.94	56.3	69.1	14.70	54.20	8.9	35.9	9.40	34.70	7.73	7.89
21-Aug-01	10	11H30	S29°13'30.5" / E31°30'00.1"	0.5	20.41		7.60		5.60		73.6		42.40		28.9		28.90		7.73	
21-Aug-01	12	10H40	S29°13'30.5" / E31°30'00.1"	1.7	19.48	20.76	6.99	6.43	4.03	4.62	46.1	64.9	10.41	53.00	6.0	35.2	7.23	34.20	7.64	7.83

Appendix G

Fish of the Thukela Estuary

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EXECUTIVE SUMMARY

A total of 40 fish species from 20 families have been recorded from the Thukela Estuary but most of these species are absent from the system during high river flow conditions. Seven species are dependent on estuaries for breeding purposes and include resident taxa such as the estuarine round-herring *Gilchristella aestuaria* and speartail goby *Oligolepis keiensis*. A total of nine marine species, including the estuarine bream *Acanthopagrus berda* and longarm mullet *Valamugil cunnesius*, are dependent on estuaries as nursery areas, but would only be able to colonise the estuary under low or medium river flow conditions. A further 15 marine species (e.g. bluetail mullet *Valamugil buchanani* and mangrove snapper *Lutjanus argentimaculatus*) are at least partially dependent on estuaries as nursery areas but would leave the system under high river flows. Four of the remaining taxa were marine species (e.g. bluespotted blaasop *Chelonodon laticeps* and blacktip kingfish *Caranx heberi*) that sometimes occur in the lower reaches of the estuary where seawater penetration is maximal.

The overwhelming dominance of juveniles belonging to the family Mugilidae in the system may be linked to the shallowness of the estuary and high organic loading from upstream sources. These juveniles, especially *Valamugil cunnesius*, occur throughout the estuary, with some species (e.g. freshwater mullet *Myxus capensis*) probably extending into the riverine areas above the estuary. Gill netting during May 1996, February 1997 and February 1999 revealed an absence of large piscivorous fishes within the estuary. This is probably a reflection of the shallowness of the system, widely fluctuating densities of potential prey, and freshwater dominated nature of the river mouth.

Only one freshwater fish species (Mozambique tilapia *Oreochromis mossambicus*) is regularly recorded in the estuary but is only likely to proliferate under closed mouth conditions. Other freshwater species are likely to enter the estuary during river flooding, many of which will probably be washed out the sea where they will perish. Anguillid eels (e.g. longfin eel *Anguilla mossambica*) make extensive use of the estuary during migrations to and from the river catchment.

Based on their distributional ranges six (15%) of the fish recorded in the Thukela Estuary are southern African endemics.

Eight estuarine scenarios used in the Intermediate Level Reserve Determination templates were selected for testing using the fish recruitment index (FRI). Under Reference Conditions the mean annual FRI was 56, increasing to 62 during Present Conditions. The reason for the lower fish recruitment under high river flow Reference Conditions is the flushing effect these large water volumes have on the salinity profiles, food resources and potential nursery areas within the Thukela Estuary.

The behaviour of the FRI during River Categories A to D indicates a progressive increase in potential fish recruitment between these four flow regimes, with the highest values recorded under Scenarios C and D. The reduction in high river flows through the estuary during these scenarios promotes saline penetration of the estuary as well as facilitating the trapping of autochthonous and allochthonous primary and secondary production within the system.

The FRI during the two Worst Case scenarios indicates exceptionally poor fish recruitment, with little difference between these two regimes. Worst Case 1 and 2 were considerably lower than any of the other scenarios tested, primarily due to the extended closed mouth phases during winter and early spring, and the effect that this has on marine fish recruitment into the system.

1 INTRODUCTION

The state of our knowledge of the Thukela Estuary was, prior to the DWAF water reserve initiative, exceedingly poor (Begg 1978). This assessment applied not only to the physico-chemical conditions but also to the aquatic organisms of the estuary, about which virtually nothing was known. The findings outlined below build on the preliminary research conducted during the 1990s as part of an initial assessment of the Thukela estuarine flow requirements.

The Thukela Estuary, even in its present condition, appears to function more as a river mouth than an estuary. Although closure of the mouth now occurs frequently during prolonged low flow conditions, it is unlikely that this was a regular feature of the system in its pristine state. Penetration of saline water is usually limited to the lower reaches, with intrusions of seawater most effective on spring high tides when river flow is at a minimum.

The Thukela Estuary is a relatively small system, with a water surface area of approximately 55 ha during low flow periods (Begg 1978), i.e. it covers only about 0.2% of the surface area of the nearby Lake St Lucia system. Therefore in the context of a nursery area for juvenile marine fishes in the KwaZulu-Natal region, this system does not rank very highly from a conservation perspective. It does however perform a very important role, acting as a conduit for large numbers of anguillid eel larvae that colonize the vast Thukela River catchment.

1.1 BACKGROUND TO THE PRESENT STATE

Despite the fact that this estuary is riverine in character, only two freshwater fish species (Mozambique tilapia *Oreochromis mossambicus* and sharptooth catfish *Clarias gariepinus*) have been recorded from the system. Past studies (Ramm *et al.* 1986, Whitfield & Harrison 1999) have shown that the estuary is dominated by marine fish species, many of which were captured in freshwater sections of the system. With the exception of four goby species and the clupeid *Gilchristella aestuaria*, all the marine taxa utilise the estuary and tidal riverine section as a nursery area, probably vacating the area when the river comes down in flood.

This report investigates the fish component of the Thukela Estuary Reserve Study, including:

- A synthesis of existing information on the species composition and estuarine dependence categories.
- An assessment of the relative importance of the estuary to different species or groups of species.
- An assessment of the likely effects of altered river inflows on the ichthyofauna.
- An analysis of the fish recruitment potential (Fish Recruitment Index) of the Thukela Estuary under eight different scenarios.
- To provide recommendations for further work in order to enhance the reliability of predictions of fish responses to changes in Thukela River flow.

1.1.1 Previous 1997 Workshop

At the earlier Thukela workshop it was concluded that the present state of the estuary was more conducive to occupation by estuarine associated fish species than the natural state. This was because the higher river flows in the pristine condition would reduce the size and duration of the saline zone within the estuary. It was also suggested that protracted mouth closure could be detrimental to the estuarine fish stocks, depending upon timing and the possible development of low dissolved oxygen conditions within the estuarine lagoon. A strong recommendation from the previous workshop was therefore to monitor both the physico-chemical conditions and status of fish populations during the estuarine closed phase. The importance of continuous open mouth conditions during the spring and summer months for anguillid eel migrations was stressed.

2 FISH STUDY

2.1 INTRODUCTION TO THE FRI

The finding by Whitfield (1994) that the longitudinal salinity gradient in South African estuaries is an important indicator of the magnitude of juvenile marine fish recruitment into these systems, has led to the development of a fish recruitment index (FRI) for South African estuaries (Quinn *et al.* 1998, 1999). A primary aim of this index is to integrate available ichthyological knowledge into a methodology for the assessment of different river flow regimes and mouth condition scenarios on the recruitment of juvenile fishes into a particular estuary. In this report the FRI has been applied to the data collected during fish sampling of the Thukela Estuary.

Before presenting FRI results from selected physical states in the above estuary, it is necessary to outline the methodology used. The FRI is a biologically meaningful management index that is based on the integration of three key information sets. The first information set is the current understanding relating to the dependency of coastal fish species on the estuarine environment; the second is the preferred timing of the recruitment period for key species; and the third is the known environmental requirements for recruitment by juvenile marine fish (Quinn *et al.* 1999).

2.1.1 Dependency score

Whitfield (1998) has provided a revised estuary-dependence categorization for fishes in South African estuaries, comprising five major categories (Table 2.1). Of the five major categories, only divisions Ia and IIa are totally dependent on estuaries. Categories Ib, IIb and IIc represent species which are at least partially dependent on estuarine systems, a large proportion of which could be regarded as marine/estuarine opportunists. Category III comprises mainly stenohaline marine species which occur in low numbers in estuaries. Category IV consists of mainly euryhaline freshwater species, for which the degree of penetration into estuaries is determined primarily by salinity tolerance. Finally Category V includes obligate catadromous species which use estuaries as transit routes between marine and freshwater environments.

In order to distinguish between those species that merely benefit from estuaries, and those which are dependent on estuaries, a simple scoring system was devised. This system reflects the extent of dependency of the species on the estuarine environment (Table 2.2). Thus Category IIc species, being only partially dependent on estuaries scored lower than Category IIa species which are entirely dependent on estuaries.

A further point of note is that not all juvenile marine fish are of equal conservation significance. Some may be distributed throughout the Indo-Pacific region, whereas others may be endemic to certain areas of the southern African coastline. The latter are therefore considered of greater conservation than the former. Consequently the score of an endemic species, regardless of its category of dependence, was increased to 5 (Table 2.2).

2.1.2 Optimal recruitment score

Whitfield (1998) has provided a summary of the recruitment periods for common marine fish species entering estuaries along the KwaZulu-Natal, Eastern and Western Cape coasts. Figure 1 in Quinn *et al.* (1999) summarises the species included in the model and their recruitment periods. The Optimal Recruitment Score (ORS_i) was defined as being 5 for the main immigration period, decreasing linearly to 0 towards the outer limits of the species recruitment period.

Table 2.1 The five major categories of fishes that utilize 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.	
IV	Euryhaline freshwater species, whose penetration into estuaries is determined primarily by salinity tolerance and 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 2.2 Dependency scores allocated to categories of fish

Category	Dependency score (DS _i)
IIa	5
IIb	3
IIc	1
V	5
Endemic	5

2.1.3 Mouth status multiplier

A major limiting condition is that the mouth must be open for fish recruitment to occur. The values assigned to the mouth condition were set to zero if the mouth of the estuary is closed, or one while the mouth remains open.

2.1.4 Flow rate multiplier

Recent evidence suggests that very high river flow inhibits juvenile fish recruitment. Figure 2.1 shows a logarithmic decrease [$y = -104.28\ln(x) + 577.29$; $r^2 = 0.9908$] in seine net catch per unit effort based on an analysis of four sampling events in the Thukela Estuary. It would appear that for a given estuary there is a range of outflow rates which correspond to an optimum volume of land based cues entering the marine environment without compromising the ability of juveniles to enter and locate suitable habitat within the estuary. Successively higher flow rates are thus likely to limit the extent of recruitment to an increasing extent by either making access to the estuary difficult or by eliminating suitable habitat within the estuary.

2.1.5 Fish recruitment index formula

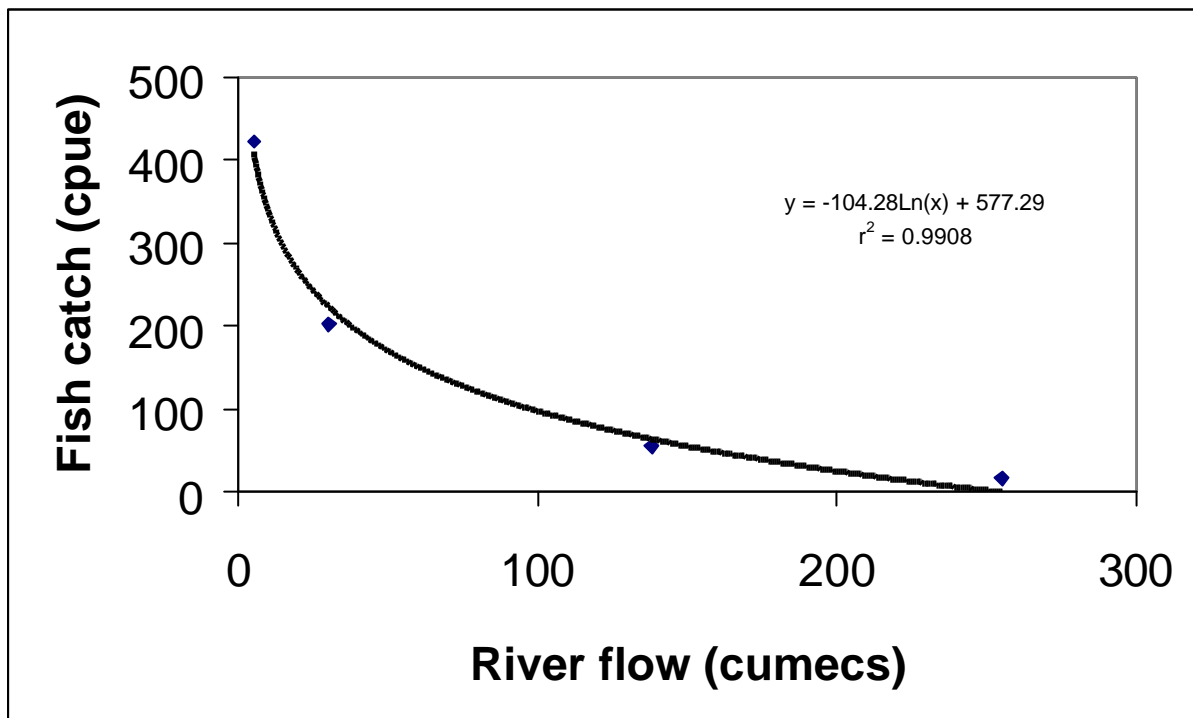
The above scores and multipliers were integrated into a single index, namely:

$$FR_i = S_i (ORS_{it} \cdot DS_i) \cdot (MSM_t \cdot FRM_t)$$

where:

FR_t = Fish Recruitment Index at time t
 MSM_t = Mouth Status Multiplier at time t
 ORS_{it} = Optimal Recruitment Score of species i at time t
 DS_i = Dependency Score of species i
 FRM_t = Flow Rate Multiplier at time t

Fig. 2.1 Seine net data showing the decline in fish catch per unit effort (CPUE) with successively higher Thukela River flow rates



2.2 THE THUKELA ESTUARY ICHTHYOFAUNA

A total of 40 fish species from 20 families have been recorded from the Thukela Estuary (Table 2.3 and 2.4). Seven of these species are dependent on estuaries for breeding purposes and include resident taxa such as *Gilchristella aestuaria* and *Oligolepis keiensis*. Marine species such as *Acanthopagrus berda* and *Valamugil cunnesius*, which are dependent on estuaries as nursery areas, numbered nine. A further 15 species, e.g. *Valamugil buechanani* and *Lutjanus argentimaculatus*, are at least partially dependent on estuaries as nursery areas. In all, 85% of the fish species recorded from the Thukela can be regarded as either partially or completely dependent on estuaries for their survival. Four of the remaining taxa were marine species (e.g. *Chelonodon laticeps* and *Caranx heber*) which occur in but are not dependent on estuaries, and one (*Oreochromis mossambicus*) is a euryhaline freshwater species (Table 2.3). Although the freshwater catfish *Clarias gariepinus* has been recorded in the Thukela Estuary it is not a resident in this part of the system.

Anguillid eels (e.g. *Anguilla mossambica* and *Anguilla marmorata*) 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 (Skelton 2001). Anguillid eels are probably the single most important fish species in

the Thukela system due to their abundance and widespread distribution throughout the catchment.

Based on their distributional ranges six (15%) of the fish recorded in the Thukela Estuary are southern African endemics.

There are strong indications (Figure 2.1) that the fish assemblage in the Thukela Estuary changes considerably during periods of river flooding. This is probably due to salinities throughout the system declining to zero and many marine species then finding temporary refuge in the sea. The above pattern has recently been confirmed for other permanently open estuaries and river mouths in southern Africa (Whitfield & Paterson 1995) and is a reflection of the natural cycle of perturbation brought about by alternating high and low river flow regimes. Persistent high river flows will also prevent the estuary from acting as a natural detritus trap and therefore lower the fish carrying capacity of the system.

The seine net composition of fish species captured in the Thukela Estuary in July 1986, May 1996, February 1997 and February 1999 is shown in Table 2.4. The overwhelming dominance of juveniles belonging to the family Mugilidae in the system may be linked to high organic loading associated with the SAPPI mill effluent. Gill netting during May 1996, February 1997 and February 1999 revealed an absence of large piscivorous fishes within the estuary. This is probably a reflection of the shallowness of the system, widely fluctuating densities of potential prey, and freshwater dominated nature of the river mouth. The paucity of zooplanktivores and benthic invertebrate feeding fishes, especially during high river flow conditions, can be linked to the low abundance of these food sources during such periods.

The regular capture of the tripletail *Lobotes surinamensis* by anglers in the Thukela Estuary mouth is a noteworthy feature of this system. Although the tripletail enters estuaries it is generally rare in southern African waters. The reason for the attractiveness of the Thukela system for the tripletail is unknown.

Table 2.3 A list of indigenous fish species recorded in the Thukela Estuary during the current study (including fish taxa collected during the benthic invertebrate sampling programme). The species are classified into five major categories of estuarine-dependence as outlined in Table 2.1 and endemic taxa are indicated with an asterisk (*)

Family	Scientific name	Common name	Category
Ambassidae	<i>Ambassis natalensis</i>	Slender glassy	Ib
Ambassidae	<i>Ambassis dussumieri</i>	Longspine glassy	Ib
Anguillidae	<i>Anguilla mossambica</i>	Longfin eel	Va
Carangidae	<i>Caranx heberi</i>	Blacktip kingfish	III
Carangidae	<i>Caranx ignobilis</i>	Giant kingfish	IIb
Carangidae	<i>Caranx sexfasciatus</i>	Bigeye kingfish	IIb
Carangidae	<i>Scomberoides lysan</i>	Doublespotted queenfish	IIb
Cichlidae	<i>Oreochromis mossambicus</i>	Mozambique tilapia	IV
Clariidae	<i>Clarias gariepinus</i>	Sharptooth catfish	IV
Clupeidae	<i>Gilchristella aestuaria</i> *	Estuarine roundherring	Ia
Clupeidae	<i>Hilsa kelee</i>	Kelee shad	IIc
Elopidae	<i>Lops machnata</i>	Ladyfish	IIa
Engraulidae	<i>Thryssa setirostris</i>	Longjaw glassnose	III
Engraulidae	<i>Thryssa vitrirostris</i>	Orangemouth glassnose	IIb
Gerreidae	<i>Gerres macracanthus</i>	Longspine purse-mouth	IIb
Gerreidae	<i>Gerres methueni</i>	Evenfin purse-mouth	IIb
Gobiidae	<i>Glossogobius callidus</i> *	River goby	Ib
Gobiidae	<i>Oligolepis acutipennis</i>	Sharptail goby	Ia
Gobiidae	<i>Oligolepis keiensis</i>	Speartail goby	Ia
Gobiidae	<i>Taenioides jacksoni</i> *	Bearded eelgoby	Ia
Haemulidae	<i>Pomadasys commersonii</i>	Spotted grunter	IIa

Family	Scientific name	Common name	Category
Haemulidae	<i>Pomadasys kaakan</i>	Javelin grunter	IIc
Leiognathidae	<i>Leiognathus equulus</i>	Slimy	IIb
Lobotidae	<i>Lobotes surinamensis</i>	Tripletail	III
Lutjanidae	<i>Lutjanus argentimaculatus</i>	Mangrove snapper	IIc
Mugilidae	<i>Liza dumerili</i>	Groovy mullet	IIb
Mugilidae	<i>Liza macrolepis</i>	Large-scale mullet	IIa
Mugilidae	<i>Mugil cephalus</i>	Flathead mullet	Vb
Mugilidae	<i>Myxus capensis</i> *	Freshwater mullet	Vb
Mugilidae	<i>Valamugil buchanani</i>	Bluetail mullet	IIc
Mugilidae	<i>Valamugil cunnesius</i>	Longarm mullet	IIa
Mugilidae	<i>Valamugil robustus</i>	Robust mullet	IIa
Pomatomidae	<i>Pomatomus saltatrix</i>	Elf	IIc
Sciaenidae	<i>Argyrosomus japonicus</i>	Dusky kob	IIa
Sciaenidae	<i>Johnius dorsalis</i>	Small kob	IIc
Soleidae	<i>Solea bleekeri</i> *	Blackhand sole	IIb
Sparidae	<i>Acanthopagrus berda</i>	Estuarine bream	IIa
Sparidae	<i>Rhabdosargus holubi</i> *	Cape stumpnose	IIa
Teraponidae	<i>Terapon jarbua</i>	Thornfish	IIa
Tetraodontidae	<i>Chelonodon laticeps</i>	Bluespotted blaasop	III

Table 2.4 Seine net catches from the Thukela Estuary. The catch per unit effort (average number of fish sampled per seine net haul) and approximate river flow volume (cubic metres per second) at the time of sampling are also shown

Fish taxa	July 1986	May 1996	February 1997	February 1999	Total (n)	Total (%)
<i>Acanthopagrus berda</i>	112	0	6	2	120	2.71
<i>Ambassis dussumieri</i>	0	0	32	44	76	1.72
<i>Ambassis natalensis</i>	0	0	7	5	12	0.27
<i>Argyrosomus japonicus</i>	0	0	1	0	1	0.02
<i>Caranx ignobilis</i>	0	1	4	1	6	0.14
<i>Caranx sem</i>	0	0	84	0	84	1.90
<i>Caranx sexfasciatus</i>	0	19	0	1	20	0.45
<i>Chelonodon laticeps</i>	0	0	1	0	1	0.02
<i>Clarias gariepinus</i>	0	0	1	0	1	0.02
<i>Elops machnata</i>	0	0	28	0	28	0.63
<i>Gerres macracanthus</i>	3	0	0	0	3	0.07
<i>Gerres rappi</i>	0	24	0	0	24	0.54
<i>Gilchristella aestuaria</i>	0	19	82	0	101	2.28
<i>Glossogobius callidus</i>	23	0	3	3	29	0.66
<i>Hilsa kelee</i>	0	1	2	0	3	0.07
<i>Johnius dorsalis</i>	0	0	4	0	4	0.09
<i>Leiognathus equulus</i>	32	57	205	0	294	6.65
<i>Liza dumerili</i>	2	2	22	2	28	0.63
<i>Liza macrolepis</i>	2	0	0	0	2	0.05
<i>Lutjanus argentimaculatus</i>	0	0	1	0	1	0.02
<i>Mugil cephalus</i>	0	2	7	2	11	0.25
Mugilidae (juveniles)	522	195	6	14	737	16.67
<i>Myxus capensis</i>	0	0	2	3	5	0.11
<i>Oligolepis acutipennis</i>	0	0	6	1	7	0.16
<i>Oligolepis keiensis</i>	0	10	1	0	11	0.25
<i>Oreochromis mossambicus</i>	0	4	1	0	5	0.11
<i>Pomadasys commersonnii</i>	0	9	13	0	22	0.50
<i>Pomadasys kaakan</i>	19	1	19	0	39	0.88
<i>Pomatomus saltatrix</i>	0	2	2	0	4	0.09
<i>Rhabdosargus holubi</i>	0	11	0	0	11	0.25
<i>Scomberoides lysan</i>	0	0	1	0	1	0.02
<i>Solea bleekeri</i>	85	0	0	0	85	1.92

Fish taxa	July 1986	May 1996	February 1997	February 1999	Total (n)	Total (%)
<i>Terapon jarbua</i>	0	9	128	19	156	3.53
<i>Thryssa setirostris</i>	0	0	64	0	64	1.45
<i>Thryssa vitrirostris</i>	0	0	35	0	35	0.79
<i>Valamugil buehanani</i>	38	4	0	0	42	0.95
<i>Valamugil cunnesius</i>	7	2097	52	29	2185	49.42
<i>Valamugil robustus</i>	0	162	1	0	163	3.69
Total catch	845	2629	821	126	4421	100.00
Catch per unit effort	422	202	55	16		
River flow (cumecs)	5	30	138	255		

2.3 FISH RECRUITMENT SCENARIOS

Eight estuarine scenarios used in the Intermediate Level Reserve Determination templates were selected for testing using the Fish Recruitment Index (FRI). These scenarios included the Reference Condition, Present Condition, River Category A, B, C, D, Worst Case 1, 2, and were tested for the 1925-1974 period using data supplied by the hydrodynamic team from the CSIR in Stellenbosch.

Under Reference Conditions the mean annual FRI was 56, increasing to 62 during Present Conditions (Figure 2.2). This average 11% increase between natural and present day conditions varies considerably, e.g. during drought years the differential can disappear altogether but during high run-off years the differential can exceed 50% (Table 2.5). The reason for the lower fish recruitment under high river flow Reference Conditions is the flushing effect these large water volumes have on the salinity profiles, food resources and potential nursery areas within the Thukela Estuary.

The behaviour of the FRI during River Categories A to D indicates a progressive increase in potential fish recruitment between these four flow regimes, with the highest values recorded under Scenarios C and D (Figure 2.2). On average the FRI during these latter flow regimes will be almost 50% higher than in the natural state. The reduction in high river flows through the estuary during these scenarios promotes saline penetration of the estuary as well as facilitating autochthonous and allochthonous trapping of primary and secondary production within the system.

The FRI during the two Worst Case scenarios indicates exceptionally poor fish recruitment, with little difference between these two regimes. Worst Case 1 and 2 were considerably lower than any of the other scenarios tested (Figure 2.2, Table 2.5), primarily due to the extended closed mouth phases during winter and early spring, and the effect that this has on marine fish recruitment into the system.

Fig. 2.2 Mean Fish Recruitment Index (FRI) values (1925-1994) under eight different scenarios: 1 = Reference State, 2 = Present State, 3 = River Category A, 4 = River Category B, 5 = River Category C, 6 = River Category D, 7 = Worst Case 1, 8 = Worst Case 2

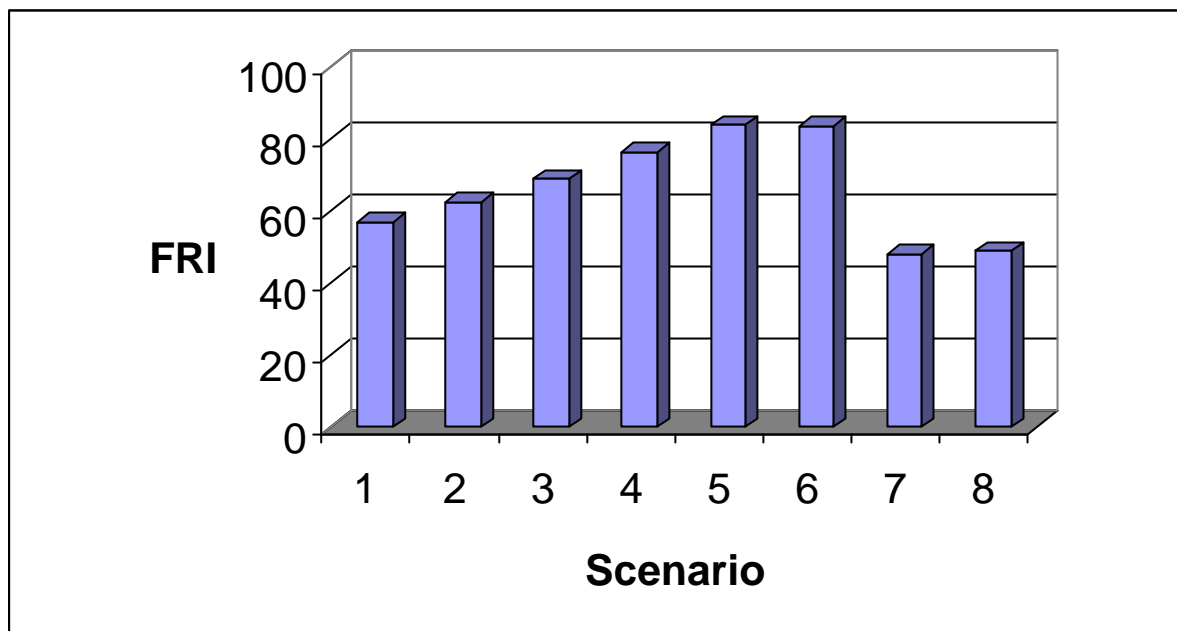


Table 2.5 Mean annual (1925-1974) Fish Recruitment Indices (FRI) under eight different scenarios

Year	Reference	Present	Category A	Category B	Category C	Category D	Worst 1	Worst 2
1925	61	80	74	89	102	103	80	81
1926	49	53	66	80	88	92	53	56
1927	64	72	73	84	99	104	58	58
1928	54	81	72	87	104	103	58	58
1929	41	46	63	68	58	57	33	38
1930	78	66	82	93	96	102	40	40
1931	84	79	90	92	91	83	20	20
1932	81	79	98	97	103	101	62	60
1933	36	42	51	60	67	70	27	28
1934	50	52	60	61	68	68	39	38
1935	65	47	78	83	94	85	18	17
1936	46	47	48	50	50	56	18	19
1937	64	68	72	86	95	92	48	48
1938	42	58	54	64	74	71	50	50
1939	46	62	64	71	79	76	60	59
1940	55	49	62	58	63	66	33	34
1941	74	75	83	90	84	81	23	22
1942	19	26	28	31	33	36	23	28
1943	30	35	35	41	48	40	28	28
1944	69	79	81	89	95	98	46	45
1945	69	47	72	76	89	90	39	39
1946	61	76	77	89	106	105	67	74
1947	45	45	65	69	69	73	27	33
1948	70	71	81	88	93	98	41	45
1949	54	66	69	80	93	91	56	52
1950	69	81	86	95	110	112	72	70

Year	Reference	Present	Category A	Category B	Category C	Category D	Worst 1	Worst 2
1951	65	77	73	84	98	96	59	64
1952	60	65	71	78	88	88	44	45
1953	65	78	75	86	98	97	66	66
1954	42	30	54	53	54	52	26	26
1955	67	74	79	82	94	97	52	49
1956	34	45	45	51	60	54	41	45
1957	44	41	50	51	57	50	32	35
1958	59	74	73	85	100	99	61	59
1959	59	71	74	88	96	99	80	81
1960	57	66	72	75	75	80	48	50
1961	67	68	76	88	93	97	62	63
1962	47	58	67	72	71	77	52	56
1963	65	81	81	89	98	98	58	58
1964	49	70	76	79	87	85	47	47
1965	77	83	84	92	102	107	53	55
1966	55	53	64	67	78	60	26	34
1967	89	85	98	109	120	106	56	55
1968	74	81	80	91	106	104	61	62
1969	63	81	77	89	104	104	87	85
1970	57	80	74	89	108	106	80	86
1971	54	59	65	79	83	88	58	59
1972	68	78	82	95	108	100	57	59
1973	48	50	61	69	76	74	61	62
1974	50	43	55	63	65	68	36	40
1975	38	42	49	55	63	58	40	40
1976	52	58	62	70	80	86	68	71
1977	49	58	59	67	80	79	51	52
1978	40	59	65	73	83	80	57	56
1979	61	80	66	80	92	97	42	47
1980	50	65	60	72	81	80	41	43
1981	76	83	84	90	102	105	81	77
1982	85	92	105	110	115	117	40	42
1983	40	55	52	61	74	71	32	31
1984	67	69	71	81	90	88	49	51
1985	42	42	58	67	74	76	43	42
1986	37	52	49	61	73	70	49	52
1987	33	42	39	44	50	46	28	31
1988	52	50	63	65	70	72	39	40
1989	60	53	74	80	74	79	36	36
1990	72	61	81	83	75	70	32	33
1991	47	46	67	72	75	78	53	52
1992	63	57	66	77	86	92	47	47
1993	38	47	61	63	63	64	55	58
1994	91	98	103	109	107	112	50	43
Mean	56.89	62.57	68.88	76.53	83.97	83.66	47.97	48.95
S.E.	1.78	1.90	1.77	1.91	2.17	2.25	1.92	1.89
Median	56.76	63.42	71.04	79.45	86.46	85.53	48.68	48.21
Count	70	70	70	70	70	70	70	70

2.4 CONCLUSIONS

The following preliminary conclusions have been arrived at, based on sampling undertaken during this and previous studies:

- (1) The Thukela Estuary, by virtue of its limited and fluctuating estuarine habitats, does not support a rich or diverse ichthyofauna. In comparison with other medium and large estuaries in the region, this system does not rank highly as a prime fish habitat.
- (2) Poor zooplankton and zoobenthic invertebrate resources have contributed to the paucity of carnivorous fish species.
- (3) High river flows tend to reduce the penetration of seawater into the estuary, thereby limiting the nursery areas available to many marine fish species.
- (4) Winter closure of the estuary mouth would be beneficial to juvenile fishes already in the system, since it would increase both the surface area and volume of aquatic nursery areas.
- (5) Prolonged estuary mouth closure leading to oligohaline or fresh conditions would be detrimental to marine species, and could result in fish kills if low salinities coincided with sudden declines in water temperature.
- (6) Perhaps the most important function of the Thukela Estuary is to act a conduit for migrating anguillid eel larvae. These migrations occur during spring and early summer when the estuary mouth is normally open. Adult eels leaving the river during their spawning migration to the sea would also require an open mouth condition.
- (7) Preliminary FRI analyses indicate that "River Category" A, B, C and D scenarios will still allow a healthy fish community to be maintained within the estuary. However, Worst Case 1 and 2 scenarios are likely to result in a considerably reduced ichthyofauna and the blocking of certain fish migrations between the sea, estuary and river catchment.
- (8) These preliminary studies have highlighted that further research is urgently required to improve our understanding of both the biotic and abiotic environment, and how the ichthyofauna responds to the river that acts with frightening suddenness (English translation of the Zulu word Thukela). Indeed, in some research areas (e.g. conditions during the closed mouth phase of the estuary), our understanding is negligible due to the fact that the mouth has remained continuously open for the past 7 years.

2.5 FURTHER STUDIES

No work has been conducted on the fishes of the Thukela Estuary under closed mouth conditions. Since this phase is likely to occur with increasing frequency and duration in the future, it is important that a pilot study be undertaken to determine how the various fish species respond to such an event. The study should be conducted in conjunction with an assessment of the responses of other biotic and abiotic components (e.g. benthic invertebrates and physico-chemical monitoring) to mouth closure.

2.6 ACKNOWLEDGEMENTS

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Appendix H

Birds of the Thukela Estuary

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1 INTRODUCTION

The assessment of the current status of the avifauna of the Thukela Estuary was derived from three data collection periods that occurred as progressive parts of the Estuarine Freshwater Requirements (EFR) studies during 1996 (one winter count), 1997/98 (12 monthly counts) and 2001/02 (winter & summer count). The data from the 1997/98 sampling period is the most comprehensive and has set the scene for this study. It has supplemented data collected during the other periods.

2 AVIFAUNAL CHARACTERISTICS OF THE THUKELA ESTUARY

Data on the avifauna of the Thukela is almost non-existent, with only two recorded counts having been conducted. The count obtained for water birds utilising the Thukela Estuary by Ryan *et al.* (1986) was 2 250 individuals comprising 32 species. However, this was based on a single undated count made during the summer of either 1980 or 1981. The count obtained during the June 1996 survey (Cyrus 1997) and conducted for the initial assessment of the Thukela EFR, comprised 406 birds of 23 species (Table 2.1). At first glance it would appear as if the Thukela had decreased in importance for aquatic birds, as a result of the decline in numbers and species over the ten year period. However, it is not relevant to compare these counts, as the surveys were conducted during different seasons. The Palaeartic migrants which utilise the estuary during the summer months were absent from the winter count.

2.1 CURRENT AVIFAUNAL CHARACTERISTICS OF THE THUKELA ESTUARY

The 1997/98 survey spanning a one year period, provided a complete set of seasonal data which was firstly consecutive and secondly, together with the other data confirmed that three major groupings of water birds occurred (Cyrus 1997). This is consistent with what is found in other estuaries in the area as well as KwaZulu-Natal, that support water associated birds (Day 1981). The three groups categorising estuarine associated birds are:

- A summer fauna, dominated by Palaeartic migrants, which utilise the estuary for feeding;
- a winter fauna which utilise the estuary for feeding; and
- a fauna which uses the system predominantly as a roosting site with most feeding taking place at sea (the species composition of roosting birds changes according to season)

The 1997/98 data (Table 2.1) showed that the Thukela held a typical estuarine associated water bird fauna. A total of 54 species were counted with the highest and lowest diversities in September (34 species) and July (20 species), respectively. As would be expected, the greatest numbers were present during summer (December 1997 - February 1998) due to the influx of migrant birds. Summer data indicated that both resident and Palaeartic migrant waders are utilising the estuary with the latter dominating the fauna during these months. Over 45% of the entire bird count for the system constituted benthic invertebrate feeders and of these, 40% were wader species. Of the remaining birds utilising the estuarine area, equal numbers (17%) were piscivorous feeders and roosting species. Large numbers of terns were also present at the estuary, but >90% were using the Thukela as a roosting site and flying offshore to feed. Tern numbers peaked during December (2 824), decreasing to 1 166 in January and tailing off to 301 in February. The tern population was primarily dominated by the Common and Little Terns. Altogether, nine tern species were recorded with some interesting once-off appearances of certain species, Black and Whitewinged Terns in autumn, Whiskered Tern in spring and a couple of Lesser Crested Terns in the summer/autumn period of 1998.

When current numbers were compared to those that had been counted in the past, it was found that the present summer surveys were very similar to data obtained by Ryan *et al.* (1986). Their count totalled 2 250 birds from 31 species as opposed to the current survey's data where there was a mean of 2 158 birds from 33 species over the three summer months. The 2001/02 summer count (Table 2.3) provided the highest density to date (4,706 birds), however this was only due to an increased number of roosting birds present and served to highlight the Estuaries role in that regard.

Table 2.2 Avifauna data from the Thukela Estuary collected between April 1997 and March 1998. Symbols depicting Red Data classifications are assigned to the relevant species

Avifauna	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
White Pelican (* / 6)					5	20		11		1	3	3
Pinkbacked Pelican (* / 7)			2		2	5	3					1
Whitebreasted Cormorant		1		4		9	3	5		1		
Reed Cormorant		1	1	2	7							
Grey Heron	8	11	7	3	3	3	1	2	6	5	4	1
Blackheaded Heron										5		1
Little Egret	5	4	12	16	12	16	5	5			1	
Cattle Egret									1			
Woollynecked Stork	1	6								2	2	2
Hadeda			1									
African Spoonbill	9	1		2	2	6	7	14	20	4		2
Greater Flamingo (** / 7)		1	1			1						
Egyptian Goose	3	16	2	5	10	6		7			1	
Yellowbilled Duck	11	19	3			4			1		4	16
African Black Duck		1										
Hottentot Teal												4
Cape Shoveler		5										
Spurwinged Goose		5	2									
African Fish Eagle	3	2	1	2	2	2			1	1		
Osprey	1											
Ringed Plover	1							12	18	3	8	7
Whitefronted Plover		43	60	58	40	7	4	32	69	23	44	24
Kittlitz's Plover		1	1									
Threebanded Sandplover	6	9	4	2	2	4		1	3	4		
Mongolian Sandplover										1		
Greater Sandplover								2				
Blacksmith Plover		2	2									
Turnstone						2	5	1				1
Common Sandpiper	2					4	1	2	1	2	3	1
Wood Sandpiper	2					1		1	1	2	2	
Marsh Sandpiper							1	2				1
Greenshank	13	3	5	13	19	16	17	64	49	12	11	47
Curlew Sandpiper	12			11	9	22	11	163	457	277	181	535
Little Stint	106				2	265	141	201	309	194	172	181
Sanderling	8	3	10	5	8		108	7	72	38	115	534
Ruff											1	

Avifauna	August 2001	December 2002
Spurwinged Goose	4	
African Fish Eagle	3	2
Osprey		
Purple Galenule	1	
Grey Plover		1
Ringed Plover		1
Whitefronted Plover	7	41
Kittlitz's Plover		4
Threebanded Sandplover		1
Blacksmith Plover	1	1
Common Sandpiper	1	2
Greenshank	7	1
Curlew Sandpiper		10
Little Stint	8	5
Sanderling		2
Kelp Gull		1
Greyheaded Gull	10	5
Caspian Tern (* / 10)	2	
Swift Tern	158	1
Sandwich Tern		5
Common Terns	1	3500+
Little Tern		100+
Pied Kingfisher	4	3
Malachite Kingfisher	2	2
Cape Wagtail	3	2
Total numbers counted	245	4,706
Number of different spp	23	26

*: Rare

7, 10: Species Conservation Action Category

Table 2.4 Comparison of bird abundance, number of species and density per kilometre between earliest and most recent surveys

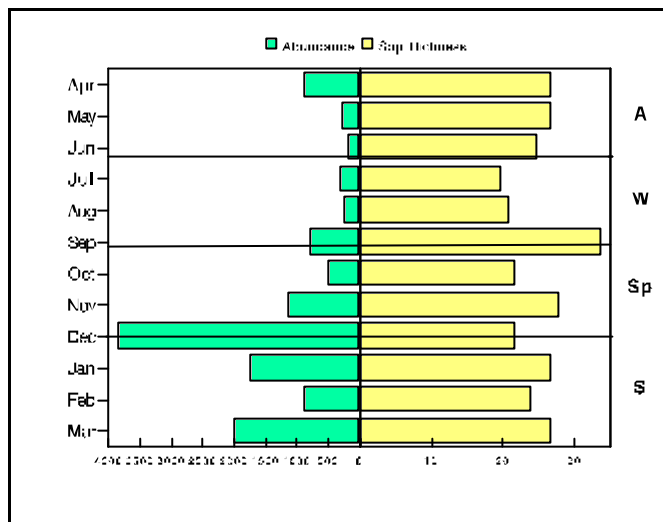
	No. of Birds	No. of Species	No. per km ⁻¹
Summer (1980/1981)	342	28	34.2
Summer (1997/1998)	701	15	175.3
Summer (2002)	4,706	26	1,176.9

On this basis, the Thukela has certainly increased in importance for benthic invertebrate feeding waders utilising the system. However, it must also be stated that Ryan *et al.* (1986) based their calculation using 10km of shoreline, whereas the current study was contained within a 1km² area. The extrapolation may therefore result in the figure obtained for the current study being slightly understated.

3 STATISTICAL ANALYSIS OF THUKELA AVIFAUNAL DATA

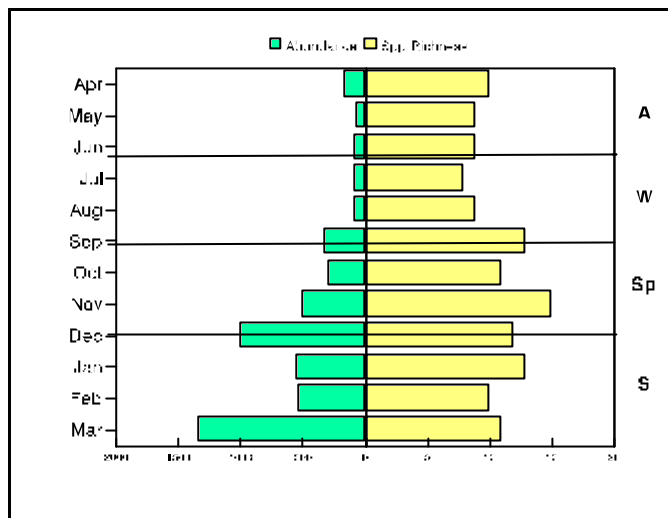
A plot of the seasonal abundance and species richness of the avifauna over the one year study period, revealed that there was a strong seasonal effect in terms of abundance, but this was not as clearly defined with regard to species richness (Figure 3.1). This was attributed to the fact that the data included all species counted every month, and therefore did not consider that certain species either appeared or disappeared over certain seasons. Specifically, the numbers presented in the plot were not necessarily the same species counted each survey. Nonetheless, the relative importance of the Thukela for all aquatic birds was highlighted during summer 1997, particularly during the month of December, when approximately 3 800 birds were counted for a single survey.

Fig. 3.1 Plot of seasonal abundance and species richness of all avifauna from April 1997 to March 1998



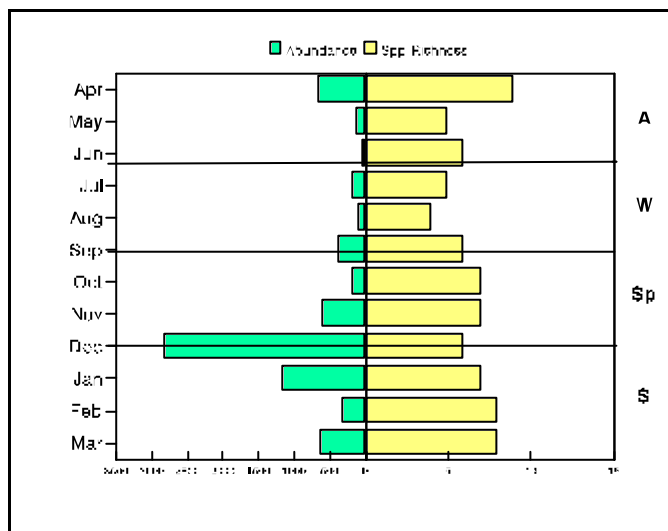
The importance of the Thukela Estuary as a major resource utilised by both resident and migrant birds can really only be estimated by considering those species that feed on benthic invertebrates. Figure 3.2 is a plot of the number of these birds as well as their richness on both a monthly and seasonal basis. From this, it was deducible that numbers belonging to this group were low when the study commenced in April 1997 as most summer migrants had already left the area. By spring 1997 (September) numbers began to steadily increase as migrants returned from the north and were at their maximum during March (autumn) 1998. Although there was a peak in abundance (approximately 1 000 benthic invertebrate feeders) during December, it should be noted that this did not constitute the majority of total abundance when all species and feeding categories were considered together (Figure 3.1). In terms of different species feeding in the estuary, the greatest variation occurred during the spring and summer months.

Fig. 3.2 Plot of seasonal abundance and species richness of macrobenthic feeding avifauna from April 1997 to March 1998



The only other utilisation of the Thukela Estuary by migrant species was for roosting purposes. This group of estuarine associated birds provided the major contribution towards the total abundance of birds at the Thukela (Figure 3.3). This was particularly evident during midsummer 1997 (December). Despite this, this group of birds of which the majority were terns, did not contribute greatly towards the overall species richness.

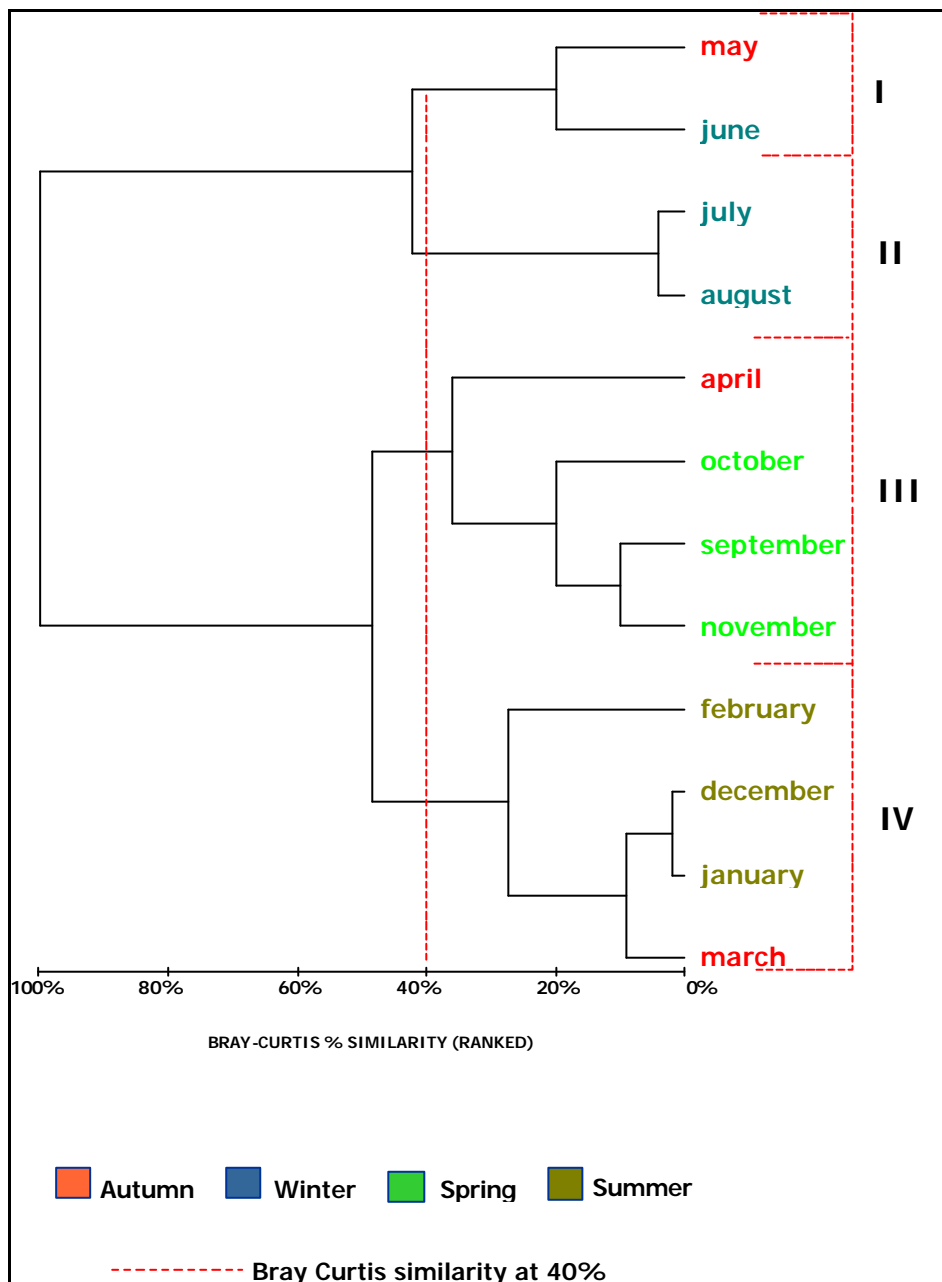
Fig. 3.3 Plot of seasonal abundance and species richness of roosting avifauna from April 1997 to March 1998



Bray-Curtis similarity matrices and dendrograms were calculated for each sampling month as well as for each taxon sampled throughout the year. The results were then used as input to nonmetric multidimensional scaling multivariate analyses. The bird count similarity of each monthly bird count is given in Figure 3.4. Although there was a seasonal effect in terms of abundance and species present it was not clearly defined. The dendrogram of birds associated with the Thukela Estuary indicated that the autumn months were very variable in terms of either abundance or occurrence of certain species. This was shown by each of the autumn months (March, April and May) as being closely associated with each of the other three seasons (winter, spring and summer). Although spring and summer bird counts were discrete clusters on their own (Figure 3.4: groups III and IV at Bray-Curtis similarity of 40%) winter months were not as closely related to each other as this. The data showed that the

June count was more similar to May (end of autumn), than the following winter months (July and August).

Fig. 3.4 Bray-Curtis ranked cluster analysis of monthly avifaunal surveys between April 1997 and March 1998 at the Thukela Estuary. A line is drawn to indicate a 40 percent level of similarity



The resultant NMDS plot (stress value indicated a very good ordination and highly representative of the data) highlighted the closeness of counts from each of the spring and summer months (Figure 3.5). The plot also gave some idea as to how fragmented the autumn, and to a lesser extent, winter counts were. Counts of the bird fauna from the Thukela Estuary reflected the inherent seasonal nature of this type of data and this is in contrast to that of the macrofauna, where no seasonal effects were observable.

The inverse analyses of these data (on species rather than samples) showed more fragmented relationships between the different species. For the purposes of graphically showing this, each species was assigned a code according to its major utilisation of the Thukela. On the basis of this, all birds from the system could therefore be divided into three groups:

- Those that feed on benthic invertebrates (coded BI).
- Those that are primarily piscivorous (coded F).
- Those that roost within, or adjacent to the system (coded R).

Fig. 3.5 NMDS of monthly avifaunal surveys between April 1997 and March 1998 at the Thukela Estuary. A line is drawn to indicate a 40 percent level of similarity

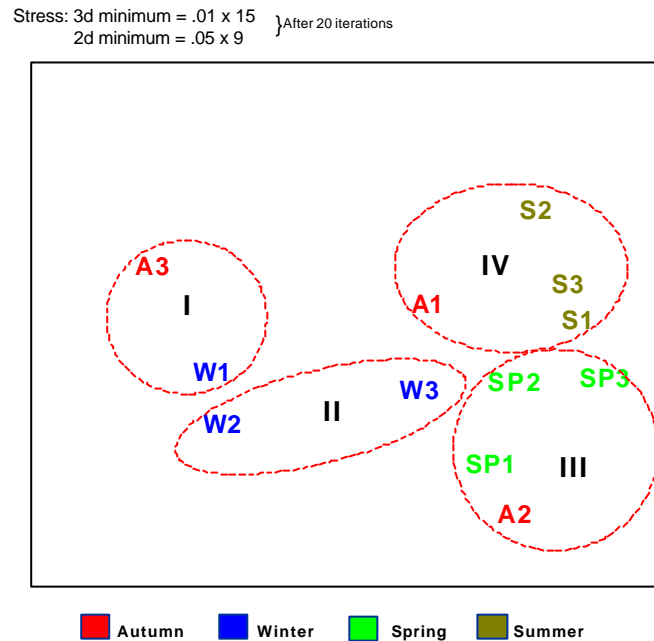


Figure 4.1 represents the NMDS plot of these data. Benthic invertebrate feeders form the interface of the other two utilisation categories. That is, species that feed on fish are more or less separated from those that only roost at the Thukela. The reason for this may be that most of the piscivorous species are resident and are therefore non-seasonal, whereas most of the roosting species are highly migratory. The waders are a group of birds with species feeding during the winter months as well as others feeding in the summer.

4 IMPORTANCE OF THE THUKELA ESTUARY FOR AVIFAUNA

The water bird fauna of the Thukela Estuary was in the earliest comprehensive study by Ryan *et al.* (1986) considered to be of some significance in the KwaZulu-Natal context, and worthy of being given some conservation status. In addition to the densities of feeding birds present the number of migrant terns present during both summer and winter accentuated it's importance as a site for estuarine associated avifauna.

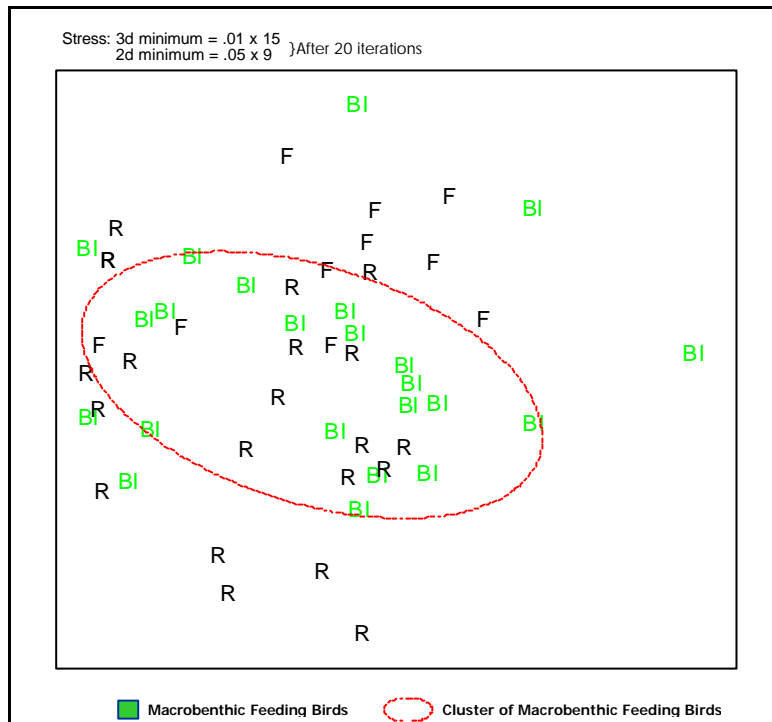
Turpie (1995) also indicated the importance of the Thukela as a water bird site in the South African context. However, the status afforded to the Thukela as only being given the rank of 'average' cannot be considered accurate in the current sense for two reasons. Firstly, the status assigned to 42 estuaries around South Africa's coastline by Turpie (1995) was based on data collected from estuaries which were by that time almost a decade out of date. Secondly, during the intervening time substantial anthropogenic and climatic changes took place to physically alter many of the ranked systems (Cyrus 1997).

Utilisation of the Thukela has not decreased in the years following these studies. The importance of this year long survey in obtaining seasonal counts of the aquatic avifauna feeding and roosting within the system, will be invaluable in attempting to re-evaluate the conservation status of the Thukela. The fact that the density of birds has not declined over the recent years is surprising, given the fact that there have been an undoubtable increase in agricultural and industrial anthropogenic uses of the estuary. This is in addition to the many anthropogenic social uses of the system. The latter include intensive utilisation of the system and surfzone by recreational and subsistence (legal and illegal) fishermen often accompanied by heavy beach vehicle traffic. This leaves fewer options for roosting terns to use the beach, and they therefore maximise use of areas within the backwaters as they are exposed. They do however, return to the water edge once the vehicle and other traffic subsides at night (*pers. obs.*). This also has implications for non-roosting birds who may be utilising the beach to feed as well as nest and rear young.

The Richards Bay area was once categorised as being one of the most important in the province for wading birds. It was secondary in position to St Lucia which was given primary status for supporting large numbers of these avifauna (Ryan *et al.* 1986). Since that time, Richards Bay has been severely impacted resulting in substantial decreases in migrant waders (*pers. obs.*). This may be the reason why numbers at the Thukela and other systems have remained the same, and it should be noted that this is of significance in a provincial context.

Fig. 4.1

NMDS result of inverse analyses (on utilisation categories) of avifauna at the Thukela Estuary between April 1997 and March 1998. A line is drawn to indicate macrobenthic feeders



5 IMPORTANCE OF THE THUKELA ESTUARY FOR RED DATA LISTED SPECIES

The Red Data species are limited to those which have been recorded as breeding in the South African region. Non-breeding migrants and visiting species are not included any of the categories as they are usually seasonal populations (Brooke 1984). The principal action required in this respect is to therefore protect the specialised habitats (coastal wetlands and estuaries) that they use. Of the 108 species that occur in the South African Red Data listed bird species, four have been recorded at the Thukela Estuary on more than one occasion. Two of the species the Greater Flamingo and Caspian Tern were also recorded in past surveys (Table 2.1). Since then Pinkbacked and White Pelicans have also begun to utilise the estuary for feeding purposes (Table 2.2). The latter to a greater extent in the spring of 1997, when 20 individuals were observed at one time. Of these four Red Data species, three have been given a 'rare' status in South Africa, and these represent 7% of the 42 species that are considered to be rare in the country. The 'rare' avifaunal species utilising the Thukela Estuary at the moment are the Pinkbacked and White Pelicans and Caspian Terns. The other Red Data listed species is the Greater Flamingo (an occasional breeder in South Africa), which has been given an 'Interdeterminate' status, and represents 2% of the birds in this category.

6 THE EFFECT OF MOUTH CLOSURE ON THE AVIFAUNA

The effects that this may have on the avifauna are considered in relation to the feeding groups of the different species which inhabit the Thukela Estuary.

6.1 PISCIVOROUS PREDATORS (EXCLUDING ROOSTING SPECIES)

Unless there is a major decrease in fish densities (lack of recruitment through the closed mouth). This feeding category of bird will not be affected, if these fauna are able to capture their prey from the air (Day 1981; Cyrus 1997). However, an increase in water depth and reduction in the areas of shallow water may have some impact on their hunting success. Wading species, which include herons and egrets that hunt fish in the shallow waters will be affected by a reduction of suitable hunting areas, particularly if the shallow backwaters are permanently inundated and deepen. Birds such as cormorants or darters may be relatively unaffected as they hunt their prey while swimming underwater. Of the 54 water associated species recorded at the Thukela Estuary from April 1997 to March 1998, 19% were piscivorous feeders. This was thought to be important when one considers that from previously conducted surveys, a figure of 26% was assigned to this feeding group. However, this is not a 'real' reduction in piscivorous feeders, but was the result of an increase in the number of benthic invertebrate feeders present.

6.2 BENTHIC INVERTEBRATE FEEDERS

The most significant impact on the avifauna of the Thukela Estuary, resulting from more frequent and extended mouth closure would be on the benthic invertebrate feeders. This in part will be due to the fact that the intertidal sand and mudflats will become totally inundated for extended periods, at depths that would make them inaccessible to waders. Over 85% of the total abundance of the macrobenthos was contributed to by aquatic oligochaetes. These invertebrates are freshwater species and presumably, would be unlikely to survive within a system that is fairly estuarine in nature. However, these animals may well be replaced by others of an estuarine component. The reduction in benthic feeding birds would last for the entire period that the mouth remains closed. Following the breaching of the mouth, and depending on the period of inundation, there may also be reduced opportunities for the waders, as previously mentioned components of the benthic fauna may also have been adversely affected by the period of inundation. The impact on this group will be greater when mouth closure occurs during the summer, as the majority of the benthic feeding waders are summer migrants from the Palaearctic regions. Birds belonging to this feeding group would then probably move out in search of other estuarine or wetland areas where they could feed. However, these areas may not be available to them as due to the reduction of coastal aquatic habitats, most niches are occupied. This is of further concern as currently most estuarine and wetland systems are more anthropogenically impacted than they have been in the past (Cyrus 1997). At the conclusion of the present sampling survey, 41% of all the bird species counted were from this feeding group. This is similar to the figure calculated for this feeding category by Cyrus (1997) during the previous survey but was from a total of 40 water associated species.

6.3 SPECIES USING THE ESTUARY PREDOMINANTLY AS A ROOSTING SITE

More frequent closure of the mouth would affect this group from the point of view of a reduction in roosting sites. While terns, of both the summer and winter species groups, are known to roost at estuaries when their mouths are closed they do show a distinct preference for sand spits either at the immediate mouth area or where these occur elsewhere in the tidal area of the estuary. Utilisation of the estuary for roosting purposes may also be tied to the availability of resources within or at sea adjacent to the system. The implications of more frequent mouth closure may affect the offshore conditions, in the immediate vicinity of the mouth, due to reduced volumes of water and what is suspended in this outflow to sea. The implications of this are that it will not only affect the tern populations feeding at the Thukela

mouth, but also the offshore ecosystems the outflow supports. Finally, although areas of open beach will theoretically be available for roosting purposes, it is not an envisaged feasible option, due to the nature of the aforementioned beach traffic.

On the basis of the above it can be stated that any reduction in tidal exchange due to the closure of the Thukela Estuary mouth will result in a reduction in the wader population. This is because they are dependent on regular exposure of tidal mud and sandflats. These same conditions could however favour piscivorous birds. The results of this study have shown that there will be significant impacts on the bird fauna of the Thukela Estuary as a result of reduced flow, and resulting in extended periods of mouth closure. However, these impacts can be minimised if the system were to remain open/intermittently open during the months of September through to April when the majority of invertebrate feeders are present.

7 MACROBENTHOS AND AVIFAUNA

The number of benthic invertebrate feeding birds associated with the Thukela Estuary is greater than any other group that utilises the system. The dominance of freshwater macrobenthos throughout the lower or 'estuarine' part of the system, evidently points to this being the major food source for benthic invertebrate feeding water birds. This has implications for the success of this group when the future conditions of system are considered.

7.1 CONTRIBUTIONS OF MACROBENTHOS TOWARDS BIRD DIET

The benthic invertebrate feeders were primarily concentrated around macrobenthic sampling sites characterised by a fairly fine sandy/muddy substrate. To determine the primary source of food and to establish whether it was of a freshwater or estuarine component, the macrobenthic taxa were ordered according to their total contribution at each site. The five invertebrate taxa that contributed the greatest towards total density per square metre were then noted. These are presented in Table 7.1.

Table 7.1 Percentage contributions of the five most abundant macrobenthic taxa at four sites within the backwater area of the Thukela Estuary

	Site 1		Site 2		Site 3		Site 6	
	taxa	%	taxa	%	taxa	%	taxa	%
1	Oligochaeta	•	Oligochaeta	•	Oligochaeta	•	Oligochaeta	•
2	Oligochaeta (eggs)	•	Oligochaeta (eggs)	•	Oligochaeta (eggs)	•	Oligochaeta (eggs)	•
3	Brachyura	•	Polychaeta	•	Polychaeta	•	Isopoda	•
4	Polychaeta	•	Brachyura	•	Diptera (larvae)	•	Mysidacea	•
5	Hemiptera	•	Macrura	•	Brachyura/ Isopoda	•	Diptera (larvae)	•

•: >90% contribution •: <5% contribution •: 1% contribution

Oligochaetes provided the greatest source of food to benthic invertebrate feeders, and contributed >90% of the total macrobenthic densities at all sampling sites within the backwater. Although oligochaete eggs were often present in very large numbers, they only contributed to 5% of the total invertebrate densities at sites 1 and 2. The other invertebrate groups which were found at each of the sites each contributed to <1% of the total density. Although they represented an interesting array of organisms, they were not present in sufficient numbers to be an important source of food. Excluding the oligochaetes, crabs and polychaete worms were commonly dominant amongst the remaining taxa at sites 1, 2 and 3. Mysid and Isopod crustaceans dominated the fauna at site 6. Two points are noteworthy of the invertebrate fauna available for bird consumption. Firstly, the majority of faunal densities at the feeding site (macrobenthic sites 1, 2, 3, and 6) were significantly freshwater in origin and were represented by only one taxa. Secondly, excluding the species responsible for >90% of the overall density, the next dominant taxa were predominantly estuarine.

7.2 IMPLICATIONS OF THE EFFECTS OF REDUCED FLOW ON EXISTING FOOD SOURCES

The implication of a reduction in flow on the invertebrate resources currently available for bird consumption, would be that tidal influence would become more significant and lead to an increase in the overall salinity of the area. This would cause a decline in the number of freshwater species, as few are able to survive under estuarine conditions. Initially, there could also be a temporary decline in populations of waders feeding on invertebrates, as the currently dominant oligochaetes would more than likely be unable to survive the change in salinity regime. However, if conditions remained estuarine for lengthy periods, estuarine species that have been found in the Thukela and others that are present in large numbers in other KwaZulu-Natal estuaries, would begin to colonise and establish themselves. Fauna

that dominate other estuaries with similar substrates along the Zululand coast, include several species of polychaetes and crustaceans such as amphipods, isopods, tanaids, cumaceans and mysids. These estuarine fauna would then presumably provide an alternative source of food for the birds.

It is likely that this estuarine state may take some time to become established and there may be temporary instability within the system. As previously mentioned, temporary unstable states within an estuary initially cause depauperation, albeit for a relatively short period (weeks). Even this short a period may have an impact on the avifauna. A reduction in food resources to levels insufficient to sustain the bird populations utilising the estuary may cause a) resident benthic invertebrate feeders to search elsewhere for a more reliable source of food or b) decrease the importance of the Thukela to Palaearctic migrant waders which would then attempt to utilise other systems to the north and south of the Thukela. However, as all niches are considered full it is likely that they will simply be displaced and lost to the population.

Despite the fact that closure of the Thukela Estuary mouth will not be as frequent in summer as it will be in winter, any such occurrence may have long term implications for the estuarine invertebrates of the system. As a direct result of this, and other forcing factors (inundation, increase in depth etc.), the importance of the Thukela Estuary for water associated birds in KwaZulu-Natal may decrease dramatically.

8 CONCLUSIONS

8.1 GENERAL

This study has indicated the avifaunal variability associated with the Thukela Estuary. Although it is referred to as an estuarine system, due to the volume of outflow the Thukela functioned as a river mouth from April 1997 to March 1998. Its physico-chemical state tended towards one that is closer to riverine than estuarine conditions and the associated macrobenthic fauna were primarily freshwater species found in local rivers. There were however, areas within the system that showed some influx of estuarine organisms when there was a reduction in river outflow. The largest of these areas, referred to as the 'backwater', was subject to less dynamic physical processes than the main channel area containing the bulk of the outflow. It was also an area of sediment deposition from the upper reaches of the system.

The avifauna comprised a relatively diverse population of aquatic birds that included a Palaearctic migrant and a resident component. It is apparent that the system is providing a feeding or roosting ground for birds and perhaps for other displaced aquatic species associated with estuaries, as few of the wetlands remain unimpacted in the surrounding areas. This fact alone lends credence to the significance of the Thukela as an important wetland area for aquatic birds.

8.2 EFFECT OF REDUCED RUNOFF ON THE ESTUARINE HABITAT AND AVIFAUNA

A reduction in flow will result in mouth closure for variable lengths of time. The primary result of this will be inundation of the estuarine area. This would occur more regularly during the winter months but will also extend to summer months during dry years when flow is further reduced. Following mouth closure, the backing up of water flowing into the estuary will result in inundation of the intertidal areas. In addition, normally shallow backwaters will be flooded and deepen for extended periods. The impact of the inundation on the habitats will depend on the period for which the mouth remains closed.

The avifauna will be affected in two ways. Firstly, inundation of certain areas will restrict feeding for certain birds and if macrobenthic numbers were to decrease then less resources would be available for these species. The second impact would be a reduction in the space available for roosting birds that currently use the exposed areas within the backwaters and the beach. If the backwater areas are inundated, the beach (subject to heavy human utilisation) would then be the next best available roosting site.

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APPENDIX I

Detailed Assessment: Quantification of Ecological Reserve Scenarios and Ecological Consequences of Operational Scenarios

Estuary Team

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1 RESERVE ASSESSMENT PROCESS

To derive the water quantity component of the Reserve, runoff scenarios (refer to Section 5.1 in the main report), hierdie moet verander aangesien dit vervang is met scenario report together with an understanding of the present functioning of an estuary, are used to estimate the occurrence and duration of the pre-defined typical Abiotic states within an estuary for each of these flow scenarios. Changes in abiotic characteristics are then assessed in terms of the biological implications (using the EHI). Results from these evaluations are then used to select the 'recommended reserve scenario', 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.

Results from the assessments of the initial and additional set of runoff scenarios are provided in the following chapters.

2 SCENARIO: RIVER CATEGORY A (INITIAL SCENARIO)

2.1 SEASONAL VARIABILITY IN RIVER INFLOW

Monthly simulated runoff data for the River Scenario: Category A is provided in Table 2.2 on the following page. A summary of flow distribution (mean monthly flows in m³/s) for the River Scenario: Category A, derived from the 70-year simulated data set, is provided Table 2.1.

Table 2.1 A summary of flow distribution (mean monthly flows in m³/s) for Scenario: River Category A (derived from 70-year simulated data set)

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
90%ile	48.18	70.09	139.58	277.28	466.55	249.27	98.23	56.57	39.72	30.55	26.88	36.48
80%ile	47.81	69.62	122.41	123.56	352.85	175.17	92.21	56.13	37.31	29.02	26.64	35.16
70%ile	46.86	68.48	112.79	111.13	258.83	134.71	90.34	52.59	32.22	24.84	22.25	25.37
60%ile	42.66	66.77	104.74	102.23	228.82	132.42	86.80	46.35	29.36	22.17	18.24	20.64
50%ile	33.64	62.94	91.48	96.46	211.82	124.51	79.66	42.45	28.44	19.19	16.54	16.02
40%ile	24.94	57.11	77.02	86.09	170.87	110.53	68.77	37.13	25.88	18.17	14.80	14.43
30%ile	19.61	47.06	64.71	69.88	139.49	89.78	53.56	33.00	22.90	16.57	13.87	13.62
20%ile	16.69	33.84	44.62	48.03	100.14	67.98	35.55	22.15	15.87	12.37	10.99	11.94
10%ile	10.75	18.91	24.69	27.06	55.16	35.86	20.33	13.01	9.50	7.60	6.80	8.61
1%ile	7.20	8.67	10.33	13.94	26.31	17.69	13.27	8.79	6.60	5.35	4.85	5.94

2.2 PREDICTED FLOOD REGIME

The post-dam flood regimes are considered the same for all future scenarios.

Higher environmental flood releases at the future dams will result in less spillage, but the relative impact on flood volumes and peaks are considered negligible. The estimated flood peaks with the post-dam scenario are indicated in the table below, and shows a general decrease in peak discharge of about 19% from Present State conditions, and about 27% from Reference State conditions.

Flood recurrence (year)	Flood peak (m ³ /s)
2	850
10	3600
20	5400
50	8700

While the floods peaks would be affected in future, all the floods would still occur similar to the natural frequency.

Table 2.2 Monthly runoff data (in m³/s) for Scenario: River Category A, simulated over a 70-year period

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	AVE
1925	45.57	57.21	36.13	95.49	123.01	75.02	61.88	17.24	25.35	21.57	14.17	36.47	50.76
1926	48.07	68.69	94.48	67.52	211.88	132.01	89.94	32.99	16.83	16.63	17.92	15.36	67.69
1927	46.94	36.55	85.95	86.10	105.13	86.71	65.90	20.02	14.89	7.67	6.64	14.50	48.08
1928	27.96	26.38	68.23	69.95	101.21	133.93	92.95	46.05	39.67	30.61	26.88	36.53	58.36
1929	48.07	69.62	111.18	109.31	158.59	122.10	86.86	37.49	24.52	17.75	15.78	17.38	68.22
1930	19.73	16.26	48.53	110.74	220.88	59.45	35.69	22.25	9.57	16.41	14.53	8.05	48.51
1931	9.30	18.58	11.67	18.37	300.64	140.36	98.01	54.66	39.72	26.95	16.72	13.60	62.38
1932	10.86	33.99	73.93	27.29	55.41	35.97	19.87	12.51	6.60	12.00	13.93	7.65	25.84
1933	7.20	70.09	134.27	925.98	462.89	119.60	90.30	56.52	39.79	30.54	26.88	35.94	166.67
1934	35.70	69.63	412.86	230.87	130.19	102.12	70.94	40.29	31.62	22.96	15.18	11.34	97.81
1935	8.30	18.94	15.29	105.12	268.83	181.06	86.76	70.78	51.67	30.47	17.12	13.21	72.30
1936	21.04	172.71	187.32	273.90	400.32	138.82	25.26	14.01	7.52	6.03	4.85	5.94	104.81
1937	15.26	9.48	112.88	93.67	142.29	46.31	75.21	55.70	32.89	30.61	26.85	25.12	55.52
1938	47.72	64.36	126.94	103.94	639.64	411.81	88.96	47.81	34.69	28.84	26.39	26.79	137.32
1939	40.07	70.09	207.45	87.97	78.85	43.96	27.34	147.59	135.39	30.61	26.63	26.47	76.87
1940	26.95	56.77	129.27	258.00	269.39	148.70	91.48	56.45	30.73	18.13	13.13	10.84	92.48
1941	13.19	12.84	20.48	104.15	261.50	184.71	107.49	53.32	32.03	22.54	19.46	23.69	71.28
1942	41.73	88.21	474.97	479.71	211.75	118.89	552.44	283.04	44.87	65.01	398.50	192.44	245.96
1943	374.13	438.41	248.71	156.94	427.69	209.06	53.33	22.45	38.39	30.53	20.89	36.53	171.42
1944	47.89	56.97	24.88	13.94	36.16	134.71	170.49	44.09	25.08	16.73	9.10	6.79	48.90
1945	7.20	6.86	7.34	49.16	132.95	128.40	87.47	27.65	12.47	7.03	4.89	5.94	39.78
1946	37.07	69.24	65.57	13.94	169.48	129.17	84.11	37.65	30.73	26.92	18.22	14.74	58.07
1947	30.29	69.96	124.02	108.71	157.62	130.50	92.18	50.96	29.33	18.97	13.48	11.87	69.82
1948	21.48	27.74	35.25	93.65	215.43	121.65	90.45	56.02	28.67	17.37	10.36	12.32	60.86
1949	25.65	67.82	112.76	66.55	78.02	132.88	92.93	55.87	36.62	22.97	22.01	20.15	61.19
1950	19.32	26.12	108.50	62.01	59.48	50.32	37.07	21.57	15.94	10.64	26.88	36.41	39.52
1951	46.29	28.28	39.57	116.70	257.69	102.23	59.36	38.24	25.92	25.31	23.27	16.01	64.91
1952	17.99	63.75	99.34	75.07	308.94	133.64	55.43	36.33	21.73	15.63	18.29	18.30	72.04
1953	17.98	57.29	73.30	35.88	256.39	129.11	69.15	47.07	37.21	23.11	14.86	21.36	65.23
1954	48.18	70.09	110.19	356.95	678.20	247.44	77.46	44.53	28.48	19.26	13.44	8.67	141.91
1955	20.68	41.16	78.27	24.44	238.57	134.71	92.90	41.57	28.33	18.81	13.45	13.96	62.24
1956	22.92	69.38	508.07	526.25	188.83	145.23	91.28	56.17	32.29	30.61	26.88	366.55	172.04
1957	535.81	187.24	63.25	236.00	216.03	78.80	100.17	56.56	32.17	18.19	11.05	13.74	129.09
1958	20.00	59.26	102.91	75.31	206.87	78.86	20.39	56.63	39.79	29.74	20.33	16.64	60.56
1959	45.34	68.81	88.48	32.29	95.85	113.46	89.66	56.12	29.39	17.42	13.72	14.32	55.41
1960	25.02	66.73	132.21	101.08	46.83	92.91	91.86	56.46	36.12	22.38	14.73	15.97	58.52
1961	19.08	47.50	64.22	100.37	218.48	91.09	67.46	42.78	23.42	14.91	14.00	14.28	59.80
1962	14.42	66.69	104.08	111.92	149.11	106.13	80.17	37.06	28.89	30.61	26.88	24.57	65.04
1963	24.84	67.95	45.88	97.42	121.87	33.79	35.00	24.42	21.21	18.34	14.52	25.95	44.27
1964	48.23	69.85	82.50	77.75	91.09	17.69	13.27	8.79	32.20	30.52	26.83	36.29	44.58
1965	32.29	40.58	34.22	110.88	209.42	23.76	13.27	12.61	14.29	7.60	8.72	13.35	43.41
1966	16.13	46.06	101.77	117.35	434.51	328.11	184.13	56.63	39.66	26.58	19.30	13.75	115.33
1967	16.09	45.89	55.87	21.86	25.68	21.23	18.47	9.51	6.60	5.35	8.75	13.63	20.74
1968	9.80	24.30	64.71	37.76	72.05	134.35	92.95	56.34	39.65	24.80	17.14	16.30	49.18
1969	47.50	54.79	81.56	48.49	103.74	34.80	13.86	8.79	8.12	7.40	26.55	36.44	39.34
1970	47.80	61.73	30.46	100.00	149.00	34.75	44.68	56.63	39.79	30.13	26.67	24.47	53.84
1971	43.52	49.80	96.86	86.06	227.57	134.59	92.95	46.00	32.87	23.11	16.70	11.96	71.83
1972	16.84	44.87	35.85	15.21	254.45	125.16	84.17	54.60	26.45	14.73	26.80	36.53	61.30
1973	47.02	67.91	84.44	111.73	280.86	132.10	92.31	56.25	37.72	27.79	20.86	14.78	81.15
1974	9.28	67.79	122.01	112.93	576.49	265.72	80.26	47.48	29.24	18.62	13.61	36.53	115.00
1975	47.45	68.39	128.03	441.64	441.28	635.23	271.26	56.63	39.79	30.53	22.81	19.33	183.53
1976	47.47	66.82	85.40	98.76	167.57	94.08	79.15	42.41	19.69	11.59	7.61	36.29	63.07
1977	47.90	65.72	72.18	187.19	342.40	134.59	88.47	52.27	28.41	18.50	16.79	26.28	90.06
1978	48.23	68.81	118.24	69.71	171.86	86.49	26.26	33.36	25.83	21.70	26.88	36.43	61.15
1979	42.10	48.05	52.71	81.21	205.22	101.43	31.32	13.06	7.50	5.89	4.85	34.57	52.32
1980	35.00	57.74	117.15	114.58	499.43	214.93	35.90	35.25	28.47	22.02	24.66	34.96	101.67
1981	28.44	63.32	64.70	46.19	35.25	53.06	53.60	21.76	11.04	7.59	5.91	12.45	33.61
1982	47.83	60.27	22.98	25.01	26.60	17.69	15.41	10.07	8.94	15.31	16.38	13.94	23.37
1983	37.36	70.00	132.21	420.03	394.66	173.69	90.61	46.81	27.00	24.94	26.78	29.15	122.77
1984	46.17	33.23	21.33	84.70	581.66	328.95	31.22	15.16	11.69	9.81	6.02	6.63	98.05
1985	48.17	69.53	106.90	307.73	230.71	123.85	83.97	45.45	26.50	19.13	16.04	14.88	91.07
1986	46.82	62.57	117.23	91.43	254.52	240.02	91.54	35.48	24.75	19.46	26.88	929.21	161.66
1987	566.90	177.52	112.08	138.60	451.01	371.29	107.56	51.72	39.66	30.61	26.72	24.72	174.87
1988	46.45	64.67	121.35	100.96	654.79	278.79	50.47	35.50	27.98	21.33	15.29	11.41	119.08
1989	14.45	70.09	310.63	99.20	52.92	70.12	73.01	42.48	23.40	12.46	16.11	16.04	66.74
1990	16.84	12.62	75.14	119.81	537.33	207.67	71.60	28.91	20.79	17.42	10.73	12.25	94.26
1991	48.23	68.31	117.35	62.49	171.80	84.92	19.61	12.58	7.14	5.35	5.45	6.76	50.83
1992	7.75	52.85	105.73	44.53	214.51	123.59	68.20	28.85	15.58	8.88	6.82	11.79	57.42
1993	48.23	69.67	95.89	94.90	235.80	144.41	81.00	37.17	19.25	15.98	26.52	21.67	74.21
1994	17.73	10.95	16.06	45.03	43.00	54.31	53.47	33.00	29.14	21.01	14.35	9.42	28.96
Median	33.64	62.94	91.48	96.46	211.82	124.51	79.66	42.45	28.44	19.19	16.54	16.02	68.60
Average	50.85	63.60	105.32	131.66	236.29	137.10	79.42	43.86	28.14	20.38	22.69	39.98	79.94
10%ile	10.75	18.91	24.69	27.06	55.16	35.86	20.33	13.01	9.50	7.60	6.80	8.61	39.75

1: Closed < 2.0 2: Open (closed for) 2.0-5.0 3 Open (Saline) 5.0-30 4 Open (Riverine) > 30.0

< 2.0	0	0	0	0	0	0	0	0	0	0	0	0	0.00%
2.0-5.0	0	0	0	0	0	0	0	0	0	0	3	0	0.36%
5.0-30	33	13	8	8	2	4	11	20	43	57	66	54	37.98%
> 30.0	37	57	62	62	68	66	59	50	27	13	1	16	61.67%

2.3 PREDICTED CHANGES IN SEDIMENT PROCESSES AND CHARACTERISTICS

Key expected changes from present to future scenarios:

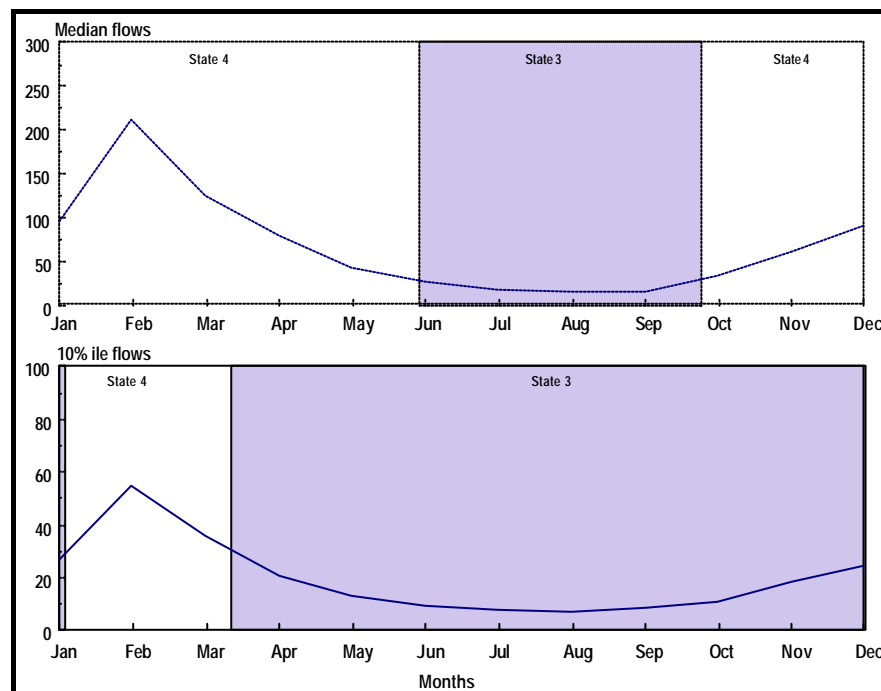
- Estuary length similar at about 5km.
- Estuary width decrease by 11%.
- Flood peaks decrease by 19%, with lower sediment transport capacity.
- Mean flow velocities will decrease only slightly.
- General morphological processes similar in both scenarios.
- Deeper estuary by about 0.3m (median) and slightly steeper bed slope.
- Percentage fine sediment could decrease by a third, during periods without large floods, from May to October.

Possible higher future sediment yield will create shorter and shallower estuary

2.4 PREDICTED OCCURRENCE AND DURATION OF DIFFERENT ABIOTIC STATES

The occurrence and duration of the different Abiotic States under Scenario: River Category A are illustrated in the simulated monthly river flow table (Table 2.2).

To provide a conceptual overview of the annual distribution of Abiotic States under Scenario: River Category A, median monthly flows and 10%ile flows were used to depict the situation for normal and drought periods, respectively:



2.5 PREDICTED CHANGES IN BIOTIC CHARACTERISTICS

<p>MICROALGAE</p> <p>Phytoplankton: Spatial and temporal distribution of phytoplankton would resemble that of the reference state typified by a marine dominated community in the lower reaches and freshwater species in the upper reaches of the estuary.</p> <p>Confidence: Medium</p> <p>Benthic microalgae: The estuary will be characterised by Abiotic States 3 and 4. As a result, the microalgal community will range from fresh/brackish (State 3) to freshwater (State 4) species. Reduced sediment yield will cause the estuary to become shorter, narrower, deeper and the banks steeper. This will reduce the total area available for estuarine benthic microalgae, resulting in a lower total biomass for the estuary. The intertidal area will become narrower and the subtidal area will become deeper, resulting in a further decrease in total benthic microalgal biomass for the entire estuary. Conditions are expected to be more stable so benthic biomass and species richness could increase.</p> <p>Confidence: Medium</p>
<p>MACROPHYTES</p> <p>The decrease in the magnitude of major floods will mean a less dynamic estuary, less uprooting of reeds and sedges during floods and thus these plants can be expected to occupy a larger area. A number of opportunistic species may be lost. The nitrate and phosphate concentrations are not expected to change from present conditions and therefore nuisance aquatics such as <i>Eichhornia crassipes</i> (water hyacinth) may still be present. The estuary will become shorter and deeper, which will probably have little effect on the macrophytes as overall the post-dam fluvial morphology will be similar.</p> <p>Confidence: Medium</p>
<p>INVERTEBRATES</p> <p>Zooplankton: Zooplankton community should be similar to the reference state.</p> <p>Confidence: Low</p> <p>Macroinvertebrates: With a river dominated system just under one third of the time at Abiotic State 4 and in Abiotic State 3 for a predicted 38% of the time, the macroinvertebrates will be similar (species richness) to those in the reference condition. However, abundance may decrease slightly (shift towards estuarine species that are not present in such numbers) even in the more sheltered areas of the estuary with the settlement of second order colonising species (molluscs and crustaceans). The predicted deepening of the system will have an insignificant effect on these fauna.</p> <p>Confidence: Medium</p> <p>Macrocrustacea: The macrocrustacean community would be similar to that of the reference state characterised by some marine species in the lower reaches and dominated by brackish and freshwater species in the middle and upper reaches.</p> <p>Confidence: Low</p>
<p>FISH</p> <p>The decline in length and width of the estuary will impact negatively on the abundance of estuarine and marine fish species capable of being supported by the estuary. The deepening of the estuary by about 1m will facilitate an increased occupation of the system by larger fish, including piscivorous species that are currently absent from the system. The nursery role of the estuary for juvenile marine and estuarine fish species will be reduced compared to the Present State.</p> <p>Confidence: Low</p>
<p>BIRDS</p> <p>The decline in length and width of the estuary as well as some deepening, will impact negatively on the abundance of benthic feeding birds present. The intertidal areas will decrease and with this the accessibility to the benthic food sources. Piscivores and roosting species will not be affected to any degree.</p> <p>Confidence: Low</p>

2.6 ESTUARINE HEALTH SCORE ASSESSMENT FOR SCENARIO: RIVER CATEGORY A

Hydrology

Variable	Score	Motivation	Confidence
a. % similarity in period of low flows	100	No marked deviation of Abiotic States from the Reference Condition to Scenario: River Category A.	Medium
b. % similarity in the magnitude of major floods (e.g. 1:20, 1:50 and 1:100) in comparison with the reference condition	73	Based on statistical analysis of observed present and simulated post-dam floods, assuming new dams are in place (27% decrease in flood peaks from Reference Condition)	High
Hydrology score	89		

Hydrodynamics and mouth condition

Variable	Score	Motivation	Confidence
Change in mean duration of closure over a 70-year period	100	No marked deviation of Abiotic States from the Reference Condition to Scenario: River Category A.	Low
Hydrodynamic score	100		

Water quality

Variable	Score	Motivation	Confidence
1. Change in longitudinal salinity gradient (%) and vertical salinity stratification	100	No marked deviation of Abiotic States from the Reference Condition to Scenario: River Category A.	Medium
2a. Nitrate/phosphate concentration in the estuary	70	Similar to the Present State, assuming potential impacts of Industrial area at Mandini remains intact.	Low
2b. Suspended solids in inflowing freshwater	50	Similar to the Present State, assuming potential impacts of Industrial area at Mandini and other catchment activities remains intact.	Low
2c. Dissolved oxygen (DO) in estuary	80	Similar to the Present State, assuming potential impacts of Industrial area at Mandini remains intact.	Low
2d. Levels of toxins	100	Similar to the Present State, i.e. no marked difference from Reference Condition.	Medium
Water quality score	70		

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 exposed	60	Assuming that Scenarios for River Category A-D can only be achieved with additional dam development in the catchment, resulting in further flood intenuation and/or sediment yield, although not much different from Present State.	High
1b	% similarity in sand fraction relative to total sand and mud	60	Assuming that Scenarios for River Category A-D can only be achieved with additional dam development in the catchment, resulting in further flood intenuation and/or sediment yield, although not much different from Present State.	High
2	Resemblance of subtidal estuary to reference condition: depth, bed or channel morphology	75	Flood peaks decrease with future dams. Sediment will be trapped in future dams, but as a result of overgrazing and land use changes, the sediment yield could actually increase.	High
Physical habitat score		67.5		

Microalgae

	Variable	Score	Motivation	Confidence
<i>Phytoplankton</i>				
1.	Species richness	65	Flow conditions and the longitudinal salinity gradient will be similar to that of reference condition. There will be a reduction in the magnitude of major floods, which may change species richness as some of the opportunistic species may be lost.	Medium
2a.	Abundance	80	Phytoplankton densities would be pronounced around the REI zone, low at the mouth and with slight increases of nuisance forms during low flow periods.	Medium
2b.	Community composition	80	Community composition would resemble that of present state; however, a decrease in river inflow would alter phytoplankton composition favouring marine tolerant phytoplankton communities in the lower reaches and freshwater forms in the upper reaches.	Medium
<i>Benthic microalgae</i>				
1.	Species richness	80	Conditions have not changed drastically from the reference condition (States 3 and 4). Slightly higher proportion of mud content in sediment could cause some epipsammic taxa to be replaced by epipellic taxa.	Medium
2a.	Abundance	90	Slightly more stable conditions would favour a slight increase in benthic biomass. Shorter, narrower and deeper estuary will reduce the total biomass of the estuary.	Medium
2b.	Community composition	90	Conditions have not changed drastically from the reference condition (States 3 and 4). Mouth won't close. Slight change from epipsammic community to epipellic community.	Medium
Microalgae score		65		

Macrophytes

Variable	Score	Motivation	Confidence
1. Species richness	75	Because flood peaks are reduced (general decrease in peak discharge of about 19% from present state conditions, and about 27% from reference state conditions) and the estuary is not reset as often as it may have been under present conditions, there may be a loss of opportunistic species. Approximately 85% of the original species remain.	Medium
2a. Abundance	62	The increase in sediment stability as a result of the decrease in flood peaks and lower sediment transport capacity may result in an increase in the area covered by reeds and sedges.	Medium
2b. Community composition	80	A more stable system would mean less weedy species on the floodplain. However, the nitrate and phosphate concentrations are not expected to change from present conditions and therefore nuisance aquatics such as <i>Eichhornia crassipes</i> (water hyacinth) may still be present. There would be an 80% resemblance to the original composition.	Medium
Macrophyte score	62		

Invertebrates

Variable	Score	Motivation	Confidence
<i>Zooplankton</i>			
1. Species richness	100	Species richness of the marine community should not change.	Low
2a. Abundance	80	No major changes expected.	Low
2b. Community composition	100	No major changes expected.	Low
<i>Macroinvertebrates</i>			
1. Species richness	80	Similar species to reference condition, with the inclusion of one or two others during stable states.	Medium
2a. Abundance	70	Although there may be an increase in stability (less flooding frequency and sediment deposition), fauna may decrease slightly due to the settlement of estuarine species (molluscs and crustacean).	Medium
2b. Community composition	70	Freshwater taxa with some brackish water taxa in the lower reaches.	Medium
<i>Macrocrustacea</i>			
1. Species richness	65	Flow conditions and salinity gradients will be similar to present conditions. Some species less tolerant of fine sediment deposition may be lost. With a loss in habitat (macrophytes) it is expected that some of the species may have disappeared. The conduit function of the estuary for species with an obligate marine phase such as <i>Varuna litterata</i> would be maintained.	Medium
2a. Abundance	75	Any increased salinity will favour the intrusion of estuarine species that increase abundance in the short term. However, abundance of species utilising the estuary as a nursery area and breeding habitat such as <i>Macrobrachium</i> would be slightly reduced due to sediment deposition and habitat shrinkage.	Medium

Variable	Score	Motivation	Confidence
2b. Community composition	75	Inflow of the river water and increased saline intrusion would create a salinity gradient in the estuary under the present state. High flows are normally associated with nutrient input and there would be increased food source for post-larva and juveniles. However, the community structure will change due to occasional DO deficiency during low flow, resulting in unfavourable conditions for macrocrustacea in the estuary. There would be 75% resemblance to the original composition.	Medium
Invertebrate score	65		

Fish

Variable	Score	Motivation	Confidence
1. Species richness	90	The loss of marine 'stragglers' will occur due to the absence of States 1 and 2. This will lead to fish species richness in the estuary becoming more like the Reference condition than the Present State.	Medium
2a. Abundance	80	Decrease in abundance from Reference State due to reduction in size of the estuary but increased fish recruitment due to reduced high river flow periods.	Low
2b. Community composition	70	More marine species in the fish community compared to the Reference State due to increased marine fish recruitment arising from decreased river flow volumes.	Low
Fish score	70		

Birds

Variable	Score	Motivation	Confidence
1. Species richness	80	Due to the limited predicted changes in the benthos and fish fauna it is unlikely that there would be any substantial change in the species richness of the bird fauna from present state to this state.	Medium
2a. Abundance	70	No real decrease in abundance from Present State due to limited changes taking place relating to other factors.	Medium
2b. Community composition	80	Similar species composition to Present State.	Medium
Bird score	70		

3 SCENARIO: RIVER CATEGORY B (INITIAL SCENARIO)

3.1 SEASONAL VARIABILITY IN RIVER INFLOW

Monthly simulated runoff data for the River Scenario: Category B is provided in Table 3.2 on the following page. A summary of flow distribution (mean monthly flows in m³/s) for the River Scenario: Category B, derived from the 70-year simulated data set, is provided in Table 3.1.

Table 3.1 A summary of flow distribution (mean monthly flows in m³/s) for Scenario: River Category B (derived from 70-year simulated data set)

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
90%ile	33.39	65.47	151.76	302.51	534.73	275.35	96.11	33.97	24.35	19.04	16.93	24.54
80%ile	33.15	49.04	96.90	205.43	378.13	210.88	81.59	33.74	24.19	18.91	16.80	24.38
70%ile	32.54	48.28	87.28	129.35	238.21	148.53	60.92	33.14	23.79	18.63	16.50	23.84
60%ile	30.99	47.14	78.04	80.55	195.40	115.05	55.88	31.84	22.96	17.94	15.98	20.64
50%ile	28.68	44.60	68.19	71.02	169.96	90.94	50.57	29.91	21.49	16.74	14.88	16.02
40%ile	24.94	40.73	55.40	61.48	157.05	86.90	44.40	26.37	18.99	14.91	13.19	14.50
30%ile	19.61	34.06	47.05	49.00	110.62	76.23	35.78	21.48	15.29	12.17	10.76	13.62
20%ile	14.24	25.27	33.42	33.81	77.72	51.42	25.57	15.73	11.50	9.11	8.17	11.03
10%ile	9.25	15.35	19.90	21.32	45.23	30.98	16.95	10.89	8.07	6.51	5.87	7.44
1%ile	6.96	8.40	9.91	13.51	24.77	17.00	12.94	8.64	6.51	5.27	4.79	5.80

3.2 PREDICTED FLOOD REGIME

Refer to Scenario: River Category A.

3.3 PREDICTED CHANGES IN SEDIMENT PROCESSES AND CHARACTERISTICS

Refer to Scenario: River Category A.

Table 3.2 Monthly runoff data (in m³/s) for Scenario: River Category B, simulated over a 70-year period

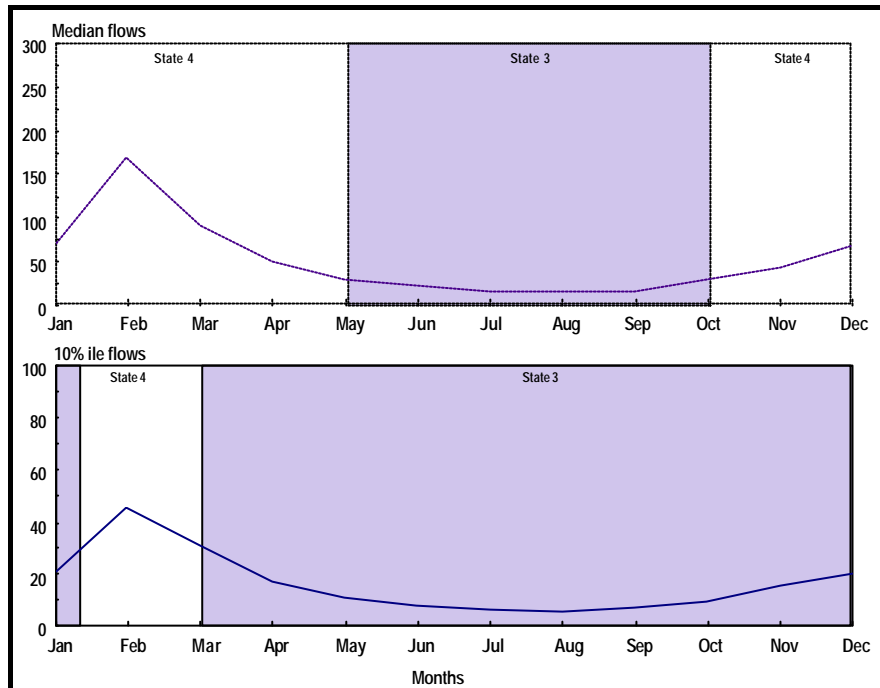
Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	AVE
1925	31.71	40.80	27.65	63.36	93.20	53.40	40.50	13.12	18.26	17.71	11.65	24.54	36.32
1926	33.32	48.42	68.83	45.42	159.84	89.59	56.41	21.47	12.02	12.26	15.77	15.36	48.22
1927	32.59	27.07	62.21	56.92	80.34	60.82	42.78	14.60	10.97	6.54	5.77	14.63	34.60
1928	26.70	20.31	49.44	46.87	77.79	90.80	58.11	31.69	24.32	19.07	16.93	24.57	40.55
1929	33.33	49.04	82.15	200.62	161.13	142.53	61.63	26.64	17.05	14.22	14.15	17.38	68.32
1930	19.73	13.59	36.07	74.70	167.08	43.51	25.65	15.78	8.10	11.98	12.60	7.09	36.32
1931	8.32	15.14	11.06	16.14	235.75	373.09	91.59	33.39	24.35	18.82	15.00	13.60	71.35
1932	9.32	25.37	53.31	21.45	45.41	28.61	16.68	10.62	6.51	8.91	10.94	6.84	20.33
1933	6.96	49.35	140.76	919.78	456.03	113.34	76.86	33.94	24.39	19.03	16.93	24.39	156.81
1934	29.33	49.05	466.24	224.67	117.93	99.99	45.63	28.49	23.49	18.37	13.60	9.11	93.83
1935	7.67	15.38	13.52	70.23	230.43	236.30	60.61	83.67	45.27	18.99	15.25	13.21	67.54
1936	21.04	154.24	181.12	267.70	393.46	132.56	19.74	11.41	7.00	5.65	4.79	5.80	100.38
1937	12.50	9.09	83.56	62.10	106.84	35.17	48.05	33.53	23.88	19.07	16.92	23.78	39.54
1938	33.10	45.54	95.65	119.97	751.62	405.55	63.93	32.73	24.06	18.90	16.71	24.23	136.00
1939	30.28	64.80	238.02	81.77	61.76	33.68	20.92	155.20	128.98	19.07	16.79	24.14	72.95
1940	26.23	40.50	125.84	257.92	262.52	142.44	83.00	33.91	23.30	14.84	9.35	8.80	85.72
1941	10.83	11.32	17.04	69.48	200.75	253.82	101.06	33.21	23.69	18.12	16.19	23.51	64.92
1942	30.64	91.86	468.78	473.51	204.89	112.64	546.02	276.84	38.47	58.81	392.24	185.96	240.06
1943	367.85	431.98	242.51	150.75	421.06	202.80	35.65	15.89	24.24	19.03	16.38	24.57	162.73
1944	33.21	40.63	20.03	13.51	31.79	148.18	181.15	30.73	17.88	12.44	7.13	6.32	45.25
1945	6.96	6.86	7.34	34.48	100.23	87.30	55.00	18.64	9.67	6.19	4.81	5.80	28.61
1946	29.63	48.79	47.63	13.51	126.06	87.78	53.10	26.75	23.30	18.82	15.96	14.75	42.17
1947	27.49	49.27	93.11	73.04	117.46	179.70	92.25	33.00	22.92	16.34	9.68	10.81	60.42
1948	21.48	21.22	27.06	62.09	162.69	83.01	56.69	33.68	21.85	13.60	7.82	12.32	43.62
1949	25.65	47.84	83.46	44.84	61.39	90.14	74.38	33.60	24.16	18.38	16.48	20.15	45.04
1950	19.32	20.14	79.91	42.13	48.28	37.72	26.43	15.42	11.54	8.17	16.93	24.50	29.21
1951	32.18	21.58	29.99	79.73	294.12	100.22	39.07	27.14	19.05	18.67	16.57	16.01	57.86
1952	17.41	45.14	72.63	49.91	375.65	253.96	36.84	25.28	14.66	10.97	16.00	18.30	78.06
1953	17.39	40.85	52.88	26.57	196.39	87.75	44.62	32.24	24.19	18.40	13.31	21.36	47.99
1954	33.39	58.51	148.49	489.73	671.34	241.19	49.33	30.94	21.54	16.86	9.57	7.47	148.20
1955	20.68	30.13	56.25	19.76	182.00	164.22	114.69	29.33	21.38	16.05	9.58	13.96	56.50
1956	22.92	48.88	517.44	520.05	181.97	138.97	81.24	33.76	23.83	19.07	16.93	391.84	166.41
1957	529.54	180.81	46.06	240.80	209.17	72.55	93.75	33.97	23.76	14.95	8.21	13.74	122.28
1958	20.00	42.16	75.41	50.06	155.82	55.84	16.98	34.00	24.39	18.94	16.32	16.64	43.88
1959	31.56	48.50	64.18	24.43	73.78	77.81	56.24	33.73	23.02	13.69	10.35	14.32	39.30
1960	25.02	47.12	100.26	186.26	39.34	86.30	89.10	33.91	24.13	18.02	13.02	15.97	56.54
1961	19.08	34.34	46.72	66.72	165.15	63.61	43.66	30.08	15.57	10.50	11.14	14.28	43.40
1962	11.62	47.09	76.32	84.69	145.62	105.29	50.86	26.28	22.20	43.68	63.70	23.65	58.42
1963	24.84	47.93	34.27	103.71	108.39	31.25	25.26	16.93	14.38	15.22	12.57	23.98	38.23
1964	33.42	134.93	67.54	128.04	77.46	17.00	12.94	8.64	23.78	19.02	16.90	24.43	47.01
1965	28.19	29.75	26.36	74.81	157.87	20.85	12.94	10.67	10.65	6.51	6.92	13.35	33.24
1966	13.55	33.39	74.52	239.54	573.14	321.86	177.71	39.81	24.32	18.79	16.16	13.75	128.88
1967	13.51	33.28	41.05	18.22	24.17	19.25	15.89	9.03	6.51	5.27	6.94	13.63	17.23
1968	8.64	18.94	47.05	27.69	57.17	91.08	58.11	33.85	24.31	18.62	15.26	16.30	34.75
1969	32.96	39.18	58.81	34.08	79.58	27.86	13.28	8.64	7.33	6.40	16.75	24.52	29.11
1970	33.15	43.79	23.81	66.46	111.58	27.83	30.75	34.00	24.39	18.95	16.82	23.63	37.93
1971	31.40	35.87	70.69	56.89	172.83	91.22	58.11	31.66	23.88	18.40	14.99	11.08	51.42
1972	14.41	32.60	27.47	14.26	194.74	85.24	53.13	33.38	19.56	10.40	16.89	24.57	43.89
1973	32.65	47.90	61.04	75.51	258.48	219.72	95.56	33.80	24.22	18.86	16.37	14.78	74.91
1974	8.30	47.82	91.36	258.40	619.66	259.47	50.91	32.51	22.78	15.72	10.02	24.57	120.13
1975	32.92	48.22	130.90	478.28	434.66	628.98	264.84	44.83	24.39	19.03	16.55	19.33	178.58
1976	32.94	47.18	61.79	71.81	173.93	88.85	50.28	29.89	13.56	8.68	6.31	24.43	50.80
1977	33.21	46.45	52.12	300.02	335.54	128.33	62.17	33.12	21.47	15.49	15.04	24.08	88.92
1978	33.42	48.50	96.06	104.13	181.82	83.25	20.31	21.67	18.91	17.76	16.93	24.52	55.61
1979	30.72	34.71	38.91	53.57	154.84	70.17	23.17	10.91	6.99	5.57	4.79	24.37	38.23
1980	29.18	41.15	87.18	77.97	676.32	208.68	25.77	23.58	21.52	17.88	16.63	24.38	104.19
1981	26.78	44.85	47.05	32.71	31.15	39.46	35.80	15.52	8.90	6.50	5.37	12.45	25.55
1982	33.17	42.83	18.73	20.10	25.03	17.00	14.15	9.33	7.76	10.71	14.77	13.94	18.96
1983	29.72	49.29	100.26	454.99	388.04	167.44	78.92	32.06	20.09	18.64	16.87	24.27	115.05
1984	32.10	24.86	17.62	55.96	625.81	322.70	23.12	12.02	9.25	7.71	5.43	6.22	95.23
1985	33.39	48.98	78.62	324.89	223.85	117.60	55.64	31.40	19.61	16.62	14.39	14.88	81.65
1986	32.52	44.35	87.26	60.57	265.28	300.71	83.34	24.11	17.41	16.93	16.93	930.79	156.68
1987	560.63	171.10	105.88	132.40	444.39	365.03	101.13	33.07	24.32	19.07	16.84	23.69	166.46
1988	32.28	45.75	90.80	139.40	675.06	272.54	34.03	24.14	21.04	17.63	13.70	9.32	114.64
1989	11.64	49.35	318.79	93.00	43.64	66.04	46.81	29.93	15.56	9.16	14.44	16.04	59.53
1990	14.41	11.18	54.13	132.88	530.47	201.41	46.01	19.31	14.15	13.70	8.03	12.25	88.16
1991	33.42	48.16	87.35	45.17	179.66	84.08	16.53	10.66	6.79	5.27	5.12	6.30	44.04
1992	7.32	37.90	77.66	31.72	161.95	84.24	44.08	19.28	11.35	7.20	5.88	10.53	41.59
1993	33.42	71.50	89.04	190.21	243.96	149.36	51.33	26.43	13.32	11.42	16.73	21.67	76.53
1994	16.75	10.07	14.04	32.02	36.63	40.25	35.73	21.48	22.61	17.51	12.20	7.93	22.27
Median	28.68	44.60	68.19	71.02	169.96	90.94	50.57	29.91	21.49	16.74	14.88	16.02	51.92
Average	44.01	51.35	91.24	132.50	226.19	135.16	63.83	31.92	20.61	15.54	19.01	37.62	72.41
10%ile	9.25	15.35	19.90	21.32	45.23	30.98	16.95	10.89	8.07	6.51	5.87	7.44	29.20

1: Closed < 2.0 2: Open (closed for days) 2.0-5.0 3: Open (Saline) 5.0-30 4: Open (Riverine) > 30.0

< 2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00%
2.0-5.0	0	0	0	0	0	0	0	0	0	0	3	0	0	0.36%
5.0-30	39	17	14	11	2	7	17	36	67	68	65	67	67	48.81%
> 30.0	31	53	56	59	68	63	53	34	3	2	2	3	3	50.83%

3.4 PREDICTED OCCURRENCE AND DURATION OF DIFFERENT ABIOTIC STATES

The occurrence and duration of the different Abiotic States under Scenario: River Category B are illustrated in the simulated monthly river flow table (Table 3.1). To provide a conceptual overview of the annual distribution of Abiotic States under Scenario: River Category B, median monthly flows and 10%ile flows were used to depict the situation for normal and drought periods, respectively:



3.5 PREDICTED CHANGES IN BIOTIC CHARACTERISTICS

<p>MICROALGAE</p> <p>Phytoplankton: Low rates and magnitude of floods are reduced by about 27% from that of reference state conditions with a decrease in the frequency of saltwater intrusion up the estuary. Longitudinal salinity gradients would become broad and extend deep up the estuary especially during low flow periods (i.e. States 2 and 3). This is important in maintaining phytoplankton densities and community structure; however, the continued increase in the frequencies of these conditions would shift phytoplankton community structure toward saline tolerant ones. Sediment load would decline possibly improving light penetration. Spatial and temporal distribution of phytoplankton would resemble that of the present state typified by marine dominated phytoplankton community in the lower reaches and freshwater species dominating the upper reaches of the estuary.</p> <p>Confidence: Medium</p> <p>Benthic microalgae: The estuary will be characterised by Abiotic States 3 and 4. State 3 will last about a month longer but this will not have a significant effect on community composition because diatom communities can become well established over a short period of time (few weeks). As a result, the microalgal community will range from fresh/brackish (State 3) to freshwater (State 4) species. No change in the estuary morphology is expected from Category A so the effects will be similar. Conditions are expected to be more stable so benthic biomass and species richness could increase.</p> <p>Confidence: Medium</p>
<p>MACROPHYTES</p> <p>The decrease in the magnitude of major floods will mean a less dynamic estuary; less uprooting of reeds and sedges during floods and thus these plants can be expected to occupy a larger area. A number of opportunistic species may be lost. The nitrate and phosphate concentrations are not expected to change from present conditions and therefore nuisance aquatics such as <i>Eicchornia crassipes</i> (water hyacinth) may still be present. The estuary will become shorter and deeper, this will probably have little effect on the macrophytes as overall the post-dam fluvial morphology will be similar.</p> <p>Confidence: Medium</p>

INVERTEBRATES
Zooplankton: Marine dominated community would be present for slightly longer periods in the estuary (State 3), but high flow in early spring would prevent any major changes in zooplankton abundances.
Confidence: Low
Macroinvertebrates: Low flow conditions increase in duration (State 3), but without an increase in the longitudinal intensity of saline intrusion. Thus, similar species should be present to the reference condition and river category A (80% similarity to species richness). A decline in flow will not significantly alter abundance and biomass in the system. The establishment of one or two species that prefer nutrient enriched sediments may also replace any sensitive/intolerant species (nitrate and phosphate concentrations are similar to present state).
Confidence: Medium
Macrocrustacea: The macrocrustacean community would be similar to that of the reference condition characterised by some marine species in the lower reaches and dominated by brackish and freshwater species in the middle and upper reaches.
Confidence: Medium
FISH
Compared to the Reference Condition, the occupation of the estuary by marine fish species will be higher during the winter months when State 3 predominates. Fish assemblages during the summer months (State 4) are likely to be similar to those recorded in the Present State during this season.
Confidence: Medium
BIRDS
Compared to the Reference Condition, as with River Category A, it is not anticipated that there will be much change at all under this state.
Confidence: Medium

3.6 ESTUARINE HEALTH SCORE ASSESSMENT FOR SCENARIO: RIVER CATEGORY B

Hydrology

Variable	Score	Motivation	Confidence
a. % similarity in period of low flows	83	For the Thukela Estuary, low flow is assumed to be flows less than 30m ³ /s, i.e. States 1, 2 and 3. Under the Reference State low flows occurred for 4 months of the year. This increased to 6 months per year under Scenario: River Category B.	Medium
b. % similarity in the magnitude of major floods (e.g. 1:20, 1:50 and 1:100) in comparison with the reference condition	73	Based on statistical analysis of observed present and simulated post-dam floods, assuming new dams are in place (27% decrease in flood peaks from Reference Condition).	High
Hydrology score	79		

Hydrodynamics and mouth condition

Variable	Score	Motivation	Confidence
Change in mean duration of closure over a 70-year period	100	No marked deviation of Abiotic States from the Reference Condition to Scenario: River Category B.	Medium
Hydrodynamic score	100		

Water quality

Variable	Score	Motivation	Confidence
1. Change in longitudinal salinity gradient (%) and vertical salinity stratification	80	Under Reference Condition, the estuary was more river dominated than under Scenario: River Category B, i.e. State 4 decreased from 8 months per year to 6 months. State 3 (i.e. open, with saline intrusion) also increased from 4 months under Reference to 6 months under Present State. Within State 3 the median flows remained similar to the Reference Condition. This suggests that although the duration of State 3 increased, the longitudinal intensity of saline intrusion probably will not increase under Scenario: River Category B.	Medium
2a. Nitrate/phosphate concentration in the estuary	70	Similar to the Present State, assuming potential impacts of Industrial area at Mandini remains intact.	Low
2b. Suspended solids present in inflowing freshwater	50	Similar to the Present State, assuming potential impacts of Industrial area at Mandini and other catchment activities remains intact.	Low
2c. Dissolved oxygen (DO) in estuary	80	Similar to the Present State, assuming potential impacts of Industrial area at Mandini remains intact.	Low
2d. Levels of toxins	100	Similar to the Present State, i.e. no marked change from the Reference Condition.	Medium
Water quality score	62		

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 exposed	60	Assuming that Scenarios for River Category A-D can only be achieved with additional dam development in the catchment, resulting in further flood intenuation and/or sediment yield, although not much different from Present State.	High
1b	% similarity in sand fraction relative to total sand and mud	60	Assuming that Scenarios for River Category A-D can only be achieved with additional dam development in the catchment, resulting in further flood intenuation and/or sediment yield, although not much different from Present State.	High
2	Resemblance of subtidal estuary to reference condition: depth, bed or channel morphology	75	Flood peaks decrease with future dams. Sediment will be trapped in future dams, but as a result of overgrazing and land use changes, the sediment yield could actually increase.	High
Physical hbitat sore		67.5		

Microalgae

Variable	Score	Motivation	Confidence
<i>Phytoplankton</i>			
1. Species richness	65	The River Category B state increases occurrence of low flows from 4/12 months to 6/12 months from Reference State. This would have minimal effect on species richness. This represents a 27% decrease in river inflow, which would mean a greater frequency in flows less than 30 m ³ /s (i.e. States 2 and 3). Increased salinity intrusion will shift species composition favouring marine type species.	Medium
2a. Abundance	75	Since the River Category B state represents 27% deviation from that of Present State conditions, this would effectively reduce phytoplankton abundance. Phytoplankton densities would be less pronounced around the REI zone and diminishing at the mouth and with slight increases of nuisance forms during lowflow periods.	Medium

Variable	Score	Motivation	Confidence
2b. Community composition	75	The River Category B state represents 27% deviation from that of Present State conditions and thus would effectively reduce phytoplankton abundances and alter phytoplankton community composition favouring marine tolerant phytoplankton communities. The phytoplankton communities in the upper reaches of the estuary would typify eutrophic forms of phytoplankton community structure.	Medium
<i>Benthic microalgae</i>			
1. Species richness	80	Conditions have not changed drastically from the reference condition (States 3 and 4).	Medium
2a. Abundance	90	Slightly more stable conditions would favour a slight increase in benthic biomass. Shorter, narrower and deeper estuary will reduce the total biomass of the estuary.	Medium
2b. Community composition	90	Conditions have not changed drastically from the reference condition (States 3 and 4). Mouth won't close.	Medium
Microalgae score	65		

Macrophytes

Variable	Score	Motivation	Confidence
1. Species richness	75	Because flood peaks are reduced and the estuary is not reset as often as it may have been under present conditions, there may be a loss of opportunistic species. Approximately 85% of the original species remain.	Medium
2a. Abundance	64	The increase in sediment stability as a result of the decrease in the flood peak and lower sediment transport capacity may result in an increase in the area covered by reeds and sedges.	Medium
2b. Community composition	80	A more stable system would mean less weedy species on the floodplain. However, the nitrate and phosphate concentrations are not expected to change from present conditions and therefore nuisance aquatics such as <i>Eicchornia crassipes</i> (water hyacinth) may still be present. There would be an 80% resemblance to the original composition.	Medium
Macrophyte score	64		

Invertebrates

Variable	Score	Motivation	Confidence
<i>Zooplankton</i>			
1. Species richness	80	Species richness of the marine community should not change substantially.	Low
2a. Abundance	75	No major changes expected.	Low
2b. Community composition	80	No major changes expected.	Low
<i>Macroinvertebrates</i>			
1. Species richness	65	Low flow conditions increase in duration (State 3), but without an increase in the longitudinal intensity of saline intrusion. Thus 80% similar species should be present to the reference condition and river category A.	Medium
2a. Abundance	70	A decline in flow will not significantly alter abundance and biomass in the system. The establishment of one or two species that prefer nutrient enriched sediments may also replace any sensitive/intolerant species (nitrate and phosphate concentrations are similar to present state).	Medium
2b. Community composition	70	Several species that prefer nutrient enriched sediments may colonise the system. Dominated by river fauna but with a larger proportion brackish and some estuarine taxa in the lower reaches.	Medium
<i>Macrocrustacea</i>			

Variable	Score	Motivation	Confidence
1. Species richness	65	Flow conditions and salinity gradient will be similar to present conditions. Some species less tolerant of fine sediment deposition may be lost. With a loss in habitat (macrophytes) it is expected that some of the species may have disappeared. The conduit function of the estuary for species with an obligate marine phase such as <i>Varuna litterata</i> would be maintained.	Medium
2a. Abundance	75	Any increased salinity will favour the intrusion of estuarine species that increase abundance in the short term. However, abundance of species utilising the estuary as a nursery area and breeding habitat such as <i>Macrobrachium</i> would be slightly reduced due to sediment deposition and habitat shrinkage.	Medium
2b. Community composition	75	Inflow of the river water and increased saline intrusion would create a salinity gradient in the estuary under the present state. High flows are normally associated with nutrient input and there would be increased food source for post-larva and juveniles. However, the community structure will change due to occasional DO deficiency during low flow, resulting in unfavourable conditions for macrocrustacea in the estuary. There would be 75% resemblance to the original composition.	Medium
Invertebrate score	65		

Fish

Variable	Score	Motivation	Confidence
1. Species richness	90	The loss of marine 'stragglers' will occur due to the absence of States 1 and 2. This will lead to fish species richness in the estuary becoming more like the Reference condition than the Present State.	Medium
2a. Abundance	80	Decrease in abundance from Reference State due to reduction in size of the estuary but increased fish recruitment due to reduced high river flow periods.	Low
2b. Community composition	70	More marine species in the fish community compared to the Reference State due to increased marine fish recruitment arising from decreased river flow volumes.	Low
Fish score	70		

Birds

Variable	Score	Motivation	Confidence
1. Species richness	80	Due to the limited predicted changes in the benthos and fish fauna it is unlikely that there would be any substantial change in the species richness of the bird fauna from present state to this state.	Medium
2a. Abundance	70	No real decrease in abundance from Present State due to limited changes taking place relating to other factors.	Medium
2b. Community composition	80	Similar species composition to Present State.	Medium
Bird score	70		

4 SCENARIO: RIVER CATEGORY C (INITIAL SCENARIO)

4.1 SEASONAL VARIABILITY IN RIVER INFLOW

Monthly simulated runoff data for the Scenario: River Category C is provided in Table 4.2 on the following page. A summary of flow distribution (mean monthly flows in m³/s) for the Scenario: River Category C, derived from the 70-year simulated data set, is provided in Table 4.1.

Table 4.1 A summary of flow distribution (mean monthly flows in m³/s) for Scenario: River Category C (derived from 70-year simulated data set)

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
90%ile	21.39	128.60	175.42	321.73	527.87	269.10	96.07	23.46	15.33	12.21	10.99	15.86
80%ile	21.26	31.94	102.34	223.76	392.17	216.78	83.08	20.73	15.25	12.15	10.92	15.77
70%ile	20.91	31.46	56.05	168.05	238.99	157.37	67.87	20.44	15.05	12.00	10.77	15.47
60%ile	20.04	30.78	48.93	105.56	173.80	115.64	45.15	19.81	14.63	11.65	10.50	14.97
50%ile	18.73	29.28	43.37	46.67	132.57	92.67	33.44	18.88	13.90	11.05	9.94	14.20
40%ile	16.92	26.98	34.91	39.21	104.17	76.01	28.51	17.16	12.66	10.12	9.07	12.61
30%ile	13.91	23.02	30.14	32.11	76.00	57.36	24.12	14.79	10.82	8.73	7.82	10.76
20%ile	10.56	17.81	22.36	23.49	51.74	39.70	18.91	12.00	8.93	7.18	6.49	8.41
10%ile	7.75	11.93	14.63	16.85	34.02	24.71	14.51	9.65	7.23	5.86	5.31	6.44
1%ile	6.45	7.79	8.89	12.70	20.77	15.52	12.47	8.56	6.45	5.23	4.75	5.53

4.2 PREDICTED FLOOD REGIME

Refer to Scenario: River Category A.

4.3 PREDICTED CHANGES IN SEDIMENT PROCESSES AND CHARACTERISTICS

Refer to Scenario: River Category A.

Table 4.2 Monthly runoff data (in m³/s) for Scenario: River Category C, simulated over a 70-year period

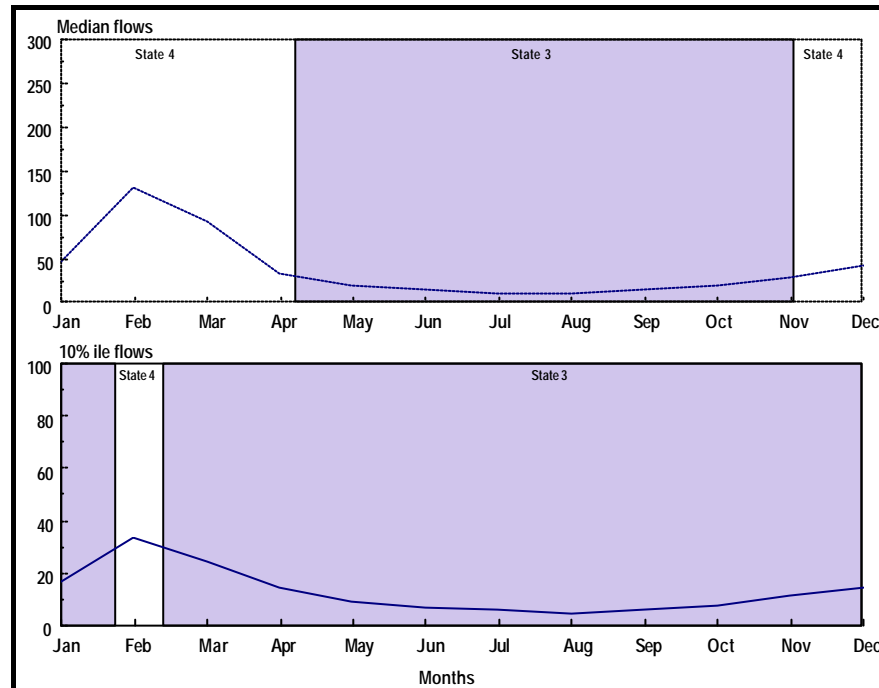
Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	AVE
1925	20.44	27.02	19.06	39.50	59.67	36.31	26.52	10.73	12.29	11.54	8.28	15.82	23.93
1926	21.35	31.54	42.82	29.66	98.22	105.76	66.78	14.78	9.19	8.77	10.39	13.53	37.73
1927	20.94	18.88	38.92	35.88	52.14	40.55	27.69	11.45	8.67	5.87	5.26	12.79	23.25
1928	17.61	14.87	31.51	30.43	50.92	57.67	84.71	19.74	15.31	12.23	10.99	15.88	30.16
1929	21.35	135.65	145.84	262.37	154.27	136.28	55.20	17.29	11.69	9.77	9.56	14.44	81.14
1930	14.02	10.88	23.87	46.05	155.43	51.84	18.95	12.02	7.24	8.63	8.77	6.25	30.33
1931	7.22	11.80	9.59	14.10	157.47	407.91	85.16	20.56	15.32	12.10	10.00	10.74	63.50
1932	7.79	17.87	33.72	16.92	32.56	22.15	14.38	9.52	6.45	7.08	7.91	6.11	15.20
1933	6.45	32.09	129.47	913.59	449.17	107.09	70.43	23.44	15.34	12.21	10.99	15.78	148.84
1934	19.10	31.91	483.61	218.47	111.07	93.74	29.14	18.18	14.90	11.87	9.28	7.36	87.39
1935	6.85	11.94	10.99	43.41	243.43	230.05	54.19	77.47	38.86	12.19	10.13	10.35	62.49
1936	15.58	142.82	174.92	261.50	386.60	126.31	15.94	9.91	6.70	5.42	4.75	5.53	96.33
1937	9.59	8.21	51.58	38.79	67.40	25.90	30.37	20.63	15.09	12.23	10.99	15.44	25.52
1938	21.22	29.83	58.88	216.23	744.76	399.30	57.50	20.24	15.18	12.14	10.88	15.69	133.49
1939	19.63	74.08	231.82	75.57	50.66	30.74	16.54	147.90	122.58	12.23	10.92	15.64	67.36
1940	17.34	26.84	131.47	251.73	255.66	136.19	76.58	20.81	14.80	10.08	7.10	7.19	79.65
1941	8.64	9.54	13.00	42.98	200.02	250.37	94.64	20.47	15.00	11.75	10.61	15.29	57.69
1942	19.84	100.38	462.58	467.32	198.03	106.38	539.59	270.64	32.07	52.61	385.99	179.48	234.58
1943	361.58	425.56	236.31	144.55	414.44	196.55	24.05	12.07	15.27	12.21	10.71	15.88	155.76
1944	21.29	26.92	14.71	12.70	24.83	155.73	174.72	19.27	12.10	8.86	5.96	5.82	40.24
1945	6.45	6.86	7.34	23.85	63.66	55.67	33.92	13.41	8.02	5.70	4.77	5.53	19.60
1946	19.27	31.76	30.47	12.70	78.31	55.94	32.95	17.34	14.80	12.10	10.49	12.91	27.42
1947	18.06	32.04	57.34	165.97	155.77	191.98	85.83	20.37	14.61	10.84	7.27	8.29	64.03
1948	15.73	15.41	18.73	38.78	99.91	59.55	72.54	20.70	14.08	9.46	6.31	9.29	31.71
1949	17.07	31.20	51.52	29.35	41.62	165.23	108.94	20.66	15.23	11.88	10.76	14.89	43.20
1950	13.63	14.77	49.40	27.92	34.19	27.35	19.35	11.85	8.95	6.70	10.99	15.84	20.08
1951	20.70	15.62	20.40	57.69	356.46	93.96	25.79	17.53	12.69	12.03	10.81	14.19	54.82
1952	12.36	29.59	45.07	32.05	419.79	247.70	24.66	16.63	10.50	8.12	10.52	14.59	72.63
1953	12.35	27.05	33.47	19.64	119.96	89.50	28.62	20.00	15.24	11.89	9.13	15.09	33.50
1954	21.39	150.51	142.30	483.54	664.48	234.93	36.03	19.37	13.93	11.11	7.21	6.46	149.27
1955	15.15	20.69	35.40	16.02	111.25	235.90	108.27	18.60	13.85	10.70	7.21	11.84	50.41
1956	16.22	31.81	518.64	513.86	175.10	132.72	74.81	20.74	15.06	12.23	10.99	395.11	159.77
1957	523.27	174.39	29.58	244.88	202.31	66.29	87.33	26.36	15.03	10.14	6.51	11.14	116.44
1958	14.35	27.83	46.71	32.13	97.75	74.54	14.53	23.64	15.34	12.16	10.68	14.32	32.00
1959	20.36	31.59	40.08	18.51	48.42	56.65	63.50	20.73	14.66	9.50	7.61	12.35	28.66
1960	16.94	30.77	179.93	211.63	29.11	83.08	82.67	20.82	15.22	11.70	8.98	14.15	58.75
1961	13.41	23.19	29.95	41.39	126.37	81.01	28.14	18.96	10.96	7.88	8.02	12.30	33.46
1962	9.09	30.75	47.25	149.72	138.76	99.04	40.54	17.12	14.26	45.72	57.45	15.37	55.42
1963	16.88	31.25	22.84	116.09	101.77	24.99	18.75	12.58	10.36	10.28	8.75	15.55	32.51
1964	21.41	128.36	61.34	121.84	70.60	15.52	12.47	8.56	15.04	12.20	10.98	15.80	41.18
1965	18.45	20.47	18.33	46.12	121.72	17.72	12.47	9.54	8.51	5.86	5.85	10.49	24.63
1966	10.18	22.63	46.19	269.44	566.28	315.60	171.29	33.61	15.31	12.09	10.60	11.15	123.70
1967	10.15	22.56	26.72	15.20	20.27	16.80	13.97	8.75	6.45	5.23	5.86	10.77	13.56
1968	7.40	14.05	30.14	20.24	39.23	57.82	35.50	20.79	15.30	12.00	10.14	14.26	23.07
1969	21.14	26.06	36.91	23.64	51.94	21.72	12.64	8.56	6.86	5.80	10.90	15.85	20.17
1970	21.25	28.80	16.87	41.25	70.09	21.71	21.55	20.86	15.34	12.17	10.93	15.36	24.68
1971	20.27	24.10	43.92	35.86	105.78	91.59	110.77	19.73	15.09	11.89	9.99	8.44	41.45
1972	10.66	22.16	18.96	13.10	118.97	54.49	32.96	20.56	12.94	7.83	10.97	15.88	28.29
1973	20.97	31.23	38.23	194.13	420.14	213.47	89.14	20.76	15.26	12.12	10.71	12.95	89.92
1974	7.21	31.19	56.29	290.55	612.80	253.22	41.42	20.14	14.54	10.53	7.44	15.88	113.43
1975	21.13	31.42	148.65	472.08	428.03	622.73	258.41	38.63	15.34	12.21	10.80	14.76	172.85
1976	21.13	30.80	38.67	98.53	167.07	82.60	39.03	18.87	9.96	6.96	5.53	15.80	44.58
1977	21.29	30.37	33.04	320.62	328.68	122.08	55.75	20.43	13.89	10.41	10.02	15.61	81.85
1978	21.41	31.59	112.95	97.93	174.96	76.99	16.23	14.88	12.62	11.57	10.99	15.85	49.83
1979	19.88	23.41	25.49	34.00	95.14	58.76	17.65	9.66	6.69	5.38	4.75	15.77	26.38
1980	19.01	27.23	53.76	172.90	669.46	202.42	19.01	15.80	13.92	11.63	10.84	15.77	102.65
1981	17.65	29.43	30.14	22.91	24.47	28.34	24.13	11.90	7.64	5.85	5.05	9.61	18.09
1982	21.27	28.22	13.97	16.20	21.00	15.52	13.05	8.89	7.08	7.99	9.88	11.98	14.59
1983	19.32	32.06	61.67	493.21	381.41	161.19	72.50	19.92	13.20	12.01	10.96	15.71	107.76
1984	20.66	17.57	13.33	35.34	648.87	316.45	17.66	10.20	7.81	6.47	5.08	5.76	92.10
1985	21.39	31.87	48.62	331.75	216.99	111.34	49.22	19.60	12.97	10.99	9.68	13.05	73.12
1986	20.90	29.13	53.81	47.22	310.99	294.46	76.92	16.06	11.87	11.14	10.99	924.61	150.68
1987	554.35	164.67	99.69	126.20	437.76	358.78	94.71	20.41	15.31	12.23	10.95	15.39	159.20
1988	20.78	29.96	55.95	187.20	668.20	266.28	23.23	16.08	13.68	11.50	9.33	7.48	109.14
1989	9.10	37.33	314.87	86.80	34.42	61.92	29.74	18.89	10.95	7.20	9.71	14.22	52.93
1990	10.66	9.45	34.18	136.48	523.61	195.16	29.33	13.74	10.25	9.50	6.42	9.14	82.33
1991	21.41	31.39	53.87	78.99	173.04	77.82	14.30	9.54	6.59	5.23	4.92	5.81	40.24
1992	6.65	25.30	48.05	22.38	99.47	53.92	28.35	13.72	8.86	6.21	5.31	8.14	27.20
1993	21.41	130.72	82.85	184.01	237.09	143.11	42.44	17.19	9.84	8.35	10.89	15.11	75.25
1994	11.99	8.79	11.25	22.54	27.58	28.80	24.05	14.79	14.46	11.44	8.56	6.71	15.92
Median	18.73	29.28	43.37	46.67	132.57	92.67	33.44	18.88	13.90	11.05	9.94	14.20	38.72
Average	36.16	44.26	78.28	135.09	211.97	130.73	57.86	23.65	14.58	11.03	14.99	33.25	65.99
10%ile	7.75	11.93	14.63	16.85	34.02	24.71	14.51	9.65	7.23	5.86	5.31	6.44	22.49

1: Closed < 2.0 2: Open (closed for days) 2.0-5.0 3: Open (Saline) 5.0-30 4: Open (Riverine) > 30.0

< 2.0	0	0	0	0	0	0	0	0	0	0	0	0	0.00%
2.0-5.0	0	0	0	0	0	0	0	0	0	0	4	0	0.48%
5.0-30	67	39	20	19	6	12	32	65	67	68	64	67	62.62%
> 30.0	3	31	50	51	64	58	38	5	3	2	2	3	36.90%

4.4 PREDICTED OCCURRENCE AND DURATION OF DIFFERENT ABIOTIC STATES

The occurrence and duration of the different Abiotic States under Scenario: River Category C are illustrated in the simulated monthly river flow table (Table 4.2). To provide a conceptual overview of the annual distribution of Abiotic States under Scenario: River Category C, median monthly flows and 10%ile flows were used to depict the situation for normal and drought periods, respectively:



4.5 PREDICTED CHANGES IN BIOTIC CHARACTERISTICS

<p>MICROALGAE</p> <p>Phytoplankton: The Scenario: River Category C increases the frequencies of low flow (States 2 and 3) conditions from 4/12 months to 7/12 months from that of the Reference State. Mouth may close but less frequently than at present and then only for a day or two. The prevalence and severity of saline conditions would promote a marine tolerant phytoplankton community toward the mouth of the estuary when flows fall below 30 m³/s. The estuary would behave like a typical tidal estuary with a well-developed REI zone in the middle reaches of the estuary and become fresh at the upper estuary. This condition would be different from that of the Reference State.</p> <p>Confidence: Medium</p> <p>Benthic microalgae: Abiotic States 3 and 4 will characterise the estuary. During extended drought periods, State 3 could last for 11 months of the year. This could affect community composition near to the mouth of the estuary, as it will leave very little time for successional change once the entire estuary is fresh. However, the upper reaches of the estuary will always be fresh and will maintain a similar community composition. As a result, species richness will not be significantly affected compared to categories A and B. No change in the estuary morphology is expected from Category A and B so the effects will be similar. Conditions are expected to be more stable so benthic biomass and species richness could increase.</p> <p>Confidence: Medium</p>
<p>MACROPHYTES</p> <p>Low flow (States 1, 2, 3) occurs for 7 months of the year compared to 4 months for the reference condition. Saline conditions together with an increase in sediment stability would promote the growth of reeds and sedges. There is a possibility that the mouth can close but this would occur less frequently than that of present day conditions and will therefore have little influence on the macrophytes.</p> <p>Confidence: Medium</p>

INVERTEBRATES

Zooplankton: Species richness of the marine dominated community during low flows should not change from the reference state. Some plankters such as the paracalanids may increase substantially during spring but would be decimated again when high flows return in November.

Confidence: Low

Macroinvertebrates: The estuary will primarily be characterised by low flow conditions (State 3, <30 m³/s). The system will begin to function more like a typical estuary with a horizontal salinity gradient. Estuarine and some marine species will dominate the lower reaches and decline in diversity upstream. In the mid and upper reaches, brackish tolerant and intolerant freshwater invertebrates will replace them. The community structure will change to a dominance of polychaete species in the lower reaches (similar to present low flow conditions) and biomass will be more similar to that of communities reflective of category A and B conditions.

Confidence: Medium

Macrocrustacea: The flow would be further reduced which might result in the closure of the mouth for a few days. Saline conditions would increase, resulting in conditions much less favourable for freshwater species. Only under high flow would *Macrobrachium* species move down into the mid-lower reaches for breeding purposes. This condition would be different from that of the Reference State.

Confidence: Medium

FISH

Compared to the Reference Condition, the occupation of the estuary by marine fish species will be higher during the winter, spring and autumn months when State 3 predominates. Fish assemblages during the summer months (State 4) are likely to be similar to those recorded in the Present State during this season.

Confidence: Medium

BIRDS

The system will primarily be characterised by low flow conditions, which allow saline intrusion, and it will thus begin to function more like a typical estuary. This should create the potential to enhance the benthic feeding fauna if there is sufficient intertidal exchange so as to expose the feeding areas. This would apply to a lesser degree to Piscivorous species while roosting species will be largely unaffected.

Confidence: Medium

4.6 ESTUARINE HEALTH SCORE ASSESSMENT OF SCENARIO: RIVER CATEGORY C

Hydrology

Variable	Score	Motivation	Confidence
a. % similarity in period of low flows	75	For the Thukela Estuary, low flow is assumed to be flows less than 30 m ³ /s, i.e. States 1, 2 and 3. Under the Reference State low flows occurred for 4 months of the year. This increased to 7 months per year under Scenario: River Category C.	Medium
b. % similarity in the magnitude of major floods (e.g. 1:20, 1:50 and 1:100) in comparison with the reference condition	73	Based on statistical analysis of observed present and simulated post-dam floods, assuming new dams are in place (27% decrease in flood peaks from Reference Condition).	High
Hydrology score	74		

Hydrodynamics and mouth condition

Variable	Score	Motivation	Confidence
Change in mean duration of closure over a 70 year period	95	Following a precautionary approach, the changes in the occurrence of Abiotic States in which there is a high probability of mouth closure occurring (i.e. States 1 and 2) were calculated and then scored according to Table 2.13 in Turpie (2002). The occurrence of Abiotic States for which there is a high probability of mouth closure to occur (i.e. States 1 and 2), increased from 0% under Reference Conditions to ~1% under Scenario: River Category C.	Low
Hydrodynamic score	95		

Water quality

Variable	Score	Motivation	Confidence
1. Change in longitudinal salinity gradient (%) and vertical salinity stratification	70	Under Reference Condition, the estuary was more river dominated than under Scenario: River Category C, i.e. State 4 decreased from 8 months per year to 5 months. State 3 (i.e. open, with saline intrusion) also increased from 4 months under Reference to 7 months under Scenario: River Category C. Within State 3 the median flows were slightly higher under the Reference Condition compared with Scenario: River Category C. This suggests that in addition to the duration, the longitudinal intensity of saline intrusion also increased to some extent under the Scenario: River Category C.	Medium
2a. Nitrate/phosphate concentration in the estuary	70	Similar to the Present State, assuming potential impacts of Industrial area at Mandini remains intact.	Low
2b. Suspended solids present in inflowing freshwater	50	Similar to the Present State, assuming potential impacts of Industrial area at Mandini and other catchment activities remains intact.	Low
2c. Dissolved oxygen (DO) in estuary	80	Similar to the Present State, assuming potential impacts of Industrial area at Mandini remains intact.	Low
2d. Levels of toxins	100	Similar to the Present State, i.e. no marked change from the Reference Condition.	Medium
Water quality score	58		

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 exposed	60	Assuming that Scenarios for River Category A-D can only be achieved with additional dam development in the catchment, resulting in further flood intenuation and/or sediment yield, although not much different from Present State.	High
1b	% similarity in sand fraction relative to total sand and mud	60	Assuming that Scenarios for River Category A-D can only be achieved with additional dam development in the catchment, resulting in further flood intenuation and/or sediment yield, although not much different from Present State.	High
2	Resemblance of subtidal estuary to reference condition: depth, bed or channel morphology	75	Flood peaks decrease with future dams. Sediment will be trapped in future dams, but as a result of overgrazing and land use changes, the sediment yield could actually increase.	High
Physical habitat score		67.5		

Microalgae

	Variable	Score	Motivation	Confidence
<i>Phytoplankton</i>				
1.	Species richness	65	Increase in low flow together with an increase in saline conditions would reduce brackish species richness in the lower reaches and replace them with marine forms. Brackish species would occur further up the estuary than would have occurred under the Reference State.	Medium
2a.	Abundance	70	Increase in low flow together with an increase in saline conditions would reduce phytoplankton densities. Peaks in phytoplankton densities would occur within the REI zone that has shifted further up the estuary.	Medium
2b.	Community composition	70	A decrease in the flow rate would shift phytoplankton community composition toward opportunistic phytoplankton like blue-green algae in particularly, slow -flowing backwater pockets.	Medium

	Variable	Score	Motivation	Confidence
<i>Benthic microalgae</i>				
1.	Species richness	80	Conditions have not changed drastically from the reference condition (States 3 and 4).	Medium
2a.	Abundance	90	Slightly more stable conditions would favour a slight increase in benthic biomass. Shorter, narrower and deeper estuary will reduce the total biomass of the estuary.	Medium
2b.	Community composition	90	Conditions have not changed drastically from the reference condition (States 3 and 4). Mouth won't close.	Medium
Microalgae score		65		

Macrophytes

	Variable	Score	Motivation	Confidence
1.	Species richness	75	Because flood peaks are reduced and the estuary is not reset as often as it may have been under present conditions, there may be a loss of opportunistic species. Approximately 85% of the original species remain.	Medium
2a.	Abundance	67	The increase in low flow conditions and salinity intrusion into the estuary would create favourable conditions for the growth of brackish reeds and sedges.	Medium
2b.	Community composition	78	There may be a slight change in community composition with brackish species outcompeting freshwater species. There would be a 78% resemblance to the original composition.	Medium
Macrophyte score		67		

Invertebrates

Variable	Score	Motivation	Confidence
<i>Zooplankton</i>			
1. Species richness	65	No changes in species richness of the marine dominated community expected.	Low
2a. Abundance	70	An increase in abundance of some species during spring.	Low
2b. Community composition	50	No major changes expected.	Low
<i>Macroinvertebrates</i>			
1. Species richness	25	Low flow conditions increase in duration and salinity gradient persists for longer. Estuarine and some marine species will dominate the lower reaches and decline in diversity upstream. In the mid and upper reaches, brackish tolerant and intolerant freshwater invertebrates will replace them. 50% similarity of species to reference condition and present state.	Medium
2a. Abundance	60	A slight decrease in abundance and biomass in the system as estuarine communities become established.	Medium
2b. Community composition	60	The community structure will change to a dominance of polychaete species in the lower reaches (similar to present low flow conditions) and estuarine species in the middle reaches. River fauna will be fewer and more abundant in the upper reaches of the estuary (beyond saline intrusion).	Medium
<i>Macrocrustacea</i>			
1. Species richness	50	Increased low flow and increased longitudinal salinity intrusion would slightly displace <i>Macrobrachium</i> species to the mid and upper reaches. Some loss of freshwater taxa is predicted for the lower reaches during low flow conditions. There would be an increase of estuarine associated species. River water quality will start affecting the <i>Macrobrachium</i> species. 70% of the original species will remain. The conduit function of the estuary for <i>Varuna litterata</i> would be maintained since there is no mouth closure under this scenario.	Medium
2a. Abundance	65	Increased salinity would create favourable conditions for penaeid prawn post-larval development. Abundance is expected to increase but not towards the reference state.	Medium
2b. Community composition	65	There may be a change in community composition with brackish and freshwater species being excluded in the lower reaches at low flow due to elevated salinity. There would be approximately 65% resemblance to the original composition.	Medium
Invertebrate score	25		

Fish

Variable	Score	Motivation	Confidence
1. Species richness	80	Species richness will be very similar to the Present State and richer than the Reference Condition. Dominance by marine fish species is favoured under these conditions.	Medium
2a. Abundance	90	Decrease in abundance from Reference State due to reduction in size of the estuary but increase in marine fish recruitment due to reduced river flow volumes.	Low
2b. Community composition	60	Dominance of marine and estuarine fish taxa throughout the year very different to Reference State community composition.	Medium
Fish score	60		

Birds

Variable	Score	Motivation	Confidence
1. Species richness	80	The potential exists, due to enhanced benthic status and increased fish richness for increased bird species richness when compared to the Present State.	Medium
2a. Abundance	70	The potential exists, due to enhanced benthic status and increased fish richness for increases in bird abundance when compared to the Present State. However, the impact of anthropogenic effects will probably counter this, leaving abundances much the same as in the Present State.	Medium
2b. Community composition	90	Community composition will move more towards the Reference State despite anthropogenic impacts such as disturbance occurring.	Medium
Bird score	70		

5 SCENARIO: RIVER CATEGORY D (INITIAL SCENARIO)

5.1 SEASONAL VARIABILITY IN RIVER INFLOW

Monthly simulated runoff data for the Scenario: River Category D is provided in Table 5.2 on the following page. A summary of flow distribution (mean monthly flows in m³/s) for the Scenario: River Category D, derived from the 70-year simulated data set, is provided in Table 5.1.

Table 5.1 A summary of flow distribution (mean monthly flows in m³/s) for Scenario: River Category D (derived from 70-year simulated data set)

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
90%ile	18.59	87.24	161.02	299.21	522.73	264.41	91.25	15.84	11.68	9.48	8.62	13.36
80%ile	18.48	29.25	81.57	217.58	385.57	211.86	73.25	15.44	11.64	9.44	8.58	13.30
70%ile	18.19	28.82	46.35	141.42	222.50	141.63	56.81	15.28	11.52	9.35	8.48	13.07
60%ile	17.48	28.22	40.32	97.13	168.77	110.95	40.33	14.92	11.27	9.14	8.32	12.68
50%ile	16.41	26.87	35.73	36.83	114.65	83.52	26.44	14.39	10.84	8.76	7.97	12.10
40%ile	14.92	24.82	28.81	31.33	88.54	67.70	23.13	13.41	10.10	8.20	7.43	10.88
30%ile	12.45	21.28	25.12	26.02	65.25	49.32	20.18	12.06	9.01	7.35	6.65	9.47
20%ile	9.71	16.61	19.11	20.02	44.25	35.85	16.68	10.48	7.90	6.40	5.82	7.67
10%ile	7.41	11.35	13.15	15.39	29.26	20.83	13.72	9.15	6.89	5.60	5.08	6.16
1%ile	6.34	7.67	8.66	12.50	19.89	15.20	12.35	8.53	6.43	5.21	4.74	5.47

5.2 PREDICTED FLOOD REGIME

Refer to Scenario: River Category A.

5.3 PREDICTED CHANGES IN SEDIMENT PROCESSES AND CHARACTERISTICS

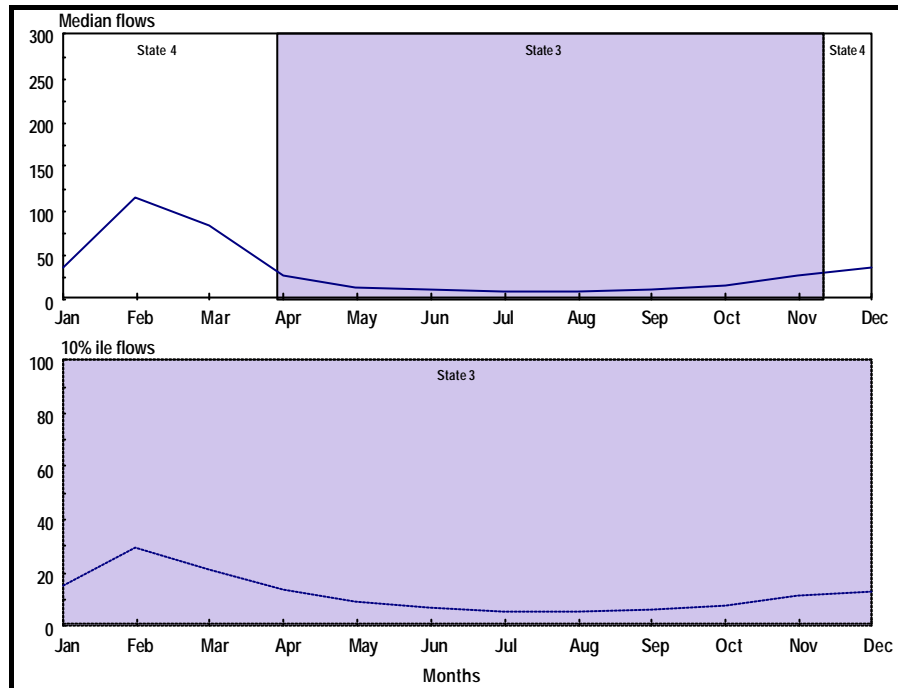
Refer to Scenario: River Category A.

Table 5.2 Monthly runoff data (in m³/s) for Scenario: River Category D, simulated over a 70-year period

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	AVE
1925	17.81	24.85	16.57	31.55	50.25	32.95	21.79	9.76	9.89	9.07	6.93	13.34	20.40
1926	18.56	28.90	35.28	24.31	81.23	97.67	61.96	12.06	8.05	7.38	8.25	11.59	32.94
1927	18.22	17.57	32.07	28.78	44.25	36.57	22.57	10.17	7.74	5.61	5.05	11.02	19.97
1928	15.49	13.98	26.18	24.85	43.43	51.19	46.47	14.88	11.67	9.49	8.62	13.38	23.30
1929	18.56	121.18	141.19	257.72	149.12	131.59	50.38	13.49	9.53	7.99	7.73	12.28	76.73
1930	12.55	10.42	20.28	36.80	132.97	47.15	16.71	10.50	6.90	7.29	7.24	6.02	26.23
1931	6.97	11.24	9.26	13.48	119.81	396.01	80.35	15.35	11.68	9.41	8.00	9.45	57.58
1932	7.44	16.67	27.88	15.44	29.11	20.86	13.63	9.07	6.43	6.34	6.71	5.91	13.79
1933	6.34	29.39	70.07	908.94	444.02	102.40	65.62	18.79	11.69	9.48	8.62	13.30	140.72
1934	16.71	29.23	466.92	213.83	105.92	89.05	23.55	14.00	11.43	9.27	7.56	6.87	82.86
1935	6.67	11.37	10.34	34.62	218.45	225.36	49.37	72.82	34.06	9.46	8.09	9.16	57.48
1936	13.82	126.57	170.27	256.85	381.45	121.62	14.68	9.29	6.57	5.33	4.74	5.47	93.06
1937	8.91	8.03	42.56	31.00	56.28	24.06	24.38	15.39	11.55	9.49	8.62	13.04	21.11
1938	18.45	27.37	48.77	182.40	739.61	394.61	52.68	15.17	11.60	9.43	8.55	13.23	126.82
1939	17.15	59.34	227.18	70.92	45.69	26.05	15.09	140.00	117.77	9.49	8.58	13.19	62.54
1940	15.27	24.70	115.01	247.08	250.52	131.50	71.76	15.49	11.37	8.18	6.20	6.74	75.32
1941	8.13	9.21	11.89	34.27	173.31	245.68	89.82	15.30	11.49	9.19	8.38	12.93	52.47
1942	17.31	85.35	457.93	462.67	192.88	101.69	534.77	265.99	27.26	47.97	381.30	174.62	229.15
1943	356.88	420.74	231.66	139.90	409.47	191.86	20.13	10.52	11.65	9.47	8.45	13.38	152.01
1944	18.50	24.77	13.21	12.50	23.09	124.13	169.91	14.61	9.78	7.43	5.49	5.69	35.76
1945	6.34	6.86	7.34	20.27	53.36	49.48	26.76	11.28	7.36	5.50	4.75	5.47	17.06
1946	16.85	29.09	25.38	12.50	64.78	49.72	26.11	13.52	11.37	9.41	8.31	11.11	23.18
1947	15.86	29.35	47.46	113.87	150.80	187.29	81.01	15.24	11.26	8.64	6.30	7.58	56.22
1948	13.94	14.46	16.31	31.00	82.63	48.94	67.73	15.43	10.94	7.79	5.71	8.35	26.94
1949	15.05	28.59	42.50	24.10	36.18	149.12	104.12	15.40	11.63	9.27	8.48	12.62	38.09
1950	12.23	13.89	40.71	23.10	30.38	25.30	16.97	10.40	7.91	6.11	8.62	13.35	17.41
1951	18.02	14.66	17.60	39.35	323.63	89.27	21.30	13.62	10.12	9.36	8.51	12.09	48.13
1952	11.18	27.16	37.12	25.98	402.05	243.01	20.54	13.11	8.83	6.98	8.33	12.39	68.06
1953	11.18	24.88	27.70	17.34	99.41	77.99	23.20	15.03	11.63	9.28	7.46	12.77	28.16
1954	18.59	135.70	137.65	478.89	659.33	230.24	31.21	14.67	10.86	8.80	6.27	6.18	144.86
1955	13.47	19.19	29.18	14.81	92.12	224.20	103.45	14.23	10.81	8.55	6.27	10.29	45.55
1956	14.35	29.14	497.64	509.21	169.96	128.03	70.00	15.45	11.53	9.49	8.62	385.28	154.06
1957	518.56	169.57	24.69	240.48	197.16	61.60	82.51	21.71	11.51	8.21	5.83	9.76	112.63
1958	12.81	25.58	38.47	26.03	79.37	69.85	13.73	15.52	11.69	9.45	8.43	12.18	26.93
1959	17.74	28.94	33.02	16.55	41.35	44.85	54.61	15.44	11.29	7.82	6.52	10.68	24.07
1960	14.94	28.21	159.99	206.98	26.43	76.17	77.86	15.49	11.62	9.16	7.37	12.06	53.86
1961	12.04	21.43	24.98	33.01	109.49	76.32	22.88	14.44	9.10	6.83	6.77	10.64	28.99
1962	8.50	28.19	38.92	129.76	133.61	94.35	35.72	13.39	11.05	38.60	52.76	12.99	49.82
1963	14.89	28.64	19.49	102.90	96.80	20.34	16.57	10.81	8.75	8.29	7.23	13.13	28.99
1964	18.60	104.28	56.69	117.19	65.45	15.20	12.35	8.53	11.51	9.47	8.61	13.31	36.77
1965	16.18	18.99	16.00	36.86	89.23	17.08	12.35	9.09	7.65	5.60	5.42	9.26	20.31
1966	9.39	20.92	38.04	232.59	561.13	310.91	166.47	28.96	11.67	9.40	8.38	9.77	117.30
1967	9.38	20.86	22.48	14.25	19.41	16.30	13.36	8.63	6.43	5.21	5.43	9.47	12.60
1968	7.12	13.25	25.13	17.75	34.31	51.32	27.83	15.47	11.67	9.35	8.09	12.14	19.45
1969	18.39	24.00	30.42	20.12	44.23	20.50	12.47	8.53	6.67	5.56	8.56	13.35	17.73
1970	18.48	26.44	14.88	32.89	58.38	20.49	18.45	15.52	11.69	9.45	8.59	12.98	20.69
1971	17.67	22.24	36.18	28.76	87.51	64.47	105.95	14.87	11.54	9.28	8.00	7.70	34.51
1972	9.79	20.50	16.49	12.78	98.58	48.48	26.12	15.35	10.27	6.80	8.61	13.38	23.93
1973	18.24	28.62	31.50	171.63	414.99	208.78	84.32	15.46	11.64	9.42	8.44	11.14	84.52
1974	6.96	28.58	46.55	276.56	607.65	248.53	36.60	15.11	11.22	8.45	6.41	13.38	108.83
1975	18.37	28.79	130.38	467.43	423.06	618.04	253.60	33.98	11.69	9.47	8.50	12.52	167.99
1976	18.38	28.24	31.87	83.94	161.93	77.91	34.21	14.38	8.50	6.27	5.22	13.32	40.35
1977	18.50	27.85	27.36	298.81	323.53	117.39	50.93	15.27	10.83	8.38	8.02	13.17	76.67
1978	18.60	28.94	95.47	93.28	169.81	72.30	14.88	12.12	10.08	9.08	8.62	13.35	45.55
1979	17.35	21.62	21.53	27.33	78.68	46.83	15.86	9.15	6.57	5.31	4.74	13.29	27.36
1980	16.64	25.04	44.41	144.97	664.31	197.73	16.75	12.64	10.85	9.12	8.53	13.29	92.02
1981	15.52	27.01	25.12	19.61	22.81	26.15	20.18	10.42	7.13	5.59	4.93	8.59	16.09
1982	18.48	25.93	12.64	14.94	20.10	15.20	12.77	8.72	6.80	6.90	7.93	10.39	13.40
1983	16.89	29.36	51.16	493.55	376.45	156.50	67.68	14.98	10.43	9.35	8.60	13.25	104.02
1984	17.99	16.40	12.15	28.36	627.11	311.76	15.84	9.46	7.23	5.97	4.95	5.65	88.57
1985	18.59	29.20	40.06	302.85	211.84	106.65	44.40	14.80	10.29	8.73	7.81	11.21	67.20
1986	18.18	26.74	44.44	32.91	305.84	289.77	72.10	12.79	9.64	8.82	8.62	910.95	145.07
1987	549.65	159.85	95.04	121.55	432.79	354.09	89.89	15.26	11.67	9.49	8.60	13.00	155.07
1988	18.07	27.48	46.26	176.04	663.05	261.59	19.58	12.80	10.71	9.04	7.59	6.96	104.93
1989	8.51	29.39	295.51	82.15	29.28	57.23	24.19	14.40	9.09	6.42	7.83	12.11	48.01
1990	9.79	9.14	28.25	113.31	518.46	190.47	23.66	11.47	8.68	7.82	5.78	8.23	77.92
1991	18.60	28.76	44.49	59.51	168.07	73.13	13.58	9.08	6.51	5.21	4.84	5.68	36.46
1992	6.51	23.32	39.59	19.24	82.27	47.99	23.02	11.46	7.85	5.81	5.09	7.47	23.30
1993	18.60	84.94	78.20	179.37	231.95	138.42	37.62	13.43	8.43	7.12	8.56	12.79	68.29
1994	10.88	8.55	10.57	19.36	25.23	26.54	20.16	12.07	11.17	9.00	7.11	6.37	13.92
Median	16.41	26.87	35.73	36.83	114.65	83.52	26.44	14.39	10.84	8.76	7.97	12.10	32.88
Average	34.15	40.28	70.71	126.20	202.24	124.94	53.27	20.01	12.05	9.07	13.31	31.24	61.46
10%ile	7.41	11.35	13.15	15.39	29.26	20.83	13.72	9.15	6.89	5.60	5.08	6.16	17.70
<div style="display: flex; justify-content: space-between; align-items: center;"> 1: Closed < 2.0 2: Open (closed for days) 2.0-5.0 3: Open (Saline) 5.0-30 4: Open (Riverine) > 30.0 </div>													
< 2.0	0	0	0	0	0	0	0	0	0	0	0	0	0.00%
2.0-5.0	0	0	0	0	0	0	0	0	0	0	6	0	0.71%
5.0-30	67	60	29	26	8	13	37	66	68	68	62	67	67.98%
> 30.0	3	10	41	44	62	57	33	4	2	2	2	3	31.31%

5.4 PREDICTED OCCURRENCE AND DURATION OF DIFFERENT ABIOTIC STATES

The occurrence and duration of the different Abiotic States under Scenario: River Category D are illustrated in the simulated monthly river flow table (Table 5.2). To provide a conceptual overview of the annual distribution of Abiotic States under Scenario: River Category D, median monthly flows and 10%ile flows were used to depict the situation for normal and drought periods, respectively:



5.5 E. PREDICTED CHANGES IN BIOTIC CHARACTERISTICS

<p>MICROALGAE</p> <p>Phytoplankton: The Scenario: River Category C increases the frequencies of low flow (States 3 and 4) conditions from 4/12 months to 8/12 months from that of the Reference State. The prevalence and severity of saline conditions would promote a marine tolerant phytoplankton community extending up to the upper reaches of the estuary when flows fall below 30 m³/s. The estuary would behave like a typical tidal estuary with a well-developed REI zone in the middle reaches of the estuary. This condition would be different from that of the Reference State.</p> <p>Confidence: Medium</p> <p>Benthic microalgae: The estuary will be characterised by Abiotic States 3 and 4. During extended drought periods, State 3 could last for the entire year. This could affect community composition near to the mouth of the estuary, as there will be no change from brackish diatom taxa to a freshwater diatom community. However, the upper reaches of the estuary will always be fresh and will maintain a similar community composition. As a result, species richness will not be significantly affected compared to categories A, B and C. No change in the estuary morphology is expected from Category A, B and C, so the effects will be similar. Conditions are expected to be more stable, so benthic biomass and species richness could increase.</p> <p>Confidence: Medium</p>
<p>MACROPHYTES</p> <p>Low flow (States 1, 2, 3) occurs for 8 months of the year compared to 4 months for the reference condition. Saline conditions together with an increase in sediment stability would promote the growth of reeds and sedges. There is a possibility that the mouth can close but this would occur less frequently than that of present day conditions and will therefore have little influence on the macrophytes. There may be a slight change in community composition, with brackish species outcompeting freshwater species.</p> <p>Confidence: Medium</p>

INVERTEBRATES
Zooplankton: Species richness of the marine dominated community during low flows should not change from the reference state. Some plankters such as the paracalanids may increase substantially during spring.
Confidence: Low
Macroinvertebrates: For the majority of the year, the system will be categorised by low flow states (<30m ³ /s) with little chance of mouth closure (~1% from reference). Those that are more estuarine dominated and fewer freshwater taxa will replace the present macroinvertebrates in the mid and lower reaches. The upper reaches will still be characterised by riverine fauna and with the predicted sediment stability could include Odonata and Ephemeroptera larvae. Succession from opportunistic species to climax stable populations will be possible given the protected length/stability of the low flow phase. Although there will be a change in species occupying the system, a long term significant reduction in abundance is not envisaged.
Confidence: Medium
Macrocrustacea: Increased frequency of low flow conditions (from 4/12 to 8/12 months of the reference condition) would result in prolonged and increased saline intrusion. This will promote colonisation of marine penaeid prawns such <i>P. japonicus</i> in the lower reaches. Other penaeid species such as <i>M. monoceros</i> found in the Thukela Estuary prefer lower salinities and if salinity increased to marine conditions, they would move further up the system. The macrocrustacean community composition will change from the reference condition in that freshwater tolerant species will be concentrated further up the estuary with juveniles of marine species recruiting further into the system.
Confidence: Medium
FISH
Compared to the Reference Condition and Present State, the occupation of the estuary by marine fish species will be higher as a result of the predominant State 3 condition. Even during the summer months the estuary will remain a suitable habitat for a wide variety of marine and estuarine fish species. The absence of mouth closure together with a well developed salinity gradient within the estuary provide optimum conditions for a wide variety of fish species.
Confidence: Medium
BIRDS
The system will primarily be characterised by low flow conditions which allow saline intrusion; it will thus begin to function more like a typical estuary. This should create the potential to enhance the benthic feeding fauna if there is sufficient intertidal exchange so as to expose the feeding areas. This would apply to a lesser degree to piscivorous species whilst roosting species will be largely unaffected. However, anthropogenic impacts will counter this to some extent.
Confidence: Medium

5.6 ESTUARINE HEALTH SCORE ASSESSMENT FOR SCENARIO: RIVER CATEGORY D

Hydrology

Variable	Score	Motivation	Confidence
a. % similarity in period of low flows	67	For the Thukela Estuary, low flow is assumed to be flows less than 30 m ³ /s, i.e. States 1, 2 and 3. Under the Reference Condition low flows occurred for 4 months of the year. This increased to 8 months per year under Scenario: River Category D.	Medium
b. % similarity in the magnitude of major floods (e.g. 1:20, 1:50 and 1:100) in comparison with the reference condition	73	Based on statistical analysis of observed present and simulated post-dam floods, assuming new dams are in place (27% decrease in flood peaks from Reference Condition)	High
Hydrology score	69		

Hydrodynamics and mouth condition

Variable	Score	Motivation	Confidence
Change in mean duration of closure over a 70-year period	95	Following a precautionary approach, the changes in the occurrence of Abiotic States in which there is a high probability of mouth closure occurring (i.e. States 1 and 2) were calculated and then scored according to Table 2.13 in Turpie (2002). The occurrence of Abiotic States for which there is a high probability of mouth closure to occur (i.e. States 1 and 2), increased from 0% under Reference Conditions to ~1% under Scenario: River Category D.	Low
Hydrodynamic score	95		

Water quality

Variable	Score	Motivation	Confidence
1. Change in longitudinal salinity gradient (%) and vertical salinity stratification	50	Under Reference Condition, the estuary was more river dominated than under Scenario: River Category D, i.e. State 4 decreased from 8 months per year to 4 months. State 3 (i.e. open, with saline intrusion) also increased from 4 months under Reference to 8 months under Scenario: River Category D. Within State 3 the median flows were much higher under the Reference Condition compared with Scenario: River Category D. This suggests that in addition to the duration, the longitudinal intensity of saline intrusion also increased under the Scenario: River Category D.	Medium
2a. Nitrate/phosphate concentration in the estuary	70	Similar to the Present State, assuming potential impacts of Industrial area at Mandini remain intact.	Low
2b. Suspended solids present in inflowing freshwater	50	Similar to the Present State, assuming potential impacts of Industrial area at Mandini and other catchment activities remain intact.	Low
2c. Dissolved oxygen (DO) in estuary	80	Similar to the Present State, assuming potential impacts of Industrial area at Mandini remain intact.	Low
2d. Levels of toxins	100	Similar to the Present State, i.e. no marked difference from Reference Condition.	Medium
Water quality score	50		

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 exposed	60	Assuming that Scenarios for River Category A-D can only be achieved with additional dam development in the catchment, resulting in further flood intenuation and/or sediment yield, although not much different from Present State.	High
1b	% similarity in sand fraction relative to total sand and mud	60	Assuming that Scenarios for River Category A-D can only be achieved with additional dam development in the catchment, resulting in further flood intenuation and/or sediment yield, although not much different from Present State.	High
2	Resemblance of subtidal estuary to reference condition: depth, bed or channel morphology	75	Flood peaks decrease with future dams. Sediment will be trapped in future dams, but as a result of overgrazing and land use changes, the sediment yield could actually increase.	High
Physical habitat score		67.5		

Microalgae

Variable	Score	Motivation	Confidence
<i>Phytoplankton</i>			
1. Species richness	65	Reduction in low flows together with an increase in saline conditions would reduce brackish species richness in the lower reaches and replace them with marine forms. Brackish species would occur further up the estuary than would have occurred under the Reference State.	Medium
2a. Abundance	65	Reduction in low flows together with an increase in saline conditions would reduce phytoplankton density. Peaks in phytoplankton density would occur within the REI zone that has shifted further up the estuary.	Medium
2b. Community composition	65	A decrease in the flow rate would shift phytoplankton community composition toward opportunistic phytoplankton like blue-green algae particularly in slow-flowing backwater pockets.	Medium
<i>Benthic microalgae</i>			
1. Species richness	80	Conditions have not changed drastically from the reference condition (States 3 and 4).	Medium
2a. Abundance	90	Slightly more stable conditions would favour a slight increase in benthic biomass. Shorter, narrower and deeper estuary will reduce the total biomass of the estuary.	Medium
2b. Community composition	90	Conditions have not changed drastically from the reference condition (States 3 and 4). Mouth won't close.	Medium
Microalgae score	65		

Macrophytes

Variable	Score	Motivation	Confidence
1. Species richness	75	Because flood peaks are reduced and the estuary is not reset as often as it may have been under present conditions, there may be a loss of opportunistic species. Approximately 85% of the original species remain.	Medium
2a. Abundance	67	The further increase in low flow conditions and salinity intrusion into the estuary would create favourable conditions for the growth of brackish reeds and sedges.	Medium
2b. Community composition	78	There may be a slight change in community composition with brackish species outcompeting freshwater species. There would be a 78% resemblance to the original composition.	Medium
Macrophyte score	67		

Invertebrates

Variable	Score	Motivation	Confidence
<i>Zooplankton</i>			
1. Species richness	65	Increasing marine conditions during longer low flow periods should not lead to any changes in the species richness.	Low
2a. Abundance	70	Some taxa should show an increase in abundance during spring.	Low
2b. Community composition	50	No major changes expected.	Low
<i>Macroinvertebrates</i>			
1. Species richness	25	Estuarine/marine dominated and fewer freshwater taxa will replace the present macroinvertebrates in the mid and lower reaches. The upper reaches will still be characterized by riverine fauna. With the predicted sediment stability, new incoming species could include Odonata and Ephemeroptera larvae.	Medium
2a. Abundance	60	A long term reduction in abundance from Category C is not envisaged or a large change (decrease of 10%) from Categories A and B.	Medium
2b. Community composition	60	The community structure will change to a dominance of estuarine/marine species and succession from opportunistic to stable climax populations will be possible given the projected duration of the low flow phase.	Medium

<i>Macrocrustacea</i>			
1. Species richness	50	Brackish species would be lost or pushed further up the river and the persistence of high salinity conditions would exclude species that require low salinity. Approximately 75% of the original species remain. The conduit function of the estuary for <i>Varuna litterata</i> would be maintained since there is no mouth closure under this scenario.	Medium
2a. Abundance	65	The further increase in salinity intrusion would disturb the recruitment success of macrocrustacea into the estuary, which would result in decreased abundance of species utilising the estuary as the nursery area. Approximately 65% of total abundance would remain.	Medium
2b. Community composition	65	There would be slight change in community composition with marine/brackish species dominating.	Low
Invertebrate score	25		

Fish

Variable	Score	Motivation	Confidence
1. Species richness	80	Species richness will be very similar to the Present State and richer than the Reference Condition. Dominance by marine fish species is favoured under these conditions.	Medium
2a. Abundance	90	Decrease in abundance from Reference State due to reduction in size of the estuary but increase in marine fish recruitment due to reduced river flow volumes.	Low
2b. Community composition	60	Dominance of marine and estuarine fish taxa throughout the year; very different to Reference State community composition.	Medium
Fish score	60		

Birds

Variable	Score	Motivation	Confidence
1. Species richness	80	The potential exists, due to enhanced benthic status and increased fish richness for increased bird species richness when compared to the Present State.	Medium
2a. Abundance	70	The potential exists, due to enhanced benthic status and increased fish richness for increased bird abundance when compared to the Present State. However, the impact of anthropogenic effects will probably counter this, leaving abundances much the same as in the Present State.	Medium
2b. Community composition	90	Community composition will move more towards the Reference State despite anthropogenic impacts, such as disturbance, occurring.	Medium
Bird score	70		

6 SCENARIO: WORST CASE 1 (INITIAL SCENARIO)

6.1 SEASONAL VARIABILITY IN RIVER INFLOW

Monthly simulated runoff data for the Worst Case Scenario 1 is provided in Table 6.2 on the following page. A summary of flow distribution (mean monthly flows in m³/s) for the Worst Case Scenario 1, derived from the 70-year simulated data set, is provided in Table 6.1.

Table 6.1 A summary of flow distribution (mean monthly flows in m³/s) for Scenario: Worst Case 1 (derived from 70-year simulated data set)

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
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