PBV000-00-10308

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

## VOLUME 1

Prepared by
IWR Source-to-sea

# THUKELA WATER PROJECT DECISION SUPPORT PHASE

# RESERVE DETERMINATION MODULE
# THUKELA ESTUARINE FLOW REQUIREMENTS REPORT

## MARCH 2004

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**Report versions**

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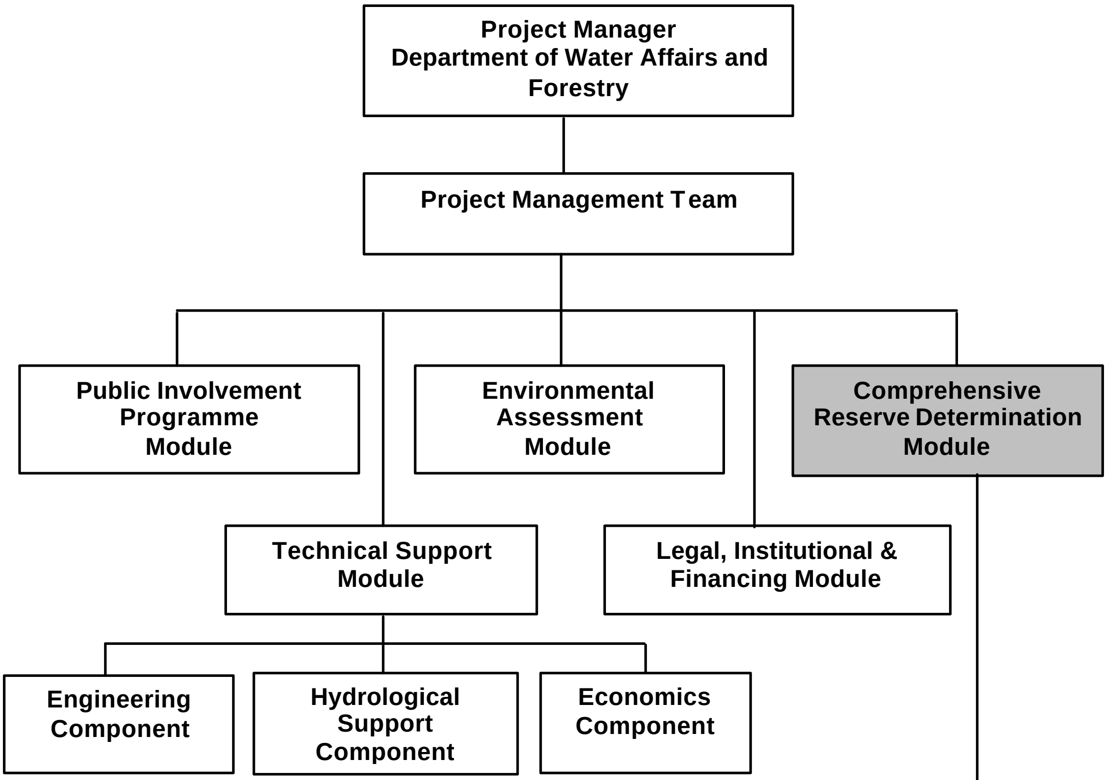
# STRUCTURE OF DECISION SUPPORT PHASE




PBV000-00-10301: Inception Report
PBV000-00-10302: Resource Unit Report
PBV000-00-10303: Ecological Reserve Category Report
PBV000-00-10304: Ground Water Scoping Report
PBV000-00-10305: Basic Human Needs Reserve
PBV000-00-10306: Thukela System Water Quality Report
PBV000-00-10307: Thukela System Instream Flow Requirements Report
**PBV000-00-10308: Thukela Estuarine Flow Requirements Report**
PBV000-00-10309: Thukela System Ecological Scenario (Rivers) Report
PBV000-00-10310: Thukela Bank: Impacts of Flow Scenarios on Prawn and Fish Catch
PBV000-00-10311: Thukela System Resource Economics Report
PBV000-00-10312: Capacity Building and Training Report
PBV000-00-10313: Results and Recommendations of the Thukela Reserve
PBV000-00-10314: Thukela System Ecospecs and Monitoring Report
PBV000-00-10315: Thukela System Main Report
PBV000-00-10316: Electronic Data

**DEPARTMENT OF WATER AFFAIRS & FORESTRY**
**DIRECTORATE WATER RESOURCE PLANNING**

# THUKELA WATER PROJECT DECISION SUPPORT PHASE
# RESERVE DETERMINATION MODULE
# THUKELA ESTUARINE FLOW REQUIREMENTS REPORT

**IWR SOURCE-TO-SEA** **MARCH 2004**

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# ACKNOWLEDGMENTS

This report was compiled by Ms Susan Taljaard

The following specialists and trainees contributed to the Estuary report:

| | | |
|---|---|---|
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| Prof Gerrit Basson | University of Stellenbosch | (sediment dynamics) |
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# EXECUTIVE SUMMARY

## ASSUMPTIONS AND LIMITATIONS

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

- The ecological reserve determination for the Thukela Estuary is done at an intermediate level. However, in this case sediment processes, not usually included on intermediate level studies, were also dealt with, being of particular importance in the case of the Thukela Estuary.
- Field data on the abiotic and biotic characteristics of the Thukela Estuary in its closed state could not be collected within the time frame of this study. Therefore assessments on the behaviour of the estuary under this state are of low confidence.
- This study provides details on the Ecological Reserve, i.e. the water needs of the estuarine aquatic ecosystem. This information will feed into the public participation process to determine the Management Class for the Thukela. Thereafter, other user requirements would be incorporated. Therefore specific needs relating to other water uses of the estuary, such as the water quality requirements for recreational use (e.g. *Eschericia coli* levels) were not included in this study.
- Criteria for confidence limits attached to statements throughout this report are as follows:

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

## GEOGRAPHICAL BOUNDARIES

The geographical boundaries for the Thukela Estuary are defined as follows (Gauss Projection, Clarke 1880 Spheroid):

- **Downstream boundary:** The estuary mouth (31°29’56”E; 29°13’24”S).
- **Upstream boundary:** Approximately 6km from mouth (31°26’23”E; 29°13’0”S).
- **Lateral boundaries:** 5m contour above MSL along the banks.

## PRESENT ECOLOGICAL STATE (PES)

The Estuarine Health Index scores allocated to the Thukela Estuary (present state) are:

| Variable | Weight | Score | Weighted score |
|---|---|---|---|
| Hydrology | 25 | 87 | 22 |
| Hydrodynamics and mouth condition | 25 | 80 | 20 |
| Water quality | 25 | 54 | 14 |
| Physical habitat alteration | 25 | 80 | 20 |
| **Habitat health score** | | | **75** |
| Microalgae | 20 | 65 | 13 |
| Macrophytes | 20 | 60 | 12 |
| Invertebrates | 20 | 60 | 12 |
| Fish | 20 | 70 | 14 |
| Birds | 20 | 70 | 14 |
| **Biotic health score** | | | **65** |
| **ESTUARINE HEALTH SCORE** | | | **70** |

The EHI score of 70 allocated to the Thukela Estuary translates into a Present Ecological State of C:

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

## IMPORTANCE OF THE THUKELA ESTUARY

The Estuarine Importance scores allocated to the Thukela Estuary are as follows:

| Criterion | Score | Weight | Weighted score |
|---|---|---|---|
| Estuary Size | 80 | 15 | 12 |
| Zonal Rarity Type | 70 | 10 | 7 |
| Habitat Diversity | 50 | 25 | 13 |
| Biodiversity Importance | 76.5 | 25 | 19 |
| Functional Importance | 100 | 25 | 25 |
| **ESTUARINE IMPORTANCE SCORE** | | | **76** |

The Estuarine Importance score of 76 allocated to the Thukela Estuary indicates that the estuary is important:

| Importance score | Description |
|---|---|
| 80 – 100 | Highly important |
| 60 – 80 | Important |
| 0 – 60 | Of low to average importance |

**RECOMMENDED ECOLOGICAL RESERVE CATEGORY FOR THUKELA ESTUARY**

The relationship between EHI Score, PES and ERC for estuaries is as follows:

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

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

The degree to which the minimum ERC, based on its PES, needs to be modified depends on the importance of the estuary and modifying determinants, i.e. protected area status and desired protected area status. The proposed rules for allocation of the recommended ERC are:

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

According to the rules, the recommended ERC for the Thukela Estuary should be:

- Because the Thukela Estuary is rated 'important' (reflected by the estuarine importance score of 76), the recommended Ecological Reserve Category should be '*Present State Category (i.e. C) +1*', which implies a Category B; or, if not possible,
- Best attainable state, with Category C the minimum requirement.

Results of the workshop indicated that non-flow related anthropogenic activities (such as human disturbance of birds, over-fishing and removal of wetlands for agriculture) have had a significant influence on the present state of the estuary. As some of the changes caused by these activities would be difficult to reverse, the specialist team suggested that the present state corresponding to a PES of C be selected as the recommended ERC, which still remains within the recommended ERC allocation rules proposed for an 'Important' estuary.

Thus, the **recommended ERC for Thukela Estuary is a Category C (Confidence = Medium).** However, it should be noted that the PES of the estuary corresponds to a high C (scored 70 in the range 61 – 75). This, together with the estuary being rated in the higher range of 'Important' estuaries (scored 76 in the range 60 – 80), is considered reasonable motivation to manage the estuary to maintain a high C category.

## QUANTIFICATION OF ECOLOGICAL RESERVE SCENARIOS

Two sets of scenarios had to be assessed, namely:

- Initial Scenarios (assessed at a workshop held in June 2002).
- Yield Scenarios (assessed at a workshop held in January 2003).

A summary of the initial and yield scenarios used in the quantification of ecological reserve process is listed below:

| Type | Scenario | MAR ($m^3 \times 10^6$) | % MAR |
|---|---|---|---|
| INITIAL | 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 |
| YIELD | 1 | 3053.6 | 81.7 |
| | 2 | 3039.2 | 81.4 |
| | 3 | 3027.3 | 81.0 |
| | 4 | 3034.8 | 81.2 |
| | 5 | 3031.3 | 81.1 |
| | 6 | 3023.8 | 81.0 |
| | 7 | 2996.8 | 80.2 |
| | 8 | 2501.0 | 67.0 |

The individual EHI scores allocated to the different initial and yield scenarios, as well as corresponding the ERC, are listed in the table on *page vi*.

According to general rule in the methodology for estuaries, Scenario: River Category D should have been the recommended 'Reserve', i.e. the scenario representing the largest modification in flow, but that would still keep the estuary in the recommended ERC, in this case C. However, the workshop was concerned that the April/May flow reduction of this scenario could be problematic, particularly in the light of recent research (Coastal Research Unit of Zululand, University of Zululand) indicating that there is a narrow window period for larval recruitment of the crab *Varuna litterata* during late autumn each year. This freshwater species has an obligate marine phase during its lifecycle.

Therefore, Scenario: River Category B is selected as the **recommended Reserve** for the Thukela Estuary that would be required to keep it in an ERC of a high C, with flow distributions as summarised below (in $m^3 \times 10^6$):

| %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 |

In term of the initial scenarios only Scenario:  River Category A and Scenario: River Category B are acceptable (i.e. they result in a C+ or higher category), while in terms of the yield scenarios, Scenarios 1 to 6 are acceptable (refer to table below).

| COMPONENT | EHI SCORING FOR DIFFERENT INITIAL AND YIELD SCENARIOS | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | INITIAL SCENARIO | | | | | | | YIELD SCENARIOS | | | | | | | |
| | **Present State** | **River Category A** | **River Category B** | **River Category C** | **River Category D** | **Worst Case 1** | **Worst Case 2** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| Hydrology | 87 | 89 | 79 | 74 | 69 | 69 | 69 | 87 | 87 | 87 | 87 | 87 | 87 | 87 | 87 |
| Hydrodynamics | 80 | 100 | 100 | 95 | 95 | 20 | 20 | 100 | 100 | 100 | 95 | 95 | 95 | 90 | 85 |
| Water quality | 54 | 70 | 62 | 58 | 50 | 46 | 46 | 62 | 60 | 58 | 56 | 56 | 56 | 54 | 50 |
| Physical habitat | 80 | 68 | 68 | 68 | 68 | 68 | 68 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 |
| **HABITAT HEALTH SCORE** | **75** | **82** | **77** | **74** | **70** | **51** | **51** | **82** | **82** | **81** | **80** | **80** | **80** | **78** | **76** |
| Microalgae | 65 | 65 | 65 | 65 | 65 | 35 | 35 | 70 | 70 | 70 | 70 | 70 | 70 | 65 | 60 |
| Macrophytes | 60 | 62 | 64 | 67 | 67 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 |
| Invertebrates | 60 | 65 | 65 | 25 | 25 | 17 | 17 | 65 | 65 | 65 | 65 | 65 | 65 | 60 | 42 |
| Fish | 70 | 70 | 70 | 60 | 60 | 40 | 40 | 80 | 80 | 80 | 70 | 70 | 70 | 70 | 60 |
| Birds | 70 | 70 | 70 | 70 | 70 | 25 | 25 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 50 |
| **BIOTA HEALTH SCORE** | **65** | **66** | **67** | **57** | **57** | **35** | **35** | **69** | **69** | **69** | **67** | **67** | **67** | **65** | **54** |
| **EHI SCORE** | **70** | **74** | **72** | **66** | **64** | **43** | **43** | **76** | **75** | **75** | **73** | **73** | **73** | **71** | **65** |
| **CORRESPONDING ERC** | **C+** | **C+** | **C+** | **C-** | **C-** | **D-** | **D-** | **B-** | **C+** | **C+** | **C+** | **C+** | **C+** | **C+** | **C-** |

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# GLOSSARY OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| BAS | Best Attainable State |
| COD | Chemical Oxygen Demand |
| DO | Dissolved Oxygen |
| DWAF | Department of Water Affairs and Forestry |
| ERC | Ecological Reserve Category |
| EHI | Estuarine Health Index |
| MAP | Mean Annual Precipitation |
| MAR | Mean Annual Runoff |
| MSL | Mean Sea Level |
| PES | Present Ecological State |
| RDM | Resource Directed Measures |
| REI | Riverine/Estuarine Interface |
| RQO | Resource Quality Objectives |
| TWP | Thukela Water Project |
| VAPS | Vaal Augmentation Planning Study |
| VRS | Vaal River System |
| WRP | Water Resource Planning |

# 1 INTRODUCTION

## 1.1 BACKGROUND

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 Thukela Vaal Transfer Scheme 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 resources 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 commensurate with the level of activities comprising the Decision Support Phase.

The investigations for the intermediate determination of the Ecological Reserve for the Thukela Estuary was co-ordinated by Coastal and Environmental Services, acting as sub-consultant to IWR Source-to-Sea.

The core specialist team appointed for this project was as follows:

| Team member | Role/Expertise | Contact details |
|---|---|---|
| Dr Angus Paterson | Project coordination | Coastal and Environmental Services<br>a.paterson@cesnet.co.za |
| Susan Taljaard | Water quality<br>Preparation of Estuaries Report | CSIR, Stellenbosch<br>staljaar@csir.co.za |
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| Team member | Role/Expertise | Contact details |
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| Dr Janine Adams | Estuarine vegetation | University of Port Elizabeth<br>btajba@upe.ac.za |
| Dr Alan Whitfield | Fish | South African Institute for Aquatic Biodiversity |
| Prof Digby Cyrus | Birds | University of Zululand<br>dcyrus@pan.uzulu.ac.za |

The following persons also participated in the project to ensure capacity building:

| Person | Role/Expertise | Contact details |
|---|---|---|
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| Philokuhle Buthelezi | Invertebrates | University of Zululand<br>c/o dcyrus@pan.uzulu.ac.za |
| Phumelele Gama | Estuarine vegetation | University of Port Elizabeth<br>c/o btajba@upe.ac.za |

For the Intermediate Ecological Reserve determination on the Thukela Estuary, the following process was followed:

## 1.2 ASSUMPTIONS AND LIMITATIONS

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

- The ecological reserve determination for the Thukela Estuary is undertaken at an intermediate level. However, the sediment processes which is not usually part of intermediate level studies, were also dealt with, being of particular importance in the case of the Thukela Estuary.
- Field data on the abiotic and biotic characteristics of the Thukela Estuary in its closed state could not be collected within the time frame of this study. Therefore assessments on the behaviour of the estuary under this state are of low confidence.
- The study is scenario-based and thus provides details of the resulting estuarine ecological status for various flow scenarios. This information will feed into the public participation process. Thereafter, other user requirements would be incorporated. Therefore specific needs relating to other water uses of the estuary, such as the water quality requirements for recreational use (e.g. *Eschericia coli* levels) were not included in this study.
- Criteria for confidence limits attached to statements throughout this report are as follows:

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

The data and information to substantiate motivations provided in Sections 4 and 5 of this report are primarily contained in the individual Specialist Reports appended to the report. Such data and information were generated through recent field surveys on the Thukela Estuary (as part of this preliminary Ecological Reserve determination), as well as historical information sources. Specialist Reports appended to this report are as follows:

- Physical dynamics and Water Quality (Appendix C)
- Microalgae (Appendix D)
- Macrophytes (Appendix E)
- Invertebrates (Appendix F)
- Fish (Appendix G)
- Birds (Appendix H)

# 2 INTERMEDIATE RESERVE DETERMINATION PROCESS FOR ESTUARIES

The detailed process (DWAF 2003) followed in the Intermediate Ecological Reserve Determination for estuaries is illustrated in Figure 2.1.

The process comprises of eight (8) main steps, namely:

***<u>Step 1: Initiation of RDM study</u>*.** During the initiation of an RDM study, it is important to establish the level as which the study needs to be conducted (e.g. rapid, intermediate or comprehensive), as well as the reserve components that need to be addressed (e.g. rivers, estuaries, wetlands or groundwater). The key outcome of Step 1 is therefore the detailed scope of the RDM study. In the case of the Thukela, the Ecological Reserve study on the estuary was conducted at an intermediate level, due to a lack of closed mouth condition survey information. Sediment dynamics, an abiotic component, that is usually only addressed at comprehensive level was however included.

***<u>Step 2: Definition of Resource Units</u>*.** It was considered appropriate to delineate each estuary as a separate resource unit within a larger catchment, characterized by site dependent abiotic and biotic characteristics. For estuaries, the default geographical boundaries are defined as follows:

**Downstream boundary:** The estuary mouth (However, there are systems where the 'estuary' often expands to the near-shore marine environment and where this boundary definition may need to be reconsidered in future).

**Upstream boundary:** The extent of tidal influence, i.e. the point up to where tidal variation in water levels can still be detected <u>or</u> the extent of saline intrusion which ever is furthest upstream.

**Lateral boundaries:** The 5m above MSL contour along each bank.

The geographical boundaries for the Thukela Estuary are addressed in Chapter 3 of this report.

***<u>Step 3: Ecological Reserve Categorisation</u>*.** The main outcome of this step is to define a recommended Ecological Reserve category for the estuary. For the Thukela, the ecological reserve categorisation step is dealt with in Chapter 4.

The method used for estuaries uses simulated runoff scenarios, where scenarios are typically simulated over a 50-70 year period and are presented as average monthly flows that represent inflows at the head of the estuary. For the Ecological reserve Categorisation simulated runoff scenarios for the *present state* and the *reference conditions* are used.

Firstly, the <u>present state</u> of an estuary is defined as a quantitative description of the present abiotic and biotic characteristics and functioning of the system (Chapter 4.1). For estuaries, the following components need to be addressed:

*<u>Abiotic (or driving components):</u>*

Physical dynamics (including hydrodynamics and sediment dynamics).
Water quality.

*<u>Biotic (response) components</u>:*

Estuarine flora (microalgae and macrophytes).
Estuarine fauna (invertebrates, fish and birds).

Thereafter the reference condition of an estuary is defined (Chapter 4.2). For the purposes of the Ecological Reserve determination process, the reference condition of an estuary refers to the ecological status that it would have had:

When receiving 100% of the natural MAR.
Before any human development in the catchment or within the estuary.
Before any mouth manipulation practices (e.g. artificial breaching).

Typically, the reference conditions in an estuary refer to its ecological status 50 to 100 years ago.

The present state and reference condition of an estuary are then used to determine the Present Ecological Status (PES) (Chapter 4.3). The PES is a measure of the health of a resource, based on a comparison between the reference condition and the present state. An Estuarine Health Index (EHI) is used to determine the PES for estuaries.

Also included in Ecological Reserve Categorisation component is an assessment of the ecological importance of an estuary (Chapter 4.4). Ecological importance is an expression of the importance of an estuary to the maintenance of ecological diversity and functioning on local and wider scales. Variables were discussed in a workshop setting, regarding their suitability for inclusion in an Estuarine Importance Index. The importance scores have been derived for most South African estuaries as part of a project entitled: *Classification and prioritisation of South African estuaries on the basis of health and conservation status for determination of the estuarine water reserve* (Turpie *et al*., 2002). The only importance score that needs to be derived by the estuarine ecological reserve team (at the specialist workshop) is that for the link with freshwater and marine environment (i.e. functionality score).

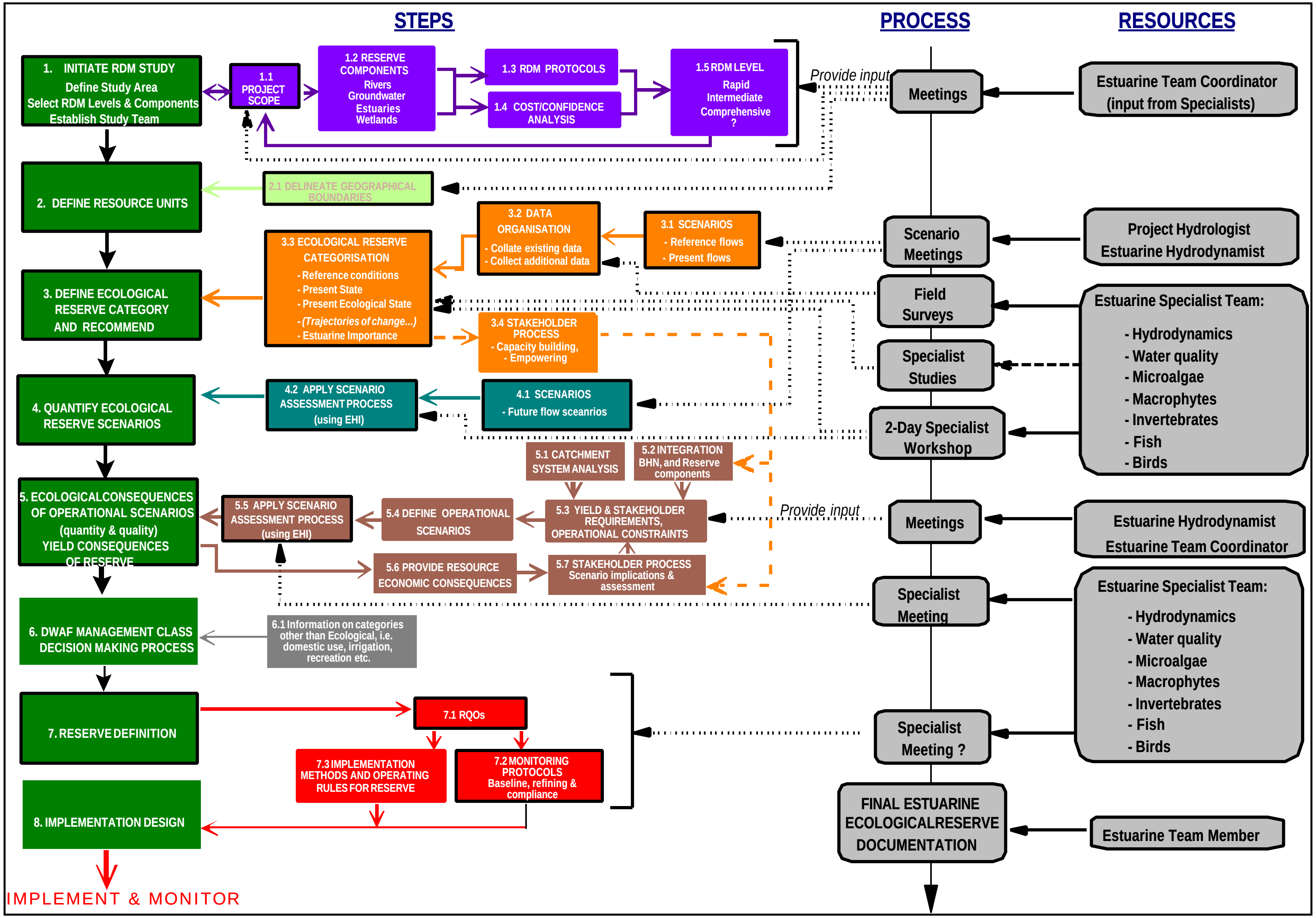
Finally, the PES and ecological importance score are used to come to a recommended Ecological Reserve Category (ERC) for an estuary, according to pre-defined guidelines as is discussed in Chapter 4.5.

***Step 4: Quantification of Ecological Reserve scenarios*.** The method for the determination of the Ecological Reserve for estuaries uses a 'top down' approach, i.e. simulated runoff scenarios are used to resource directed measures. For the quantification of Ecological Reserve Scenarios simulated flows for a range of future scenarios are required. Scenarios are typically simulated over a 50 - 70 year period and are presented as average monthly flows and should represent inflows at the head of the estuary. For the Thukela Estuary, the Reserves for Water Quantity of different Ecological Reserve Categories for the river reach just upstream of the estuary (i.e. Category A to D) were used as future scenarios, as well as two worst case scenarios provide by the DWAF (by using simulated results derived from the river component, provides a means of comparing and integrating estuarine and river Reserve results).

To determine the ecological reserve category of the estuary, associated with each of the future scenarios, the runoff simulations together with an understanding of the present state are used to determine changes in typical abiotic states within an estuary for each of the scenarios. Changes in abiotic characteristics are then assessed in terms of the biological implications, using the same estuarine health index that was used to derive the PES. Results from these evaluations are then used to select the 'recommended reserve scenario', defined as the run-off 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.

A summary of the quantification of ecological reserve scenarios for the Thukela is dealt with in Chapter 4, with the detailed assessment provided in Appendix I (River Category scenarios A to D and Worst case scenarios 1 and 2).

**Fig. 2.1 Flow diagram of the process followed in the Intermediate Reserve determination process for Estuaries**



***Step 5: Ecological Consequences of operational scenarios*.** Steps 5.1 - 5.4, 5.6 and 5.7 forms part of the information that is generated outside the estuarine Reserve study.

The main task of the estuarine specialist team in Step 5, is to basically determine the ecological reserve category of the estuary, associated with each of the operational scenarios generated. Similar to Step 4 changes in typical abiotic states within an estuary for each of the scenarios. Changes in abiotic characteristics are then assessed in terms of the biological implications, using the same estuarine health index that was used to derive the PES.

A summary of the assessment of the operational scenarios for the Thukela is also dealt with in Chapter 4, with the detailed assessment provided in Appendix I (Scenarios 1 - 8).

***Step 6: DWAF Management Category decision-making process*.** This component is not within the specific Terms of Reference for Ecological Reserve Determination for Estuarine Ecosystems and resides wit the DWAF.

***Step 7: Reserve definition*.** Once the management class, and the associated ERC, has been selected through stakeholder consultation (Step 6), the Reserve can be finalised. Superimposed on the influences that river water quantity (i.e. inflow patterns) has on water quality characteristics of estuaries, there are potential influences from anthropogenic waste inputs through:

Waste inputs into river water entering the estuary.
Waste inputs into seawater entering the estuary.
Waste inputs directly into the estuary.

The aim of setting the water quality component of the Reserve is to set concentration limits for water quality constituents so as to ensure that the aquatic ecosystem is protected. For rivers these are set in terms of monthly limits, which can be monitored at a single point within the resource unit. However, in estuarine systems where water quality along the length of the estuary may change continuously, owing to diurnal tidal variations, it is not sensible for management purposes to set the requirements for the water quality component of the Reserve as monthly limits to be measured at points within the estuary itself. For estuaries, the water quality components of the reserve for estuaries is defined as limits on the concentration and/or loads of water quality constituents which may enter the estuary from the river, from the sea or from outfalls directly into the estuary.

Included in the Reserve definition component (Step 7) is the definition of ecological Resource quality Objectives and a monitoring programme.

The Reserve definition component still needs to be conducted for the Thukela Estuary.

***Step 8: Implementation design*.** This step falls outside the scope of this Reserve study.

# 3 DEFINITION OF THE RESOURCE UNIT

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

The Thukela Catchment has a total area of approximately 29 000 $km^2$ and an undeveloped (virgin condition) Mean Annual Runoff (MAR) of 3 865 $m^3 \times 10^6$. The MAR expressed as average unit runoff is about 133mm, which is equivalent to 16% of the Mean Annual Precipitation (MAP) of 840mm. However, MAP varies from more than 1500mm in the Drakensberg to 500mm and less in the dry central regions of the basin (PBV000-00-10301).

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:

- Thukela-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.

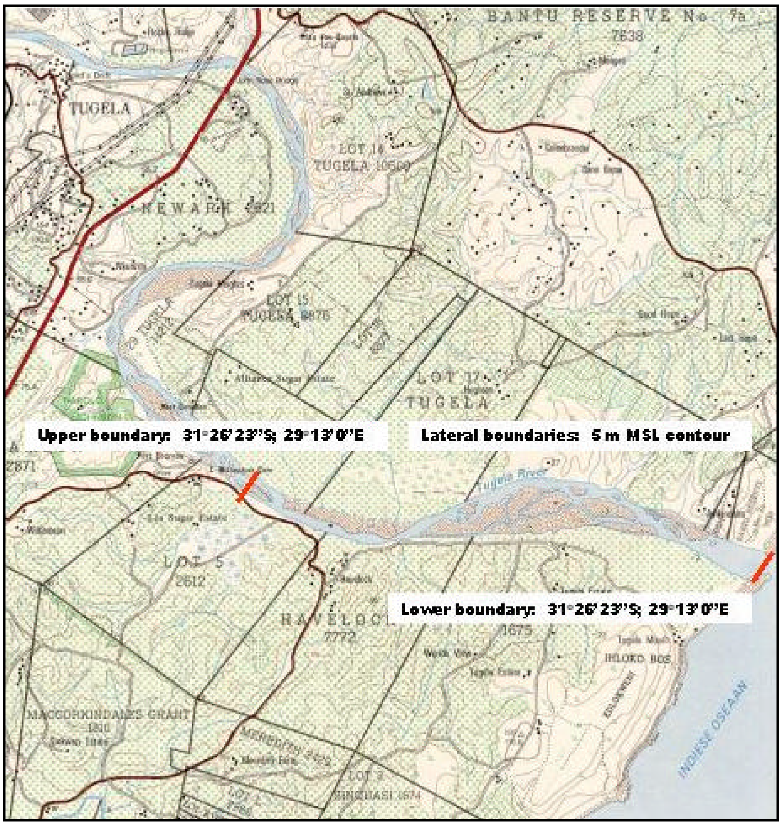
Land uses in the catchment are mainly rural subsistence farming and commercial forestry. It is only on the coastal plain that the river flows through urbanised areas. The only industries associated with the urban development are paper and sugar mills with large scale commercial sugar cane farming along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

The Thukela River estuary is situated approximately 100km north of the city of Durban on the east coast of South Africa (29.22°S, 30.50°E; Figure 3.1). 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 (the other being the Orange River).

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$km^2$. 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 800m during low flow, with a shoreline length of approximately 2km. The maximum width during natural flow periods is approximately 350m with a channel width of 50m, which increases to over 1000m 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 (Archibald, 1998) showed an average depth of less than 1.5m.

According to Begg (1978), the sandbar has a 700m stable component on the floodplain (carrying a coastal dune forest) extending in a generally northern direction. There is also a 700m 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. 3.1 Boundaries of the Thukela Estuary**




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

- **Downstream boundary:** The estuary mouth (31°29'56"E; 29°13'24"S).
- **Upstream boundary:** Approximately 6km from mouth (31°26'23"E; 29°13'0"S).
- **Lateral boundaries:** 5m contour above MSL along the banks.

# 4 ECOLOGICAL RESERVE CATEGORISATION

## 4.1 DESCRIPTION OF PRESENT STATE

### 4.1.1 Abiotic Components

#### *a. Seasonal variability in river inflow*

Monthly simulated runoff data for the Present State is provided in Table 4.2 on the following page. A summary of flow distribution (mean monthly flows in $m^3/s$) for the Present State, derived from the 70-year simulated data set, is provided Table 4.1.

**Table 4.1 A summary of flow distribution (mean monthly flows in $m^3/s$) for the Present State (derived from 70-year simulated data set)**

| %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 |

#### *b. Present flood regime*

Floods are relatively large with high sediment transport capacity (ref). The flood peaks have been affected by dams in the catchment with an estimated 8% decrease in flood peak discharge at the estuary, from Reference to Present State conditions.

Small to medium floods occur regularly, even during relatively dry periods. The recurrence interval floods under the present state are indicated below:

| Flood recurrence (year) | Flood peak ($m^3/s$) |
|---|---|
| 2 | 1000 |
| 10 | 4500 |
| 20 | 6800 |
| 50 | 11000 |

**Confidence:** High

## Table 4.2 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 days) | 2.0-5.0 | 3: Open (Saline) | 5.0-30 | 4: Open (Riverine) | > 30.0 |

| | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| < 2.0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0.60% |
| 2.0-5.0 | 6 | 1 | 1 | 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% |

### *c. Present sediment processes and characteristics*

The river has a high mean annual sediment load of about 9 million ton, corresponding to a sediment yield of 400ton/km$^2$ per annum. The estuary is, however, in dynamic equilibrium, with most of the inflowing sediment passing right through the estuary in the long term.

The estuary is relatively wide at about 500m. Regular large floods ensure deep scour at the mouth and the average estuary length is about 5.5km. The Thukela Estuary consists of relatively fine alluvial sediment (fine sand) and along some of the banks some cohesive sediment, often associated with riparian vegetation. Large floods, however, scour all cohesive sediment from time to time. During small flows the river meanders through the sand banks, which are only covered completely during floods exceeding 300m$^3$/s.

Resetting floods deposit sediment in the upper part of the estuary, which is scoured in subsequent smaller floods. Low flows could be more affected by future dams, leading to river mouth closure. The period of closure would, however, be short with limited impact on the sediment dynamics.

**Confidence:** High

### *d. Typical Abiotic State for the Thukela Estuary*

Four Abiotic States were derived for the Thukela Estuary, of which the occurrence and duration varies depending on river inflow rate. These states are:

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

## e. *Typical characteristics of Abiotic States identified for the Thukela Estuary*

**ABIOTIC STATE 1: MOUTH CLOSED, WEEKS TO A FEW MONTHS AT A TIME**

**<u>Typical flow patterns</u>:** Flow rates are between 0.0 and 2.0m$^3$/s (for this study only observed in Worst Case Scenarios).

**Confidence:** Low

**<u>State of the mouth</u>:** Mouth closes for weeks to a few months at a time in the lower flow range.

**Confidence:** Low

**<u>Floodplain inundation patterns</u>:** The berm at the mouth can build up to about 2.5m MSL, causing extended back flooding of intertidal and floodplain areas.

**Confidence:** Low

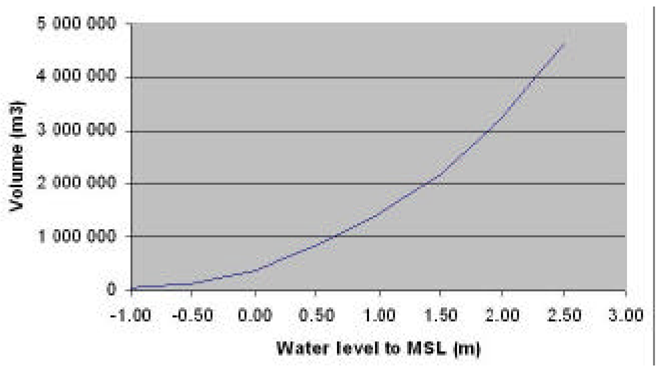
**<u>Amplitude of tidal variation (indicative of exposure of intertidal areas during low tide)</u>:** During mouth closure there will be no tidal variation, indicating that intertidal areas will not be exposed during low tides or flooded during high tides.

**Confidence:** Low

**<u>Retention times of water masses</u>:** Retention times for State 1 may range from a few weeks to months, particularly during the closed periods.

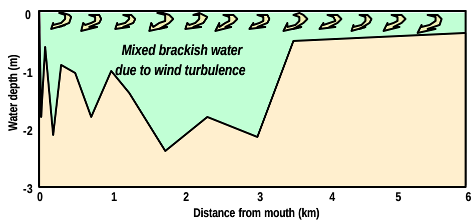
**Confidence:** Medium

**<u>Total volume</u>:** 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 +2.5m MSL correlating with a volume of approximately 4.6 x $10^6$ $m^3$ (see below).




**Confidence:** Medium

**<u>Salinity distributions in the estuary</u>:** Significant saline intrusion (about 6.0km 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.

| ESTIMATED MAXIMUM SALINE PENETRATION DURING STATE 1 | ESTIMATED SALINITY DISTRIBUTION AFTER PROLONGED MOUTH CLOSURE DURING STATE 1 |
|---|---|
|   |   |

**Confidence:** Low

**<u>System variables (Temperature, pH, suspended solids, turbidity and dissolved oxygen</u>):**

| VARIABLE | ESTIMATED CONCENTRATION |
|---|---|
| Temperature (°C) | The flow range at which State 1 occurs (i.e. < 2$m^3$/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 20mg/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 a reduction in DO levels during closure. (Fiona MacKay, CRUZ, *pers. comm.*) |

**Confidence:** Low

**<u>Nutrients:</u>**

| 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, when 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 seaw ater. |

**Confidence**: Low

**ABIOTIC STATE 2: MOUTH OPEN, OCCASIONAL MOUTH CLOSURES OF A FEW DAYS**

**Typical flow patterns:** Flow rates between 2.0 and 5.0 $m^3/s$ (only observed in Present State and Worst Case Scenarios).

**Confidence:** Medium

**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.

**Confidence:** Medium

**Floodplain inundation patterns:** Not applicable.

**Confidence:** Medium

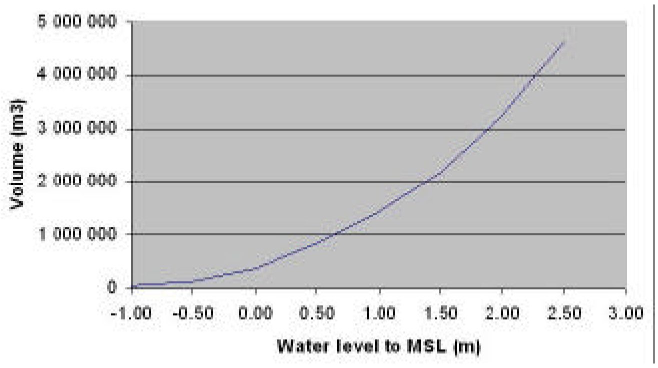
**Amplitude of tidal variation (indicative of exposure of intertidal areas during low tide):** Tidal variation could typically range between 0.3m (neap tide) and 1.5m (spring tide). During periods of mouth closure there will be no tidal variation.

**Confidence:** Medium

**Retention times of water masses:** Retention times for State 2 may range will be a few days.

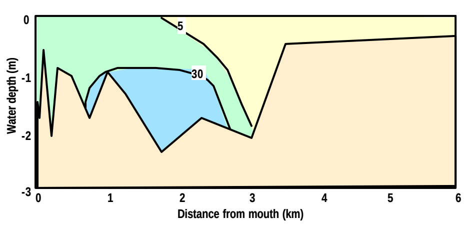
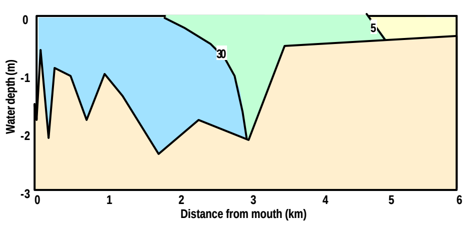
**Confidence:** Medium

**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 +2.5m MSL correlating with a volume of approximately 4.6 x $10^6$ $m^3$ (see below).




**Confidence:** Medium

**Salinity distributions in the estuary:** 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 6.0km upstream. Although mouth closure is likely to occur, it will only be for short periods, i.e. a few days. It is, therefore, 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.

| ESTIMATED MINIMUM SALINE PENETRATION DURING STATE 2 (UPPER FLOW RANGES) | ESTIMATED MAXIMUM SALINE PENETRATION DURING STATE 2 (LOWER FLOW RANGES) |
|---|---|
|   |   |

**Confidence:** Low

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

| VARIABLE | ESTIMATED CONCENTRATION |
|---|---|
| Temperature (°C) | The flow range at which State 2 occurs (i.e. 2 – 5m$^3$/s) typically occurs during the winter months when temperature throughout the estuary is expected to be in the low 20ºC. |
| 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 – 5m$^3$/s) indications are that river concentrations are also not 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 – 5m$^3$/s) indications are that river concentrations are also not 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). |

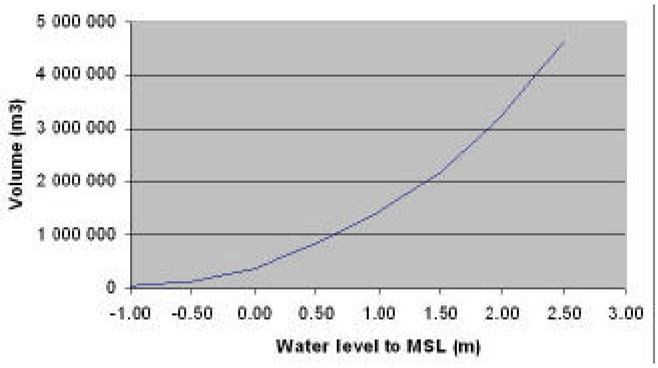
**Confidence:** Medium

**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. |

**Confidence:** Medium

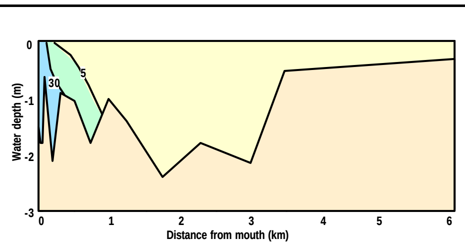
| ABIOTIC STATE 3: MOUTH OPEN, SALINE INTRUSION |
|---|
| **<u>Typical flow patterns</u>:** Flow rates between 5.0 and 30.0m$^3$/s and are at present common during autumn and winter (May to October).<br><br>**Confidence:** Medium |
| **<u>State of the mouth</u>:** The estuary mouth open, very rarely closed for up to 2 days.<br><br>**Confidence:** Medium |
| **<u>Floodplain inundation patterns:</u>** Not applicable.<br><br>**Confidence:** Medium |
| **<u>Amplitude of tidal variation (indicative of exposure of intertidal areas during low tide)</u>:** Tidal variation could typically range between 0.3m (neap tide) and 1.5m (spring tide).<br><br>**Confidence:** Medium |
| **<u>Retention times of water masses</u>:** 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.<br><br>**Confidence:** Medium |
| **<u>Total volume</u>:** For State 3 during its open phase volume will vary depending on the state of the tide (see below). |

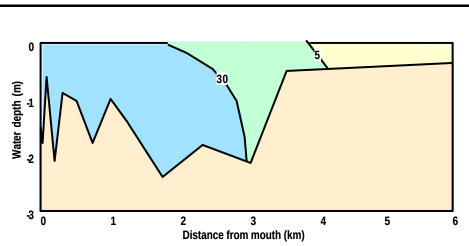



**Confidence:** Medium

**<u>Salinity distributions in the estuary</u>:** 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 6.0km upstream at river flows close to 5.0m$^3$/s. The saline intrusion will not be as far upstream as during State 2, but otherwise similar conditions will exist in the estuary.

| ESTIMATED MINIMUM SALINE PENETRATION DURING STATE 3 (UPPER FLOW RANGES) | ESTIMATED MAXIMUM SALINE PENETRATION DURING STATE 3 (LOWER FLOW RANGES) |
|---|---|




**Confidence**: Medium

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

| VARIABLE | ESTIMATED CONCENTRATION |
|---|---|
| Temperature (°C) | The flow range at which State 3 occurs (i.e. 2 – 5m³/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. ~5m³/s), it is expected that SS concentration in river inflow towards the upper flow band (~30m³/s) can increase dramatically. Concentrations 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. ~5m³/s), it is expected that turbidity levels in river inflow towards the upper flow band (~30m³/s) can increase dramatically. Concentrations 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). |

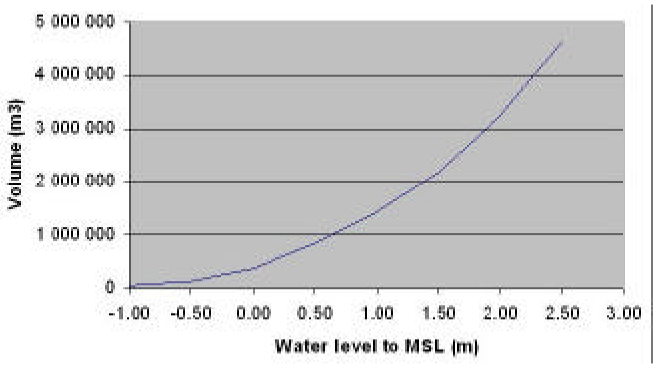
**Confidence:** Medium

**Nutrients:**

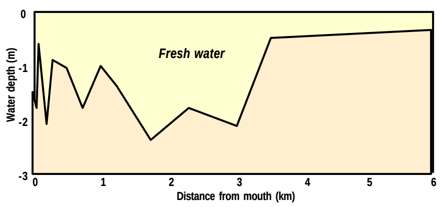
| VARIABLE | ESTIMATED CONCENTRATION |
|---|---|
| Nitrite/Nitrate-N (µg/L) | The system is marine-dominated and concentrations in the estuary will generally be low, i.e. **< 50 µg/L** (based on low concentrations measured in seawater, as well as median concentrations measured in river inflow). At times, 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. |

**Confidence**: Medium

| **ABIOTIC STATE 4: MOUTH OPEN, RIVER DOMINATED** |
|---|
| **<u>Typical flow patterns</u>:** Typical flow rates for State 4 are greater than 30.0m$^3$/s. These flows at present occur during the summer (November to April).<br><br>**Confidence:** Medium |
| **<u>State of the mouth</u>:** The estuary mouth is wide open.<br><br>**Confidence:** Medium |
| **<u>Floodplain inundation patterns:</u>** Extensive floodplain inundation during flooding events.<br><br>**Confidence:** Medium |
| **<u>Amplitude of tidal variation (indicative of exposure of intertidal areas during low tide)</u>:** Tidal variation could range between 0.3m (neap tide) and 1.5m (spring tide) depending on the flow, e.g. strong flows can reduce the amplitude of tidal variation.<br><br>**Confidence:** Medium |
| **<u>Retention times of water masses</u>:** Due to high flow velocities retention time will be zero.<br><br>**Confidence:** High |
| **<u>Total volume</u>:** For State 4 during its open phase volume will vary depending on the state of the tide (see below).<br><br>**Confidence:** Medium |




**<u>Salinity distributions in the estuary</u>:** 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 500m of the system, even at relatively high flow (e.g. 50m$^3$/s).

| **ESTIMATED CONDITION DURING STATE 4 (UPPER FLOW RANGES)** | **ESTIMATED SALINE PENETRATION DURING HIGH TIDES STATE 4 (LOWER FLOW RANGES)** |
|---|---|
|  |  |





**Confidence:** Medium

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

| VARIABLE | ESTIMATED CONCENTRATION |
|---|---|
| Temperature ($^{\circ}$C) | The flow range at which State 2 occurs (i.e. > 30 $m^3/s$) typically occurs during summer when temperature throughout the estuary is expected to be in the high $20^{\circ}$C. |
| pH | 7 – 8 |
| Suspended solids (mg/L) | The system is freshwater 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 freshwater 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). |

**Confidence:** Medium

**Nutrients:**

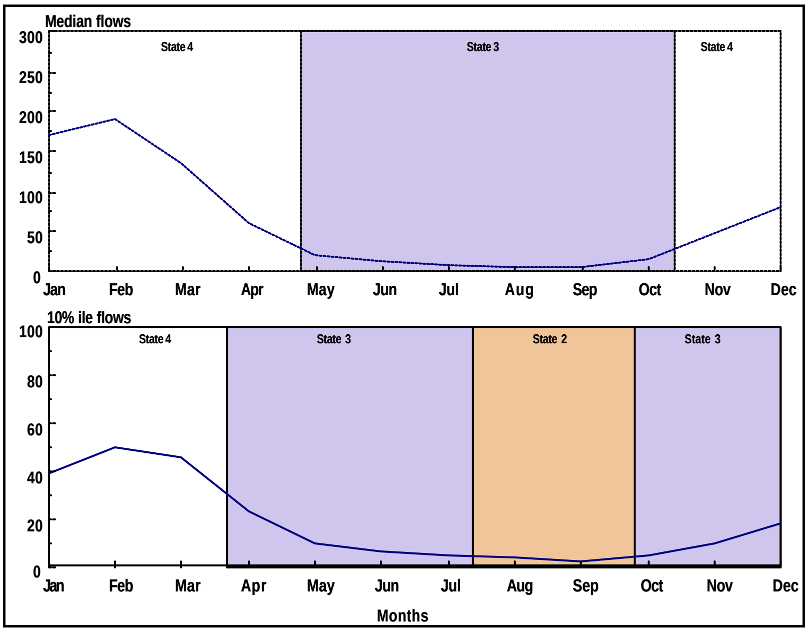
| VARIABLE | ESTIMATED CONCENTRATION |
|---|---|
| Nitrite/Nitrate-N (µg/L) | The system is freshwater dominated and although it is expected that concentrations be low, i.e. < 50µg/L (based on median levels in river inflow) it may, at times, increase to as high as 1400 µg/L (based on maximum concentrations measured in river inflow), but probably only for short periods. |
| Total Ammonia-N (µg/L) | Generally be low, i.e. < 50 µg/L |
| Reactive Phosphate-P (µg/L) | The system is freshwater dominated and although it is expected thst concentrations 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 freshwater dominated with concentrations between 5000 - 7000 µg/L. |

**Confidence:** Medium

### *f. Occurrence and duration of different Abiotic States during Present Ecological State*

The occurrence and duration of the different Abiotic States during the Present Ecological State 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 the Present Ecological State, median monthly flows and 10%ile flows were used to depict the situation for normal and drought periods, respectively.



### g. *Non-flow related anthropogenic influences, presently affecting Abiotic characteristics in the estuary*

| |
|---|
| **<u>Structures (e.g. weirs, bridges, mouth stabilisation):</u>** None: N2 bridge not in estuary and has a large opening.<br><br>**Confidence:** High |
| **<u>Human exploitation, e.g. sand mining</u>):** N/A<br><br>**Confidence:** - |
| **<u>Discharges into the estuary affecting water quality (e.g. dump sites, stormwater, sewage discharges, etc.)</u>:** Data collected from the Mandini monitoring station (V5H002) do not indicate any marked changes in nutrient input from the catchment from the reference to the Present Ecological State. However, a large industrial area (including the Sappi Thukela mill, Mandini, Thukela Rail and the Sumdumbili Sewage Treatment Works) is situated just upstream of the estuary. Based on the type of effluent (i.e. paper and pulp mill and sewage effluents) it is expected that the potential influence on the water quality would be in terms of oxygen levels (i.e. high COD inputs from paper and pulp industry and sewage effluents), suspended solids/turbidity and inorganic nutrients (particularly from sewage effluents). 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, South African Institute for Aquatic Biodiversity, 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.<br><br>The DWAF monitoring point at Mandini (V5H002) is situated upstream of this area and therefore does not reflect the influence on water quality from the industrial area. Although the Sappi Thukela Mill does collect data at a monitor point further downstream, closer to the estuary (i.e. at Havelock farm, some 8 km 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. It is recommended that the monitoring programme downstream of the Mandini area, undertaken by Sappi, be expanded to also include other relevant water quality variables such as suspended solids/turbidity and inorganic nutrients.<br><br>(Human pathogenic contamination is also a potential concern, but this is outside the scope of the ecological Reserve determination).<br><br>A limited set of sediment trace metal samples collected from the Thukela Estuary suggested that trace metals in the sediments are largely within the bounds of natural variability, suggesting that anthropogenic inputs has had no marked effect.<br><br>**Confidence:** Low |
| **<u>Other</u>:** Possible increased sediment yield since suspended sediment sampling discontinued in the early 1980s. Could lead to shorter estuary with raised bed (shallower).<br><br>**Confidence:** Medium |

## 4.2 BIOTIC COMPONENTS

### *a. Description of the Present Ecological State of biotic components*

**MICROALGAE**

**Phytoplankton:** Flagellates dominate the phytoplankton community structure with greater abundances occurring within the middle reaches of the estuary. Planktonic diatoms co-dominate the water column increasing in abundance toward the lower reaches of the estuary. These algae form an important source of carbon for planktonic invertebrates and benthic meiofauna. Dinoflagellates are important in the middle to upper reaches of the estuary, particularly in the lower more dense saline water of the water column. Euglenoids, greens and blue-green algae were found in the upper and lower layers of the water column in the upper estuary and this part of the estuary had high organic matter possibly associated with sugar cane and paper mills located upstream of the estuary. Six functional groups were used to characterise planktonic microalgal diversity along the axial length of the estuary and based on that the middle reaches of the estuary showed greater group diversity particularly in the upper layers of the water column. In the bottom waters diversity was greatest toward the upper reaches of the estuary in less saline conditions. Phytoplankton biomass measured as chlorophyll *a* was greatest in the mid to lower layers of the water column extending from the middle to the upper reaches of the estuary. The lower estuary had minimum cell densities mainly at the mouth and maximum numbers in the upper part of the estuary. Low flow conditions will support high phytoplankton biomass under increased residence time, improved photic depth and reduced flushing rate. Saline water intrusion will penetrate further upstream creating riverine estuarine interface zones that may support increased phytoplankton production. Such conditions will be expected to occur during late Winter, Spring and early Summer. Nutrient concentration is expected to increase in the estuary as there is a reduction in river inflow encouraging rapid planktonic growth particularly in the upper layers of the water column under favourable light conditions. Anthropogenic influence and increased water abstraction will alter the phytoplankton community structure by reducing palatable planktonic diatoms and flagellates in favour of unpalatable planktonic forms including the growth of nuisance forming blue-green algae.

**Confidence:** Medium

**Benthic microalgae:** The intertidal region (south bank) 1km from the mouth consists of fine, cohesive sediment. *Nitzschia umbonata, N. clausii* and *Gyrosigma scalproides* were found almost exclusively in this fine sediment, whereas *Navicula gregaria*, *N. phyllepta* and *Amphora exigua* were found in the fine sand found throughout the rest of the estuary.

Chlorophyll *a* was highest 1.5km from the mouth (intertidal: 7.5 µg/g dry weight sediment$^{-1}$ and subtidal: 4.1 µg/g) and lowest in the fine sediment 1 km from the mouth (intertidal: 4.7 µg/g and subtidal: 3.5 µg/g). There were more euglenoids in the fine sand compared to the cohesive sediment, which could be the cause of the higher microalgal biomass in the sandy sediment. There were very few cyanobacterial cells present throughout the estuarine sediment.

Common freshwater species found in the estuary: *Cyclotella meneghiniana*, *C. cyclopuncta*, *Cymbella turgidula*, *Navicula viridula* var. *rostellata* and *Nitzschia acicularis*. Common brackish species found in the estuary: *Bacillaria paradoxa* and *Nitzschia clausii*. Common marine species found in the estuary: *Nitzschia subconstricta* and *N. granulata*. There were a number of other common species present that can tolerate a broad range of saline conditions.

**Confidence:** High

**MACROPHYTES**

Behind the dune ridge and dune vegetation on the south bank there is a wetland area. The dominant plant is common reed, *Phragmites australis.* Within this wetland is a homogenous stand of the sedge, *Schoenoplectus scirpoides* and some patches of the lagoon hibiscus, *Hibiscus tiliaceus.* The wetland area covers approximately 21ha. Dense stands of Brazilian pepper trees (*Schinus terebinthifolius*) together with some dune forest species occurred approximately 2km from the mouth. 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 water's edge. The floodplain area in this vicinity is largely disturbed as a result of agriculture.

In 2001 a large sedge marsh consisting of *Schoenoplectus scirpoides* (approximate area = 19.65ha) was found at the mouth on the north bank. In 1996 the estuary mouth had a completely different morphology and these sedge areas were absent. Areas of the rush, *Juncus kraussii* were found as well as scattered brackwater mangrove trees (*Barringtonia racemosa*). The intertidal area was mostly narrow with little wetland or estuarine vegetation present.

**Confidence:** High

| INVERTEBRATES |
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| **Zooplankton:** During high flow conditions the zooplankton community is virtually absent. A few freshwater species, predominantly insect larvae, may be present. Decapod larvae such as those of *Macrobrachium* and *Varuna* may also occur.<br><br>Low flow conditions support a more diverse, mainly marine zooplankton community, extending into the system as far as there is saline penetration. Coastal marine copepods form the numerically dominant component. Estuarine plankters are present but at very low densities. Zooplankton abundance during low flow is impoverished compared with that of estuaries with predominantly estuarine communities. Based on the available data it is not certain if a more estuarine community is established higher up in the estuary, above the current upper sampling station, during low flow conditions. This, is however, probably unlikely given the relatively short duration of low flow conditions.<br><br>Data on endemic or red data species do not exist for zooplanktonic invertebrate communities.<br><br>Seasonal variation is known for estuarine zooplankton but seasonality would not be relevant under the high flow conditions of the Thukela during spring and summer. No data are available on possible inter-annual variations for this system.<br><br>**Confidence:** Medium |
| **Macroinvertebrates:** In the present state there are two separate and identifiable benthic invertebrate phases: Freshwater dominated (riverine fauna with brackish/freshwater tolerant estuarine species) and a typically estuarine phase with estuarine/marine dominated species. The latter community is comparable to those occurring in subtropical temporarily open/closed systems. The duration and timing of these community phases correspond to prolonged high and short duration, low flow conditions, respectively.<br><br>Although not as rich in estuarine species or abundant as other systems along the same stretch of coast, the system was found to support in excess of 150 taxa from April 1997 to March 1998 and in August 2001. The majority were freshwater species from a wide array of taxonomic groups. The dominance of the freshwater component in 1997/8 was a function of the physical state of the estuary at that time. The presence of estuarine fauna in lower densities was ascribed to their recruitment via the mouth during periods of decreased river flow, and a corresponding increase in tidal influence. Of the macrobenthic species encountered none were considered unusual or atypical of any other local freshwater dominated system. A point of some importance and uniqueness to the system was that these freshwater fauna were entirely dominant in what was the ‘estuarine’ area of the system. These were within the reaches where estuarine fauna usually occur in other estuaries.<br><br>During the initial study (1997-1998), a large backwater area existed adjacent to the mouth that supported the largest biomass and diversity of species in the system. >90% of this biomass was made up of freshwater oligochaete worms. During the last stages of the study, it was noted that a large portion of the intertidal backwater was covered large-scale algal growth. This was rapidly colonised by large stands of *Schoenoplectus scirpoideus* sedge marsh. A recent low flow study (August 2001) showed that the lower reaches of the estuary changed with the migration of the mouth to the north. Estuarine communities dominated the fauna in this recent study, with oligochaete biomass being replaced by polychaete tube-building worms. The current species array is tolerant of reduced salinities except for one or two amphipod and bivalve species.<br><br>Although several taxa are listed as endemic according to available classification systems, this should be interpreted with caution as these guides are extremely outdated and new distribution listings are constantly added.<br><br>**Confidence:** High |

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| **Macrocrustacea:** The penaeid prawns *Penaeus japonicus* and *Metapenaeus monoceros* (represented by juvenile forms) dominated the macrocrustacean community structure in the lower and middle reaches, during low flow conditions. Other macrocrustacean groups recorded were the mudprawn *Upogebia capensis*, a brachyuran *Sesarma* sp and *Penaeus canaliculatus*. Low flow biotic conditions were characterised by high salinity and low temperatures, which are unsuitable conditions for larval development. This is a possible reason for the lack of *Macrobrachium* species during this period (August 2001) where only a single record each of *M. rude* and *M. equidens* was recorded.<br><br>During high flow conditions no penaeid prawns were caught, but gravid females and juveniles of *Macrobrachium* species (*M. rude*, *M. equidens*, *M. lepidactylus*, *M. scabriculum*) dominated the community structure particularly in the lower and middle reaches of the estuary. Other estuarine macrocrustacea captured during high flow (February 2002) were the crabs *Sesarma* sp. and *Varuna litterata*. During high flow the estuary was river-dominated (0.1 ppt) with high turbidities and high temperatures. These were ideal conditions for the onset of migration of *Macrobrachium* species. Salinities <10 ppt are unfavourable for penaeid prawns. Flow plays a major role in structuring the macrocrustacean community in the estuary. Reduced flow and the intrusion of saline water allows colonisation of estuarine species such as *P. japonicus* and *M. monoceros*. The reproductive success of *Macrobrachium* species depends on brackish conditions for larval development in the estuary. River flooding normally occurs in late summer (February) and at this time *Macrobrachium* species such as *M. rude* move downstream into the estuary where breeding takes place. A reduction in nutrient input, resulting in a decreasing food source for larval development of penaeid prawns and *Macrobrachium* species, would also affect macrocrustacean populations utilising the estuary.<br><br>**Confidence:** Medium |
| **FISH** |
| 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. Six 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*, which are tolerant of wide fluctuations in salinity and river flow regimes. 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 12 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.<br><br>The overwhelming dominance of juveniles belonging to the family Mugilidae in the system may be linked to the shallowness of the estuary and the high organic loading associated the SAPPI mill effluent. 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.<br><br>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.<br><br>Based on their distributional ranges six (15%) of the fish recorded in the Thukela Estuary are southern African endemics.<br><br>**Confidence:** Medium |

| BIRDS |
| --- |
| A total of 64 species, most of which are typically associated with estuaries, have been recorded from the Thukela. Three groups are recognised based on their estuarine association:<br>• A summer fauna, dominated by Palaearctic migrants, which utilise the estuary for feeding.<br>• A winter fauna, which utilise the estuary for feeding.<br>• A fauna, which uses the system predominantly as a roosting site with most feeding taking place at sea. The birds use sand banks in the estuary to roost on. The species composition of roosting birds changes according to season but is dominated by terns and gulls.<br><br>The limited data clearly shows that there is substantial seasonal variation in numbers. The number of species present averages about 25 per month. However, number of individuals is highest during the summer months from November through to March when they can reach up to 4600. Apart from the roosting component, which may make up to 50% of the individuals present during the winter, the bulk of those feeding in the estuary fall into one of two groups, being either benthic invertebrate feeders or piscivores. Of these the benthic feeders dominate in terms of species and numbers.<br><br>Although four Red Data species have been recorded, none of them are resident or breed in the area. Two species, the White and Pink-backed Pelicans are post-breeding winter visitors to the estuary in small numbers (up to 20) where they probably feed mainly on mullet, which are abundant in the system. No endemics have been recorded.<br><br>Available data are limited; however, there are some indications that densities of estuarine feeders, particularly benthic feeders, may have increased between the early 1980s and the late 1990s. This may in part be attributed to anthropogenic impacts in other systems such as Richards Bay; however, data are lacking.<br><br>**Confidence:** Medium |

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

| MOUTH CONDITIONS |
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| **Microalgae:**<br><br>**Phytoplankton:** Long periods of mouth closure (State 1) are not likely to occur so mouth closure will be limited to a few days. Elevated nutrient concentrations in the water column from Mandini and reduced turbidity would increase phytoplankton production. Phytoplankton biomass will remain high following closure.<br><br>Open mouth saline intrusion condition (flow rate 5.0-30.0$m^3$/s) (State 3) occurs mainly between May and October. A true salinity gradient along the axis of the estuary will occur with less dense water flowing out to sea and overlying the more dense marine water pushing upstream. Phytoplankton biomass will be reduced because of low residence times and high flushing rates. High sediment load reduces light availability limiting the photic zone and although nutrient input is elevated, it is not exploitable for production. Saltwater intrusion into the estuary will favour marine phytoplankton species (i.e. *Chaetoceros affine*, *Asterionella glacialis*, *Ceratium fusus*, *Dinophysis* sp.) in the lower reaches of the estuary. Cell densities will generally be low owing to low nutrient concentrations in marine water. The middle reaches will have greater mixing with riverine water characterised by a riverine/estuarine interface zone that will support greater cell densities (cell numbers >$10^4$/l). Community structure will reflect that dominated by flagellated phytoplankton under moderately turbid conditions (Cuker *et al*. 1989; Burkholder *et al*. 1990; Gama unpublished data) and mainly diatoms under an increased photic depth. The upper estuary with a strong riverine water influence will show a phytoplankton community structure similar to that of a freshwater community. Nutrient input through river inflow will be moderate to high with an increase in river inflow; however, residence time might be insufficient to enable increased phytoplankton production (Taljaard *et al*. 2002).<br><br>**Confidence:** Medium<br><br>**Benthic microalgae:** Mouth closure will only occur for short periods (State 2) so a significant rise in water level is not expected. Mouth closure will cancel the effect of tides resulting in the loss of intertidal habitat. As a result, microalgal biomass will decrease in the previously tidal sediment. Open conditions allow for tidal variation and saline intrusion occurs at flows below 30 $m^3s^{-1}$. These conditions allow an intertidal microalgal community to develop and for marine, brack and freshwater taxa to colonise.<br><br>**Confidence:** High |

| MOUTH CONDITIONS |
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| **Macrophytes:**<br><br>When the mouth closes the water level will rise, inundating the reeds and sedges. Complete submergence will have a detrimental effect on the plants after approximately 3 months. The plants are more sensitive to submergence during the growing season (spring, summer) than during winter. The reed *Phragmites australis* is more sensitive to submergence than the sedge, *Schoenoplectus scirpoides.*<br><br>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. 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 (2002), the estuary may deepen by 1m in the future and under these conditions anoxia may become a problem.<br><br>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 weed water hyacinth (*Eicchornia crassipes*) may become dominant during the fresher months. Both species currently occur in the Thukela Estuary.<br><br>**Confidence:** Medium |

**MOUTH CONDITIONS**

**Invertebrates:**

**Zooplankton:** High flow, open mouth condition (State 4) does not allow the establishment of a resident estuarine zooplankton community due to the strong currents. Low flow, open mouth (State 3) will support a diverse, but relatively impoverished, marine community. Estuarine species will be present but at low abundance.

Short term mouth closure (States 1 and 2) should allow the establishment of an estuarine community, albeit low in diversity. The productivity of such a community will depend on water quality and the availability of nutrients. Long term mouth closure (State 1) leading to freshwater conditions would eventually lead to a freshwater community with estuarine relict species present for a short while. Productivity would depend on water quality and nutrient availability.

**Confidence:** Low

**Macroinvertebrates:** During Abiotic States 1 and 2, with variable lengths of mouth closure (continuous periods of days, weeks and months at a time), the direct effects to benthic macroinvertebrates will be limited to differing salinity regimes and less direct effects due to system variables and nutrients. All of the present fauna are subtidal with no intertidal requirements. The effects of prolonged back flooding to macrophyte species would pose no threat to the present benthic communities. The majority are sediment dwelling, tube building species. During a prolonged closed mouth phase and as salinity distribution in the estuary changes from a vertically stratified to a uniformly mixed situation, there will probably be an initial peak in the production of macroinvertebrates as estuarine species (characteristic of other subtropical estuaries) fully establish themselves in the lower and upper regions of the system. This will be short-lived as the estuary freshens and although brackish tolerant species will remain, the majority of estuarine species will be replaced with freshwater fauna characteristic of the lower reaches of coastal plain rivers. It is not envisaged that biomass will decrease significantly unless water quality deteriorates. The freshwater fauna present in the system (oligochaete annelids) in 1997-1998 contributed >90% of the total density in quieter backwater areas that existed prior to current mouth position. Unless levels drop significantly lower than 4 mg/l and are sustained, the possibility of lower oxygen tensions due to increased detrital input would not be reflected in decreased production in the predicted freshwater dominated communities. Oligochaetes and insect larvae are highly tolerant to anoxic conditions in fine-muddy sediments. The recruitment of estuarine species will be limited to overtopping of the sandbar.

Depending on the duration of Abiotic State 3, a fairly species rich community may develop as far as saline intrusion occurs (~6km upstream). The most productive area will be in the middle to upper reaches of the system with a larger biomass of several species of polychaete worms and the establishment of gastropod and bivalve molluscs. If this state is prolonged a short term stability will be established with a decrease in the initial peak and second order opportunists/colonisers appearing. Biomass may or may not decrease depending on recruiting species and prevailing sediment conditions (% of mud and fine sand and organic content of sediments).

Benthic invertebrates characteristic of an open and river-dominated system (Abiotic State 4) are typically riverine fauna (insects and freshwater annelids) and comparable to the secondary community that establishes after long term mouth closure. The formation of an estuarine community, even in the lower reaches subject to some tidal and saline influence is temporary. The productivity and biomass available for other faunal groups (fish and birds) would most certainly comprise freshwater species.

**Confidence:** Medium

**Macrocrustacea:** Protracted mouth closure will primarily affect the migration of penaeid post-larvae into the estuary, particularly if high flow conditions are delayed until late spring-early summer. A closed mouth in late autumn (April-May) will similarly affect the immigration of *Varuna litterata* megalopae that have an obligatory marine phase in their life cycle.

An open mouth in Abiotic States 2 and 3 (flow velocity 2-30$m^3$/s) would favour horizontal and vertical salinity gradients that are essential for larval development of *Macrobrachium* species and for feeding purposes for penaeid prawns in summer. At higher flows (>30$m^3$/s) when the estuary is river dominated, conditions are unfavourable for larval development of *Macrobrachium* species and juvenile stages of penaeid prawns.

**Confidence:** Medium

| MOUTH CONDITIONS |
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| **Fish:**<br><br>Abiotic State 1 would have negative consequences for marine fish recruitment into the estuary if the mouth remained closed for extended periods during spring (September/October) and early summer (November/December). Anguillid eel recruitment would also be adversely impacted if extended closure were to occur during these periods. Closure at other times of the year would be less detrimental to the fish stocks of the estuary.<br><br>Abiotic State 2 would not be detrimental to the fish fauna since mouth closure, when it occurred, would only be for a few days. Movement of larval fish into the estuary would not be adversely affected although the shallow nature of the mouth just prior to closure would hamper the free movement of large fish into and out of the estuary.<br><br>Abiotic States 3 and 4 would allow free movements and migrations for all fish species and size ranges to occur.<br><br>**Confidence:** Medium |
| **Birds:**<br><br>Abiotic State 1 would, particularly during late spring, summer and early autumn, be extremely negative for the benthic feeding component of the fauna as access to the benthos would be totally restricted due to no tidal fluctuations in estuarine water levels. The impact of this state on the piscivorous component particularly the Pelicans would be significant as water depths would be greater and prey more difficult to catch. The roosting groups would only be affected in as far as the total lack of islands for roosting would render them more vulnerable to human disturbances.<br><br>Abiotic States 2 and 3 would potentially provide enhanced conditions for the invetebrate feeders, if they occurred during the summer months, thus potentially offering food resources for more individuals. This would be due to the potential shift of the benthos to a richer 'estuarine' type fauna under more saline conditions. During the remainder of the year the occurrence of these states would have little or no effect on the birds. Based on the status of the fish under these conditions (see above), piscivorous birds would not be affected. It is also not foreseen that any changes would occur in the roosting fauna.<br><br>Abiotic State 4 would provide the same opportunities as currently offered to the birds and which results in the currently recorded faunal presence of all three groups. However, long term persistence of these very fresh conditions may result in some decline in food availability to particularly benthic but also piscivorous birds and thus impact on the faunal presence as a whole.<br><br>**Confidence:** Medium |

| EXPOSURE OF INTERTIDAL AREAS DURING LOW TIDE |
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| **Microalgae:**<br><br>**Phytoplankton:** N/A<br><br>**Benthic microalgae:** Under present conditions the intertidal microalgal biomass (average: 14.5 ± 3.5 µg chl-a $g^{-1}$) was higher than subtidal biomass (7.8 ± 2.2 µg chl-a $g^{-1}$). This is a general pattern found in most estuaries.<br><br>**Confidence:** High |
| **Macrophytes:**<br><br>The reeds and sedges found in the Thukela Estuary are adapted to cope with intertidal conditions. No intertidal salt marsh was found in the estuary probably because of a lack of a persistent saline influence.<br><br>**Confidence:** High |

| EXPOSURE OF INTERTIDAL AREAS DURING LOW TIDE |
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| **Invertebrates:**<br><br>**Zooplankton:** N/A<br><br>**Macroinvertebrates:** Present species are tube-dwelling organisms and as such are able to cope with short term exposure, by moving deeper into burrows. All intertidal species require a sustained saline influence. This precludes the successful colonisation of many species including mudprawn (*Upogebia spp*.) in the Thukela.<br><br>**Confidence:** High<br><br>**Macrocrustacea:** No real intertidal community, probably due to variable saline influence. However, several hundred soldier crabs were seen on the northern bank adjacent to the mouth during low flow conditions (August 2001). This community had disappeared by February 2002 when the Thukela was in its high flow, river dominated phase. The penaeid and *Macrobrachium* prawns found in the estuary are epibenthic and it is likely that they will migrate to more favourable habitats.<br><br>**Confidence:** Medium |
| **Fish:** N/A<br><br>**Confidence:** - |
| **Birds:**<br><br>The more intertidal areas exposed at low tide, the greater the opportunity for benthic feeders to obtain food. Piscivores and roosting groups essentially unaffected.<br><br>**Confidence:** High |
| **Microalgae:**<br><br>**Phytoplankton:** State 3 flow rates could generate movement of sediments causing resuspension of fine sediments including nutrients into the water column possibly reducing light penetration. Resuspended nutrients combined with nutrients from Mandini could possibly stimulate further phytoplankton production but the effect will be diminished by low retention time. However, at greater flows flushing and scouring of the estuary would supercede any biomass accumulation resulting in a reduction in phytoplankton biomass.<br><br>**Confidence:** Medium<br><br>**Benthic microalgae:** Sediment in the Thukela Estuary is dominated by fine sand, favouring episammic diatoms dominating the benthic microalgal community. Areas of fine, cohesive sediment (<63 µm) are dominated by mobile epipelic diatom taxa that exude extracellular polymeric substances, which bind sediment particles and increase sediment stability. The intertidal region (south bank) 1km from the mouth is characteristic of this sediment. *Nitzschia umbonata, N. clausii* and *Gyrosigma scalproides* exist almost exclusively in this fine sediment, whereas *Navicula gregaria*, *N. phyllepta* and *Amphora exigua* are found in the fine sands found throughout the rest of the estuary. Sandy silt and sand is generally lower in nutrients as a result of lower organic matter content and is more frequently suspended. As a result, coarser sediments generally support a lower biomass of benthic microalgae than fine cohesive sediment.<br><br>**Confidence:** High |
| **Macrophytes:**<br><br>During large floods sediment deposited on the floodplain can smother existing vegetation. This soon grows back but also encourages the rapid growth of weedy, alien vegetation.<br><br>Stable sediment conditions promote the growth of reeds and sedges. A plume of sediment was deposited at the mouth of the Thukela during the 1996 floods. On the north bank of the estuary the sedge *Schoenoplectus scirpoides* colonised this area. A large flood (1 in 5 year, > 200 $m^3 s^{-1}$) would remove this stand and this indicates that the system has been stable over the 6 years.<br><br>**Confidence:** Medium |

| EXPOSURE OF INTERTIDAL AREAS DURING LOW TIDE |
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| **<u>Invertebrates</u>:**<br><br>Zooplankton: Unknown direct effects. However, secondary effects arising from possible increase in phytoplankton biomass with resuspension of nutrients under high flow may occur. Zooplankton numbers would diminish as phytoplankton abundance decreased due to flushing effects of increased flow.<br><br>**Confidence:** Low<br><br>**Macroinvertebrates:** The nature of the sediments in combination with certain physico-chemical variables and flow conditions determine the structure of Thukela communities. The system is characterised by highly organic, muddy sediments in the slower flowing areas and marine derived coarser grained sediments in the immediate mouth area. The biota reflects these substrate conditions. Tubiculous species (annelids and insect larvae) are numerous in the muddy areas while crustaceans (amphipods, isopods) are more common in the lower reaches. The coarser sediments support a lower biomass than the fine-muddy sediments. This in part may be due to the constant movement of sand in the lower reaches during high flow conditions.<br><br>During flood conditions where all cohesive sediment is removed, a complete decimation of benthic invertebrate populations can be expected. In time, communities will return where stable sediment conditions prevail. The distribution of Thukela benthos is to some extent reliant on the fine sand, mud and organic content of the substrate.<br><br>**Confidence:** Medium<br><br>**Macrocrustacea:** Macrocrustacea were found in fine sand and mud dominated areas characterised by reeds and sedges. High levels of mud deposition during large floods would reduce habitat for penaeid prawns but would have limited effect on *Macrobrachium* spp. During large floods, smothering of intertidal vegetation such as reeds and sedges might reduce these areas of shelter against strong current, resulting in juvenile and post-larval prawns being washed out to sea.<br><br>**Confidence:** Medium |
| **<u>Fish</u>:**<br><br>Sediment stability and associated high benthic production during Abiotic States 1, 2 and 3 would promote the food resources available to fish species. Rapid sediment scour and deposition during the flooding phase of Abiotic State 4 would lead to loss of benthic food resources and a decline in the biomass and diversity of fishes within the estuary.<br><br>Exceptionally high suspended sediment levels during episodic flooding have been known to contribute to mass fish mortalities in the Sundays and Great Fish estuaries. No such mortalities have been documented for the Thukela Estuary but this does not imply that these events do not occur.<br><br>**Confidence:** Medium |
| **<u>Birds</u>:**<br><br>Sediment stability and associated high benthic production during Abiotic States 1, 2 and 3 would promote the food resources but they would only be available to benthic feeding birds under Abitotic States 2 and 3. Piscivores and roosting species would not be affected. Rapid sediment scour and deposition during the flooding phase of Abiotic State 4 would lead to loss of benthic food resources and a reduction in biomass and diversity of fishes within the estuary. This in turn would result in a decline in the numbers and species of both benthic feeders as well as piscivores present.<br><br>**Confidence:** Medium |

| RETENTION TIMES OF WATER MASSES |
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| **<u>Microalgae</u>:**<br><br>**Phytoplankton:** During State 2 residence time for phytoplankton is high with the result of a possible increase in biomass and a shift in community structure. Increased retention time disrupts axial salinity gradients possibly generating vertical stratification. High light conditions and more saline water at depth will support marine like diatom species like *Cylindrotheca closterium*, *Chaetoceros compressum*, *Rhizosolenia* sp., and dinoflagellates like *Protoperidinium pellucidum*, *Prorocentrum gracile*, *Heterocapsa* sp., whereas the less dense top layers will support more freshwater species.<br><br>**Confidence:** Medium<br><br>**Benthic microalgae:** Higher retention time, a function of flow, make nutrients more available to microalgae. In addition, suspended solids in overlying water will settle out and a reduction in turbidity will be the result. Provided flow does not scour the sediment (high flow, >30 $m^3s^{-1}$) and that a strong boundary layer between the sediment and the water column doesn't form (extremely low flow, <0.5 $m^3s^{-1}$) then benthic microalgal biomass will be at its highest. Nutrients from Mandini are expected to accumulate within the estuary during closed periods, which will support a high benthic microalgal biomass.<br><br>**Confidence:** Medium |
| **<u>Macrophytes</u>:**<br><br>The greater the water retention time the more nutrients there would be available for plant uptake and growth.<br><br>**Confidence:** High |
| **<u>Invertebrates</u>:**<br><br>**Zooplankton:** Increased retention times provide stable water column conditions that could encourage establishment of a more abundant and diverse zooplankton community. Type and productivity of such a community would depend upon nutrients and water quality.<br><br>**Confidence:** Low<br><br>**Macroinvertebrates:** Retention times of water masses may become an issue during Abiotic State 1, particularly if there is a large amount of organic loading (e.g. bagasse from pulp and paper industry) as is seen on occasion to be floating in the water column in the lower reaches. This situation could give rise to anoxic conditions, which if sustained for weeks or months, will have deleterious effects on intolerant taxa. Diversity would decrease and eventually only Oligochaeta and *Chironomidae dipteran* larvae would remain. In terms of numbers, biomass may not decrease as these taxa currently contribute the majority of the macroinvertebrate abundance.<br><br>**Confidence:** Medium<br><br>**Macrocrustacea:** Increased retention time of water during partial closure under Abiotic States 1 and 2 would mean that larval food supply would not be rapidly flushed out of the system. This would enhance the favourability of conditions for larval and post-larval development of all macrocrustacea. Decreased retention time occurring mostly during upper flow ranges will result in larval and juvenile *Macrobrachium* prawns being washed out to sea and subsequent death due to high salinity levels.<br><br>**Confidence:** Low |
| **<u>Fish</u>:**<br><br>Increased retention times of water masses that lead to increased planktonic production would benefit both newly recruited larval marine fish species as well as resident and migrant zooplanktivorous taxa. In particular, a substantial increase in the populations of the estuarine round-herring *Gilchristella aestauria* could be expected due to the retention of larvae within the estuary, in addition to improved pelagic food resources for the juveniles and adults. Low water mass retention times, especially during high flow periods in Abiotic State 4, would lead to poor survival of the larvae of certain estuary resident species, as well as a decline in the contribution of zooplanktivorous fish species to the overall community.<br><br>**Confidence:** Medium |
| **<u>Birds</u>:**<br><br>Increases in production caused by increased retention times may have the potential enhance the bird fauna due to the increased food availability. However, reduced intertidal exposure will have a negative effect.<br><br>**Confidence:** Low |

**FLOW VELOCITIES**

**Microalgae:**

**Phytoplankton:** Under State 2 no true salinity gradient develops along the axis of the estuary and the system reverts to one that has a vertical salinity profile. If these conditions are prolonged the residence time is enhanced providing for an accumulation in microalgal biomass. Under States 3 and 4 the estuary is tidal with some marine water penetrating upstream producing a salinity gradient along its axis. With greater flow rates it then becomes a riverine estuary with brackish conditions establishing offshore with the estuary being scoured with a significant reduction in phytoplankton biomass.

**Confidence:** Medium

**Benthic microalgae:** Low flow velocities of 1-30$m^3$/s are optimal for high (>5 µg chl-a/g) benthic microalgal biomass. Nutrient concentration in the estuary is expected to increase in the estuary at flows of < 0.5$m^3$/s leading to high biomass. However, this effect will be limited by a boundary layer at the sediment-water interface, which limits the exchange of nutrients. Flows above 30$m^3$/s could result in sediments becoming eroded and cells becoming suspended into the water column.

**Confidence:** Medium

**Macrophytes:**

The frequency of large floods and the high flow velocities characteristic of the Thukela Estuary would prevent the encroachment of reeds into the main channel. These fast flows would also prevent submerged macrophytes establishing in the estuary, except in quiet backwater areas. The sedge *Schoenoplectus scirpoides* often grows on the waterside of *P. australis* because of its ability to withstand greater wave action due to its leafless nature.

**Confidence:** Medium

**Invertebrates:**

**Zooplankton:** High flow, open mouth condition (State 4) does not allow the establishment of a resident estuarine zooplankton community due to the strong currents. Low flow, open mouth (State 3) will support a diverse marine community.

Short term mouth closure (States 1 and 2) should allow the establishment of a less diverse estuarine community. The productivity of such a community will depend on water quality and the availability of nutrients. Long term mouth closure (State 1) leading to freshwater conditions would eventually lead to a freshwater community with estuarine relict species present. Productivity would depend on water quality and nutrient availability.

**Confidence:** Low

**Macroinvertebrates:** Flow velocities in the Thukela indirectly affect benthic communities. The sediment and salinity changes to increased or reduced flow are reasons for this. At rates <2.0$m^3$/s subsequent to mouth closure, the typically estuarine community will persist for a short duration only in areas where there is still some salinity stratification. These communities will be tube-building species that are tolerant of suspended solid/silt deposition. As velocities initially increase (<10$m^3$/s) and a marine connection is re-established through an open mouth, a typically estuarine community (high in diversity and abundance) will become established as far upstream as there is saline intrusion. Under high flow conditions (>30.0$m^3$/s) and a reduction in saline conditions, the typically estuarine community will be replaced by riverine fauna that only reach large numbers in the quieter, less dynamic areas of the system. The frequency and duration of large floods and high flow velocities characteristic of the Thukela Estuary that result in resuspension of fine sediments and scouring, preclude successful colonisation in the main channel.

**Confidence:** Medium

**Macrocrustacea:** Increased flow velocities would have negative effects on all groups of macrocrustacea, due to the reduction in food source and instability of habitat for adults and larval development in the estuary. The potential also exists for these organisms to be flushed out of the system into the marine environment.

**Confidence:** Low

| FLOW VELOCITIES |
| --- |
| **Fish**:<br><br>Most fish species in estuaries avoid areas where high flow velocities occur. The larvae of many species are unable to regulate their position within an estuary under high flow conditions and species such as the estuarine round-herring *Gilchristella aestuaria* have been shown to be flushed out of estuaries at high river flow rates (Abiotic State 4).<br><br>The juveniles and adults of the only freshwater fish inhabitant in the Thukela Estuary, *Oreochromis mossambicus*, avoid areas where even moderate flow velocities are recorded. This species is likely to rapidly colonise the Thukela Estuary under 'lagoonal' conditions (Abiotic State 1) and will even breed in the estuary under such conditions.<br><br>**Confidence:** Medium |
| **Birds**:<br><br>High flow velocities would potentially only affect the piscivorous species. However as their prey would be avoiding the areas of high velocities (see fish above) they would follow suite. Benthic feeders and roosting species would be unaffected.<br><br>**Confidence:** High |

| VOLUME OF WATER IN ESTUARY |
| --- |
| **Microalgae**:<br><br>**Phytoplankton:** Increased volume of water would favour a planktonic microalgal community with high biomass associated with availability of nutrients. These conditions would arise particularly in the upper reaches of the estuary characterised by low flow, quiescent water and low dissolved oxygen levels. Phytoplankton community structure would thus favour large sized phytoplankton (>20µm axial length), algae that might be less palatable to planktonic grazers because of high mucilaginous content (e.g. blue-green algae). A greater volume of water, diminished light penetration and mixing will promote anoxic conditions at depth particularly when there is a supply of dissolved and particulate organic matter.<br><br>**Confidence:** Medium<br><br>**Benthic microalgae:** The greater the volume of water in the estuary, the more available habitats for benthic microalgae. This would result in a higher total microalgal biomass in the estuary and its associated floodplain.<br><br>**Confidence:** High |
| **Macrophytes**:<br><br>A greater volume of water in an estuary would mean more available habitat for submerged macrophytes. This is not currently applicable to the Thukela Estuary as no submerged macrophytes were found.<br><br>**Confidence:** High |
| **Invertebrates:**<br><br>**Zooplankton:** Depending on salinity and nutrient availability, an increase in volume may favour zooplankton abundance. An increase in volume over a long period (closed mouth) would eventually lead to a freshwater lentic-type system and a freshwater zooplankton community.<br><br>**Confidence:** Low<br><br>**Macroinvertebrates:** An increased volume will undoubtedly increase habitat area and diversity with a corresponding increase in abundance of benthic invertebrates. Species richness may improve with the inundation of vegetated marginal areas. Freshwater invertebrates are particularly diverse in this habitat and readily utilise leaves and stems to build protective cases and tubes and lay eggs on submerged stems. In a closed phase of long duration, increased volume will increase depth. Generally, depth is only a limiting factor to these fauna >5 m to MSL. The predicted depth increase is not more than +2.5 m MSL during prolonged closure in Abiotic State 1 (velocity <2 $m^3$/s).<br><br>**Confidence:** Medium<br><br>**Macrocrustacea:** Increased volume of water would increase abundance of macrocrustacea if there was a corresponding increase in habitat availability through greater macrophyte cover and other refugia.<br><br>**Confidence:** Low |

| VOLUME OF WATER IN ESTUARY |
| --- |
| **<u>Fish</u>:**<br><br>The volume of water present in the tidal reaches of the Thukela Estuary limits the penetration of large fish into the system. Increased volumes and water depths present during Abiotic State 1 would favour occupation by large fish. The inundation of marginal habitats following mouth closure would increase detrital food resources and refuge for larval and juvenile fishes.<br><br>**Confidence:** Medium |
| **<u>Birds</u>:**<br><br>Increased volume of water would increase abundance of benthos but would only be favourable for birds if large areas of mud/sand flats are tidally exposed. It is anticipated that there will be no effect on the piscivores and roosting fauna.<br><br>**Confidence:** Low |

| SALINITIES |
| --- |
| **<u>Microalgae</u>:**<br><br>**Phytoplankton:** From the phytoplankton functional groups present certain diatom species in the lower reaches of the estuary were indicative of marine species (i.e. *Chaetoceros compressum*, *Navicula lusoria*, and *Nitzschia longissima*.). Salinity intrusion into the estuary is present during low river inflow (Abiotic States 2 and 3) and maintains a salinity gradient along the length of the estuary producing a REI zone that promotes increased phytoplankton biomass. These conditions are crucial for sustaining energy flow within the estuarine ecosystem.<br><br>**Confidence:** High<br><br>**Benthic microalgae:** *Nitzschia subconstricta* and *N. granulata* are examples of marine species that are likely to be lost from the estuary during periods of high freshwater input (Abiotic State 4). However, the majority of species found in the estuary during Abiotic State 3 conditions were brack and freshwater species and will be present during most flow rates.<br><br>**Confidence:** Medium |
| **<u>Macrophytes</u>:**<br><br>There were no plants in the lower reaches of the Thukela Estuary that indicated a persistent saline influence. True mangroves and salt marsh species were absent. *Phragmites mauritianus, Cyperus*, *Paspalum* and *Echinochloa* species are considered strictly freshwater species. *Typha capensis* extends into brackish conditions (3 – 5 ppt) whereas *Schoenoplectus scirpoides, Juncus kraussii, Cladium mariscus* and *Phragmites australis* occur over a wide salinity range but grow best at salinity less than 15 ppt.<br><br>**Confidence:** High |

| SALINITIES |
|---|
| **<u>Invertebrates</u>:**<br><br>**Zooplankton:** Highly saline water would support a diverse, low abundance, marine community. Freshwater would support estuarine relicts for a short while and freshwater species in the long term. An axial salinity gradient ranging between 20 and 5 ppt should support a healthy estuarine community.<br><br>**Confidence:** Medium<br><br>**Macroinvertebrates:** Two specific communities exist in the Thukela Estuary at different times of the year, corresponding to the ambient flow and salinity conditions. The estuary is characterised by a river-derived fauna (with few brackish/freshwater tolerant estuarine species) for most of the year (Annelida, Insecta, some Crustacea). However, under low flow conditions typically present in winter and early spring, the fauna are typically estuarine with both estuarine and marine derived fauna (Diverse Polychaeta, Amphipoda, Isopoda, Tanaidacea, Gastropoda and Bivalvia). This 'estuarine' biotic phase is short-lived but relatively diverse with species from many phyla. The Thukela benthos exhibits a rapid response time to changes in salinity and, interestingly, not all initial colonisers are opportunists, indicative of a system in flux. The 'estuarine' biotic phase can attain a high biomass, but not as abundant as the dominant freshwater faunal state.<br><br>**Confidence:** High<br><br>**Macrocrustacea:** Salinity levels were elevated throughout the estuary during the low flow period in August 2001 (Abiotic States 2 and 3) with penaeid prawn juveniles of species *P. japonicus* and *M. monoceros* dominating the community structure. The genus *Macrobrachium* was poorly represented due to these highly saline conditions. This freshwater species requires a low salinity in an estuary for successful reproduction through larval development. Low salinities were measured with a corresponding increase in *Macrobrachium* abundance and absence of penaeid prawns during high flow (February 2002). Penaeids are intolerant of low salinities (<10 ppt). Salinity was determined to be the principal forcing factor of macrocrustacea in the system.<br><br>**Confidence:** Medium |
| **<u>Fish</u>:**<br><br>Salinity is an important factor determining the penetration of marine species into the estuary. The freshwater phases of either Abiotic State 1 or 4 are likely to lead to the emigration or mortality (if trapped) of some marine and estuarine species that are intolerant of riverine (phases of Abiotic State 4) or freshwater lagoon conditions (phases of Abiotic State 1). Salinity conditions and gradients prevailing under Abiotic State 2 are optimum for the development of a diverse marine, estuarine and freshwater fish assemblage within the estuary.<br><br>**Confidence:** Medium |
| **<u>Birds</u>:**<br><br>Depending on whether the system is under higher or low salinity regimes, this will dictate what benthic food availability there is for benthic feeding birds. However, the freshwater Abiotic Stages 1 or 4 are likely to result in lower food availability and thereby affect the benthic feeding and piscivorous birds adversely.<br><br>**Confidence:** Medium |

| OTHER WATER QUALITY VARIABLES |
|---|
| **<u>Microalgae</u>:**<br><br>**Phytoplankton:** Dissolved oxygen concentrations will remain sufficiently high due to adequate mixing by wind and tidal activity. There might be a minimal drop in DO levels as a result of less mixing in pockets of backwater especially if flow rates are reduced to the point of mouth closure and nutrient levels increase. Turbidity will be reduced under low flow conditions improving photic depth, however this might encourage a benthic driven ecosystem where phytoplankton biomass is low.<br><br>**Confidence:** Medium<br><br>**Benthic microalgae:** Nutrient concentrations are relatively low and oxygen concentration is high in the estuary favouring a diatom dominated benthic microalgal community. Very few chains of cyanobacteria are present in the sediment. Turbidity and suspended solids are expected to be high during periods of high flow (>30m$^3$/s). This combined with the resuspension of sediment will lead to a decrease (<3 g chl-a/g) in subtidal benthic microalgal biomass.<br><br>**Confidence:** Medium |

**OTHER WATER QUALITY VARIABLES**

**Macrophytes:**

An increase in nutrients (nitrate and soluble reactive phosphorus) increases plant growth. If the mouth closed and the estuary became fresh and nutrient rich then plants such as the bulrush (*Typha* spp.) and the weed water hyacinth (*Eicchornia crassipes*) may become dominant and displace the brackish reeds and sedges.

**Confidence:** High

**Invertebrates:**

**Zooplankton:** Low oxygen levels would affect sensitive plankters although the shallow nature of the system and wind mixing should prevent anoxic conditions. Availability of suitable nutrients would enhance zooplankton production.

**Confidence:** Low

**Macroinvertebrates:** Any increase in nutrients that promote microalgal growth would ultimately benefit benthic invertebrates. However, if nutrient loading increased to eutrophic levels (low flow conditions in a closed mouth phase) and anoxic conditions were to arise, benthic diversity would undoubtedly decrease. Only species able to tolerate low oxygen levels would remain. Many benthic invertebrates are filter feeders and as such are not tolerant of highly turbid water with high levels of suspended solids. Any process or point source of effluent that alters ambient pH has a large effect on estuarine organisms. Even relatively small-scale increases (rapid changes by <2 pH units) can result in large-scale effects to these biota.

**Confidence:** Medium

**Macrocrustacea:** The estuary is typically shallow and adequate mixing by wind and tidal action ensures sufficient dissolved oxygen levels (above 6 mg/l). High turbidity (NTU) and conductivity (mS/cm) levels caused by high river inflow and flooding are major determinants of macrocrustacean community structure. The increase in abundance of *Macrobrachium* species in the estuary in summer was due to the movement of gravid adults trying to find a suitable salinity gradient for their reproductive activities. High temperatures recorded in late summer (February) served as a cue for the initiation of the reproductive cycle in *Macrobrachium,* while floods may be used by these species to transport them to suitable breeding areas.

**Confidence:** Medium

**Fish:**

Should low dissolved oxygen levels (less than 3 mg/l) develop during any of the abiotic states, then most fish species would be forced out of the estuary if the mouth was open or face possible mass mortalities if the mouth was closed.

**Confidence:** Medium

**Birds:**

There may be some indirect effects via the response of the benthic invertebrates and the fish, particularly in relation to turbidity, oxygen levels and temperature.

**Confidence:** Low

**OTHER BIOTIC COMPONENTS**

**Microalgae:**

**Phytoplankton:** Phytoplankton provide an energy source for zooplankton and other planktonic grazers. Under the Present Ecological State conditions herbivory on phytoplankton will not be affected; however, this might be altered when flows are reduced to points of mouth closure as the system will become benthic.

**Confidence:** Medium

**Benthic microalgae** are important primary producers and an essential food source for higher trophic levels. They also assist in trapping nutrients from the water column into the sediment during periods of high nutrient input, then releasing them to overlying water during periods when water column nutrients are low.

**Confidence:** High

**Macrophytes:** Plants provide shelter and habitat for invertebrates and fish. They also provide detritus to the estuary and nearshore food chain.

**Confidence:** High

| OTHER BIOTIC COMPONENTS |
| --- |
| **<u>Invertebrates</u>:**<br><br>**Zooplankton:** An increase in phytoplankton production during reduced flows would be favourable for zooplankton productivity.<br><br>**Confidence:** Low<br><br>**Macroinvertebrates:** These fauna are the food source for other invertebrates and higher taxonomic orders such as fish and birds. Some tubiculous and burrowing species are also capable of remediating vast areas of the substrate with a corresponding release of bound nitrate and phosphate nutrients into the water column. Through their close association with sediments and the sediment-water-interface, benthic invertebrates reflect ambient abiotic conditions and sediment characteristics of estuaries.<br><br>**Confidence:** High<br><br>**Macrocrustacea:** Although no submerged macrophytes were recorded, reeds and sedges provided the alternate shelter for both penaeid juveniles and juveniles and adults of *Macrobrachium* spp. Macrocrustacea in part feed on zooplanktonic organisms. Under favourable conditions when there is sufficient phytoplankton for resident zooplankters, macrocrustacean feeding behaviour will not be affected. When zooplankton numbers are low, such as during mouth closure, macrocrustacea would feed mainly on microalgae. Macrocrustacea (adults and larval stages) are the food source of other invertebrates, fish and birds.<br><br>**Confidence:** Medium |
| **<u>Fish</u>:**<br><br>Most of fish in the Thukela Estuary are detritivores that depend on autochthonous and allochthonous inputs to the detrital food web. Many of these fish species also consume benthic microalgae directly but not phytoplankton. Phytoplankton enters the fish component of the ecosystem through the zooplankton food chain. The other major source of energy for a number of fish species in the estuary is the benthic invertebrate food chain. The fish assemblage of the Thukela Estuary will respond to changes in the primary drivers (= different abiotic states) of the food web by an alteration in overall composition and abundance.<br><br>**Confidence:** Medium |
| **<u>Birds</u>:**<br><br>As the benthos and fish are the main prey of the birds feeding inside the estuary, the impacts described above will result in negative effects on the bird fauna.<br><br>**Confidence:** Medium |

### *c. Non-flow related anthropogenic influences affecting biotic characteristics in the estuary*

| HUMAN EXPLOITATION (CONSUMPTIVE AND NON-CONSUMPTIVE) |
| --- |
| **<u>Microalgae</u>:**<br><br>**Phytoplankton:** Disturbance in the catchment and floodplain might reduce the filtering capacity of macrophytes, increasing concentrations of nutrients and suspended sediments. Cutting and removal of macrophytes may increase input of organic matter and release trapped nutrients thus influencing nutrient dynamics and phytoplankton biomass production.<br><br>**Confidence:** Low<br><br>**Benthic microalgae:** N/A |
| **<u>Macrophytes</u>:**<br><br>Some signs of harvesting of the sedge on the north bank of the mouth.<br><br>**Confidence:** Medium |

| HUMAN EXPLOITATION (CONSUMPTIVE AND NON-CONSUMPTIVE) |
| --- |
| <u>**Invertebrates:**</u><br><br>**Zooplankton:** N/A<br><br>**Macroinvertebrates:** No large polychaetes for bait harvesting.<br><br>**Confidence:** Medium<br><br>**Macrocrustacea:** Macruran prawns (*Macrobrachium* and Penaeid spp) are caught for bait by local fishermen. No evidence of Anomuran use was found (pumping for mud prawn, *Upogebia* spp).<br><br>**Confidence:** Medium |
| <u>**Fish**</u>**:**<br><br>Recreational and subsistence fishing are important activities conducted in the estuary. No information is available on the sustainability of these operations. Illegal gill and seine netting in the lower reaches of the estuary should be prevented due to the negative impact on the other fishing activities as well as the role of the estuary as a nursery area for overexploited marine fish species.<br><br>**Confidence:** Low |
| <u>**Birds**</u>**:**<br><br>N/A to benthic feeders and roosting species except in relation to the 'disturbance factor'. Piscivores may be affected by both recreational as well as illegal fishing if exploitation levels are high.<br><br>**Confidence:** Low |

| FLOODPLAIN DEVELOPMENTS |
| --- |
| <u>**Microalgae**</u>**:**<br><br>**Phytoplankton:** Development along the floodplain will exacerbate suspended sediment load into the estuary resulting in the reduction in light penetration, co-flocculation of planktonic algae and sediment particles. This might lead to increased siltation thus reducing estuarine volume.<br><br>**Confidence:** Medium<br><br>**Benthic microalgae:** Any development within the floodplain will be a loss of habitat during periods of flooding and back flooding. As a result, total microalgal biomass for the estuary will decrease during these periods.<br><br>**Confidence:** High |
| <u>**Macrophytes**</u>**:**<br><br>Agriculture has removed 80% of the natural floodplain vegetation.<br><br>**Confidence:** High |
| <u>**Invertebrates**</u>**:**<br><br>**Zooplankton:** Development that influences phytoplankton production will ultimately have an effect on zooplankton.<br><br>**Confidence:** Medium<br><br>**Macroinvertebrates:** The negative effects to floodplain developments on benthic invertebrates will be primarily related to habitat destruction, smothering (sediment deposition during flood events) or rapid changes to ambient water quality conditions.<br><br>**Confidence:** Medium<br><br>**Macrocrustacea:** Large floods will increase siltation and sedimentation in the estuary if any development takes place along the floodplain. This will lead to the estuary becoming shallower and a reduced microalgal biomass. This condition will result in the reduction of habitat and food sources for macrocrustacea. Further removal of natural floodplain vegetation would destroy areas where flow velocities are retarded. These areas are important for retaining breeding adults and prevent them from being washed out to sea.<br><br>**Confidence:** Medium |

| FLOODPLAIN DEVELOPMENTS |
| --- |
| **Fish:**<br><br>Floodplain developments will reduce organic inputs into the estuarine food web and limit the value of littoral fish refuges, especially during high water levels (Abiotic State 1).<br><br>**Confidence:** Medium |
| **Birds:**<br><br>Floodplain developments that impact on the benthos and fish will ultimately affect the bird groups utilising these resources.<br><br>**Confidence:** Medium |

| OTHER |
| --- |
| **Microalgae:**<br><br>**Phytoplankton:** Conductivity and pH under Present Ecological State are not different from that of Reference State; however, under low flow conditions conductivity might rise as the frequency of saline water and duration in the estuary increases. This will have an influence on the osmoregulatory response of phytoplankton altering membrane permeability and electrochemical gradients.<br><br>**Confidence:** Medium<br><br>**Benthic microalgae:** Increased sediment yield could lead to a shorter and shallower estuary. The average area of the estuary would become smaller resulting in a lower total microalgal biomass.<br><br>**Confidence:** High |
| **Macrophytes:** N/A |
| **Invertebrates:**<br><br>**Zooplankton:** Any anthropogenic impacts on the water quality of the system will influence the zooplankton. The response will depend upon type and duration of impact linked to physical nature of the system at the time, which make any speculation very difficult.<br><br>**Confidence:** Medium<br><br>**Macroinvertebrates:** Any changes to microalgal and macrophyte communities will be rapidly reflected by changes in diversity and abundance to the macroinvertebrates.<br><br>**Confidence:** Medium<br><br>**Macrocrustacea:** Increased sediment yield will lead to a shorter estuary, which would reduce the total macrocrustacean abundance.<br><br>**Confidence:** Medium |
| **Fish:**<br><br>Anthropogenic changes in catchment land use patterns that lead to increased sedimentation of the estuary will have an adverse effect on the fish community through a shallowing of the system and a further reduction of estuarine area available to marine and estuarine species.<br><br>**Confidence:** Medium |
| **Birds:**<br><br>The issue of recreational disturbance has the potential to negatively impact on the bird fauna. However, at present there is limited activity on the estuary itself with most being focused on the beach area around the mouth and along the periphery of the estuary.<br><br>**Confidence:** High |

## 4.3 REFERENCE CONDITION

### 4.3.1 Abiotic Components

***a. Seasonal variability in river inflow***

Monthly simulated runoff data for the Reference Condition is provided in Table 4.4 on the following page. A summary of flow distribution (mean monthly flows in $m^3/s$) for the Reference Condition, derived from the 70-year simulated data set, is provided in Table 4.3.

**Table 4.3 A summary of flow distribution (mean monthly flows in $m^3/s$) for the Reference Condition (derived from 70-year simulated data set)**

| %ile | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **90%ile** | 131.80 | 271.42 | 327.56 | 521.22 | 627.80 | 369.15 | 164.93 | 80.37 | 43.48 | 35.05 | 38.40 | 60.35 |
| **80%ile** | 91.35 | 206.37 | 262.41 | 385.30 | 474.65 | 305.85 | 141.40 | 59.95 | 37.31 | 29.02 | 29.10 | 35.16 |
| **70%ile** | 57.77 | 119.43 | 204.03 | 300.83 | 381.26 | 259.23 | 126.02 | 52.59 | 32.22 | 24.84 | 22.25 | 25.37 |
| **60%ile** | 43.34 | 90.28 | 173.14 | 263.73 | 279.65 | 217.66 | 109.59 | 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 |

***b. Flood regime for the Reference Condition***

The flood regime has been evaluated based on observed floods after dam construction (Present Ecological State) in the catchment. The Present Ecological State has all the floods as during the Reference (natural) State, but flood peaks would have been higher (about 8%) during the Reference Condition (see *Description of Present Ecological State*).

**Confidence:** High

***c. Changes in sediment processes and characteristics from Reference Condition to Present Ecological State***

Flood peaks are affected only slightly under Present Ecological State conditions due to dam development, but the existing dams also trap most of their sediment yields. These dams are however high up in the catchment, controlling a relatively small portion of the catchment.

The natural sediment yield of the catchment was probably less than the estimated Present Ecological State yield. This with the higher floods during the reference state would have resulted in a higher sediment transport capacity through the estuary and improved scouring of the estuary with less sediment deposition during major floods. The estuary under natural conditions was therefore probably longer and wider, which agrees with simulations and historical information on the estuary length.

**Confidence:** High

## Table 4.4 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 |

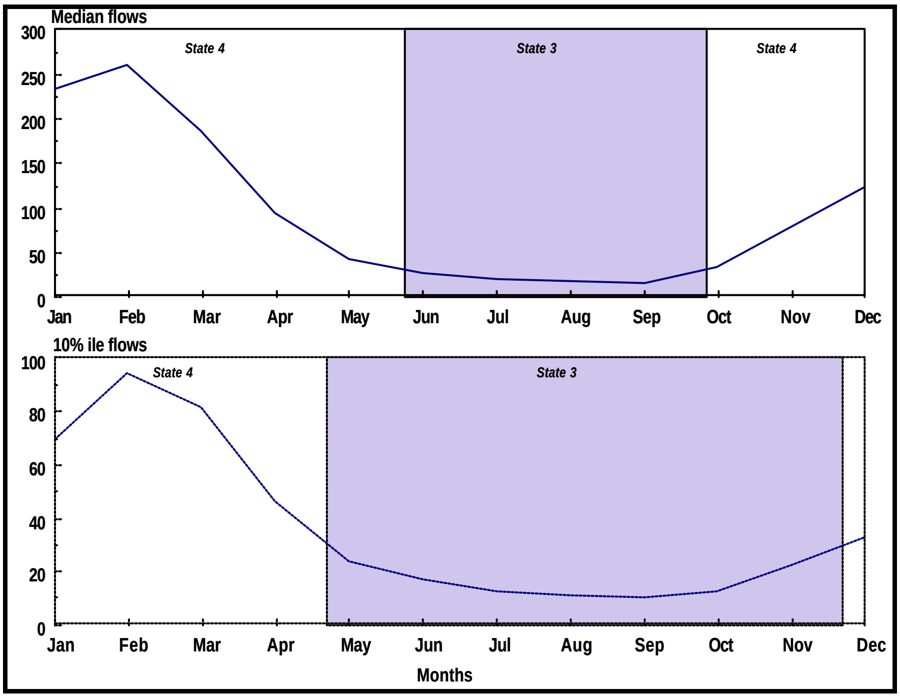
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1: Closed | < 2.0 | 2: Open (closed for | 2.0-5.0 | 3: Open (Saline) | 5.0-30 | 4: Open (Riverine) | > 30.0 |

| | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | AVE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| < 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% |

### d. *Occurrence and duration of different Abiotic states for Reference Condition*

The occurrence and duration of the different Abiotic States during the Reference Condition are illustrated in the simulated monthly river flow table (Table 4.4).

To provide a conceptual overview of the annual distribution of Abiotic States under the Reference Condition, median monthly flows and 10%ile flows were used to depict the situation for normal and drought periods, respectively:




### e. *Changes in the abiotic characteristics from Reference Condition to Present Ecological State, resulting from non-flow related anthropogenic*

| |
|---|
| **Structures within the estuary (e.g. weirs, bridges, mouth stabilisation):** N/A<br><br>**Confidence:** - |
| **Discharges into the estuary affecting water quality (e.g. dump sites, stormwater, sewage discharges, etc):** Based on the type of waste (i.e. paper and pulp mill and sewage effluents), potential additional impacts of the industrial area near Mandini on river water quality may include reduced oxygen levels at times (i.e. high COD inputs from paper and pulp industry and sewage effluents), increased suspended solids/turbidity loads, as well as increased inorganic nutrient loading (particularly from sewage effluents). The extent of influence will depend on (a) volume of wastewater releases as well as (b) the concentration of different constituents in the wastewater.<br><br>Therefore, suspended solid inputs, inorganic nutrients and organic matter (that could result in reduction of DO) in river inflow would have been lower under the reference conditions in comparison with the Present Ecological State.<br><br>**Confidence:** Low |
| **Other:** Sediment yield may have been lower under the Reference Condition (around 200 ton/$km^2$.annum), which would mean an increase in the mean annual sediment loads from 5.9 to 9.3 million ton. Thus the estuary is now shorter by about 3km and shallower than under the Reference Condition.<br><br>**Confidence:** Medium |

### 4.3.2 Biotic Components

### *a. Changes in biotic characteristics from the Reference Condition to the Present Ecological State*

| **MICROALGAE** |
|---|
| **Phytoplankton:** Under reference conditions there would be greater frequencies of high flow rates and flooding (States 3 and 4) and the phytoplankton community composition would typify that of small sized palatable flagellates and diatoms dominating the phytoplankton community structure. Higher diversity would occur within the middle reaches of the estuary where the riverine/estuarine interface (REI) zone would form. Saltwater penetration during low flow periods in Winter to late Spring would support marine to brackish phytoplankton species and would be characterised by seasonal peaks in biomass as the REI zone would be located within the estuary proper. Phytoplankton biomass during flow rates greater than 30.0m$^3$/s would be low as residence times would be brief, limiting the period required for the phytoplankton to reproduce within the estuary. Natural vegetation would cover the adjacent riparian zone and the catchment would effectively filter nutrients coming into the estuary. The frequency and duration of occurrence of phytoplankton would be predictable as dams, weirs and water abstraction have now altered the river flow patterns.<br><br>**Confidence:** Medium |
| **Benthic microalgae:** Reduced freshwater input results in saline intrusion increasing. Mouth closure, limited to only a few days, is also likely to occur each year. A strong longitudinal salinity gradient provides a broad range of habitats within an estuary. Marine, brackish and freshwater diatom communities will be present and the longer the more stable conditions persist, the more established the communities become, resulting in a higher species diversity and microalgal biomass (~10%). Episammic taxa of diatoms attach themselves to sand grains whereas epipelic diatoms move within the top few millimetres of the sediment and are capable of forming distinct biofilms. Any shift in sediment deposition/resuspension will influence sediment type in the estuary causing a shift between epipelic and episammic diatom communities.<br><br>**Confidence:** Medium |
| **MACROPHYTES** |
| The estuary would have been fresher; State 3 (salinity gradient present) would occur for 4/12 months, whereas under present conditions occurs for 6/12 months. This saline influence for one third of the year was probably sufficient to maintain the brackish reeds and sedges. Increase in inorganic nutrient loading for present conditions may have encouraged the growth of weedy species e.g. *Eicchornia crassipes*.<br><br>The magnitude of major floods has been decreased by 8% from reference to present conditions. Larger floods would have washed more reeds and sedges out of the estuary. The system is presently less dynamic than it was. Less sediment deposition would have occurred with major floods, and the vegetation would have grown back quicker. There would have been no competition from alien species such as Brazilian pepper, Spanish reed and others.<br><br>Agriculture has removed 76% of the floodplain area, decreasing the botanical importance of the estuary. Analysis of a 1937 aerial photograph showed that 22ha of reed wetland and 1.5ha of swamp forest has been lost on the south bank.<br><br>**Confidence:** Medium |

**INVERTEBRATES**

**Zooplankton:** The reference state had longer periods of high flow. Increased high flow (State 4) would create unstable conditions for zooplankton. A very poor freshwater community consisting mostly of insect larvae, probably washed into the estuary, and meroplankton larvae of the decapods *Macrobrachium* and *Varuna* would be present at certain times of the year. The relatively short low flow periods (State 3) will support a diverse, but relatively poor in terms of densities, marine community with true estuarine species present in low abundance. The reference state therefore probably supported an even more impoverished zooplankton community than the present state.

**Confidence:** Low

**Macroinvertebrates:** In the reference state the macroinvertebrate community would have been predominantly riverine in origin for >60% of the year (high and medium flow conditions - Abiotic States 3 and 4). Species richness will have been similar or less than present conditions. In addition, the abundance of benthic organisms would presumably have been less, lowering the benthic biomass and productivity of the system. At present, the most abundant taxon during high flow conditions is oligochaete worms. If sediment deposition and nutrient input (more efficient filtering capacity of a greater abundance of natural vegetation) decreased to amounts comparable to the reference state, these fauna would have a significantly lower representation. It is probable that as a true river mouth the reference state would have supported an impoverished macroinvertebrate community. The majority of invertebrates (aquatic insects at different life stages) would have moved to the margins of the estuary and made use of the abundant natural vegetation for feeding and breeding purposes.

In the reference condition, Abiotic States 1 and 2 would have been rare. The current typically estuarine communities that develop under these conditions would also have occurred less frequently. If an estuarine community developed under reference conditions, it would have been unstable and perhaps characterised by hardy opportunistic species. During drought years, a community comparable to the present would have typified the decrease in flow.

**Confidence:** Medium

**Macrocrustacea:** The reference condition would be characterised by larger and more frequent floods with fewer occasions of mouth closure. Saline intrusion would be limited to the extreme lower reaches of the system, which would support freshwater/brackish species of *Macrobrachium*. The larger dominance of riverine conditions would probably preclude the existence of penaeid prawns with a saline/marine requirement in the system. With the assumption that flows were higher and of longer duration, it is doubtful whether any intertidal species occurred. The presence of the Anomuran, *Upogebia* in the reference state is also doubtful given its estuarine/marine osmoregulatory requirement. Rather than providing a favourable environment for macrocrustacean communities within the system, the Thukela was in all probability most important as a conduit for species with an obligatory marine or freshwater requirement during their life cycle (*Macrobrachium* spp., *Varuna litterata*, *Scylla serrata*).

**Confidence:** Medium

**FISH**

In the Reference Condition, Abiotic States 1 and 2 would have been unlikely to occur, even during extreme droughts. Abiotic State 3 prevailed during the winter and early spring months and would have facilitated occupation by a similar variety of species to present day conditions. However, the higher catchment river flows through the estuary during summer and autumn would have limited the penetration of the estuary by even euryhaline marine species and resulted in a depauperate marine and estuarine fish fauna. These species are unlikely to have been replaced by freshwater taxa due to the proximity to the marine environment and danger of being swept out to sea. Anguillid eel recruitment in the Reference Condition is likely to have been considerably higher than the Present Ecological State, primarily due to the elevated olfactory cues entering the marine environment and the greater catchment availability for colonisation.

**Confidence:** Medium

**BIRDS**

In the reference condition the macroinvertebrate and fish communities would have been more or less similar to the Present Ecological State and therefore it is likely that the bird fauna would also have been fairly similar.

**Confidence:** Medium

## 4.4 PRESENT ECOLOGICAL STATE OF THE THUKELA ESTUARY

The Present Ecological State is determined using the Estuarine Health Index (EHI) described in detail in E3 of the *Resource Directed Measures for Protection of Water Resources: Estuarine Ecosystem Component, Version 1.1* (www-dwaf.pwv.gov.za/idwaf/Documents) and *Determination of the Ecological Water Requirements for Estuaries, Estuarine Methods, Version 2* (DWAF 2003). Details regarding the individual scoring systems is included in that report.

The EHI is sub-divided into:

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

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

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

*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 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 6 months per year under the Present Ecological State. | High |
| b. % similarity in the magnitude of major floods (e.g. 1:20, 1:50 and 1:100) in comparison with the reference condition | 92 | Only 8% decrease in flood peaks estimated due to dam development far up in the catchment. | High |
| **Hydrology score** | **87** | | |

*Hydrodynamics and mouth condition*

| VARIABLE | SCORE | MOTIVATION | CONFIDENCE |
|---|---|---|---|
| Change in mean duration of closure over a 70 year period | 80 | 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 et al, 2002. There was an increase from 0% under Reference Conditions to 6% under the Present Ecological State. | Medium |
| **Hydrodynamic score** | **80** | | |

*Water quality*

| VARIABLE | SCORE | MOTIVATION | CONFIDENCE |
|---|---|---|---|
| 1. Change in longitudinal salinity gradient (%) and vertical salinity stratification | 60 | Under Reference Condition, the estuary was more river dominated than under the Present Ecological State, 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 Ecological State. Within State 3 the median flows were generally much higher under the Reference Condition compared with Present Ecological State. This suggests that in addition to the duration, the longitudinal intensity of saline intrusion also increased under the Present Ecological State. | Medium |
| 2a. Nitrate/phosphate concentration in the estuary | 70 | For the Thukela Estuary, it is assumed that changes in nitrate and phosphate concentrations would have been as a result of changes in the concentrations in river inflow. Based on results from the Mandini monitoring station, there were no apparent changes in the concentration of these variables from the Reference to Present Ecological State. The influence of wastewater from the Mandini industrial area may have had some influence (allowed for in the 30% change), particularly during periods of low flow but this needs to be confirmed through an appropriate monitoring programme. This was reflected in the presence of blue-green algae as well as oligochaetes (species indicative of nutrient enrichment) in the upper reaches of the estuary. | Low |
| 2b. Suspended solids in inflowing freshwater | 50 | It is likely that catchment activities as well as wastewater from the paper mills would have resulted in a marked increase in the suspended solid concentrations in river inflow. However, there are no data to quantify the increase. Scientists have observed, on a number of occasions, fibre-like suspended material in the estuary which resulted in clogging of fish sampling nets. Assume an increase approx 50%. | Low |
| 2c. Dissolved oxygen (DO) in estuary | 80 | It is not expected for DO concentrations to have been altered markedly from Reference to Present Ecological State because the estuary is quite short thus allowing for extensive tidal flushing during flood tides. It is also relatively shallow, i.e. wind mixing maintains well-oxygenated conditions. However, under the Ecological State, reduced DO levels in river inflow, as a result of high COD inputs from the industrial areas, may have resulted in DO deficiencies in the estuary, particularly during low flows. However, levels are not expected to drop below 4 mg/L. This probably occurs only occasionally and for short periods (assume a change of 20%). | Low |
| 2d. Levels of toxins | 100 | Preliminary assessments of sediment trace metal concentrations (proxy for accumulation of toxic substances) in the Thukela Estuary do not indicate any marked accumulation as a result of anthropogenic activities. | Medium |
| **Water quality score** | **54** | | |

*Physical habitat alteration*

| VARIABLE | | SCORE | MOTIVATION | CONFIDENCE |
|---|---|---|---|---|
| 1 | Resemblance of intertidal sediment structure and distribution to reference condition | | | |
| 1a | % similarity in intertidal area exposed | 70 | Existing dams had limited influence on flood peaks but sediment yield may have increased due to catchment developments. The estuary will be shorter than under the Reference Condition, creating a smaller intertidal area. | Medium |
| 1b | % similarity in sand fraction relative to total sand and mud | 70 | Existing dams had limited influence on flood peaks but sediment yield may have increased due to catchment developments. The percentage sand would have been greater under the Reference Condition. | Medium |
| 2 | Resemblance of subtidal estuary to reference condition: depth, bed or channel morphology | 90 | Existing dams had limited influence on flood peaks but sediment yield may have increased due to catchment developments. This will, however, have limited impact on the subtidal area. | High |
| **Physical habitat score** | | **80** | | |

Influence of non-flow related anthropogenic activities on present health of the physical habitat:

| VARIABLE | SCORE | MOTIVATION | CONFIDENCE |
|---|---|---|---|
| Percentage of overall change in intertidal habitat caused by anthropogenic activity as opposed to modifications to water flow into estuary | 0 | (Changes in intertidal habitat due to catchment developments only). | Medium |
| Percentage of overall change in subtidal habitat caused by anthropogenic modifications (e.g. bridges, weirs, bulkheads, training walls, jetties, marinas) rather than modifications to water flow into estuary | 0 | (Changes in subtidal habitat due to catchment developments only). | Medium |

*Microalgae*

| VARIABLE | SCORE | MOTIVATION | CONFIDENCE |
|---|---|---|---|
| *Phytoplankton* | | | |
| 1. Species richness | 65 | Based on the functional group diversity index, not all groups were represented and of those that were present there was little variety. Changes in the catchment have probably increased the nutrient and sediment input that has reduced species richness. | Medium |
| 2a. Abundance | 70 | Phytoplankton densities have been altered since the establishment of the paper and sugar mills upstream. Sugar cane fields extend right up to the edge of the river removing the natural buffer and filtering capacity of natural vegetation that has possibly increased nutrient and sediment load into the river thus increasing abundances of undesirable phytoplankton. | Medium |
| 2b. Community composition | 70 | As a result of changes in the nutrient and sediment load into the river and the estuary, phytoplankton community composition has been altered since some planktonic microalgae (i.e. filamentous blue-greens) associated with poor water quality already occur in the upper reaches of the estuary. | Medium |
| *Benthic microalgae* | | | |
| 1. Species richness | 80 | The possibility of mouth closure as highlighted in 1930 and 1945 (Table 1) is considered to be unlikely. As a result, only a slight change (10%) in species richness as a result of lower flow and higher nutrients in particular is expected. | Medium |
| 2a. Abundance | 80 | Biomass will increase as flow decreases. | Medium |

| VARIABLE | SCORE | MOTIVATION | CONFIDENCE |
|---|---|---|---|
| 2b. Community composition | 90 | An average of 90% of the original community remains. | Medium |
| **Microalgae score** | **65** | | |

## *Macrophytes*

| VARIABLE | SCORE | MOTIVATION | CONFIDENCE |
|---|---|---|---|
| 1. Species richness | 80 | Some floodplain species may have been lost due to agricultural activities. According to the scoring system, if 90% of the original species are remaining then a score of 80 is assigned. | Medium |
| 2a. Abundance | 60 | The floodplain area has been disturbed as a result of agricultural activities and an estimated 50% of the total biomass remains (score = 50). However, there may have been an increase in the abundance of reeds and sedges because of an increase in the duration of saline conditions in the estuary as well as a lack of uprooting by floods (score = 50 +10 = 60). | Medium |
| 2b. Community composition | 80 | Increase in nutrient loading and sediment input would encourage the growth of weedy species on the floodplain and in the water (e.g. water hyacinth). Some change in community composition can be expected as a result of this. There would be an 80% resemblance to the original composition. | Medium |
| **Macrophyte score** | **60** | | |

## *Invertebrates*

| VARIABLE | SCORE | MOTIVATION | CONFIDENCE |
|---|---|---|---|
| *Zooplankton* | | | |
| 1. Species richness | 100 | A period of two months longer each year in State 3 should not lead to the loss of any zooplankton species considering that this should only result in two months longer of a marine dominated community compared to virtually no zooplankton at all during State 4 flows. | Medium |
| 2a. Abundance | 80 | An increase of about 2 months in marine conditions during winter months should mean that the marine community would be present that much longer each year but the maximum abundance for any of those plankters at any given time during low flow should not increase significantly. | Medium |
| 2b. Community composition | 100 | No change from 2 months longer of State 3. | Medium |
| *Macroinvertebrates* | | | |
| 1. Species richness | 80 | The majority of the original species will still be present given no significant change in physico-chemical state. The present species richness may be greater due to the increased penetration of estuarine species during medium and low flow phases (<30 $m^3$/s). | High |
| 2a. Abundance | 80 | It is probable that as a true river mouth the reference state would have supported an impoverished macroinvertebrate community. Thus the abundance has not changed by more than 20%. | Medium |
| 2b. Community composition | 60 | Few of the original freshwater taxa would have been lost. However, there has most certainly been a shift in abundance to more hardy, tolerant and opportunistic species. | Medium |
| *Macrocrustacea* | | | |
| 1. Species richness | 65 | Some species less tolerant of fine sediment deposition would be lost. With a loss in habitat (macrophytes) it is expected that some of the species may have disappeared. | Medium |
| 2a. Abundance | 75 | 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 *Macrobrachium* 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 present state. High flows are normally associated with nutrient input and there would be high 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** | **60** | | |

*Fish*

| VARIABLE | SCORE | MOTIVATION | CONFIDENCE |
|---|---|---|---|
| 1. Species richness | 80 | There are no indications of a decline in species richness as result of the decreased river input into the estuary. Indeed, it is probable that the species richness of the estuary has increased due to the decline in freshwater dominance of the system and greater penetration of saline water when compared to the reference condition. This represents a deviation from the Reference State. | Medium |
| 2a. Abundance | 70 | Abundance of certain species such as anguillid eels has almost certainly declined but the abundance of most marine and estuarine species has probably increased under the Present Ecological State due to the greater frequency and duration of saline conditions within the estuary. Some marine fish species may have declined in abundance due to overfishing. | Low |
| 2b. Community composition | 80 | Although the community composition is likely to have changed when compared to the Reference State, no species or functional groups are likely to have been lost. There is a high probability that a more diverse fish community occupies the estuary in its present condition when compared to the Reference State. | Medium |
| **Fish score** | **70** | | |

*Birds*

| VARIABLE | SCORE | MOTIVATION | CONFIDENCE |
|---|---|---|---|
| 1. Species richness | 80 | Due to the limited predicted changes in the benthos and fish fauna from the Reference Condition to the Present Ecological State, it is unlikely that there has been any substantial change in the species richness of the bird fauna. | High |
| 2a. Abundance | 70 | The abundance of some species will undoubtedly have changed largely due to human disturbance. | Medium |
| 2b. Community composition | 80 | The community composition is currently much the same as it would have been under the Reference Condition due to the limited changes that are predicted to have occurred within the biota in general. | Medium |
| **Bird score** | **70** | | |

Influence of non-flow related anthropogenic activities on the present health of biota:

| COMPONENT | DEGREE (%) TO WATCH ABOVE CHANGE IS CAUSED BY NON-FLOW RELATED ACTIVITIES | MOTIVATION | CONFIDENCE |
|---|---|---|---|
| Microalgae | 10 | Floodplain disturbance | Medium |
| Macrophytes | 70 | Floodplain disturbance | Medium |
| Invertebrates: | | | |
| Zooplankton | 0 | Changes in zooplankton are related to river flow. | Low |
| Macroinvertebrates | 20 | Industrial activities upstream and increases in turbidity and sedimentation due to erosion. | Medium |

| COMPONENT | DEGREE (%) TO WATCH ABOVE CHANGE IS CAUSED BY NON-FLOW RELATED ACTIVITIES | MOTIVATION | CONFIDENCE |
|---|---|---|---|
| Macrocrustacea | 20 | Floodplain vegetation removal and organic enrichment may result in the displacement of macrocrustacea. | Low |
| Fish | 20 | Fishing activities have impacted on the stocks of certain recreational marine species. | Low |
| Birds | 50 | Fishing, legal and illegal, and general recreational activities in the vicinity of the estuary mouth and along the shoreline would have been the main factors causing disturbance and the subsequent reduction in bird numbers. | Medium |

The individual scores for each of the above components are incorporated into a Habitat health score and a Biological health score. This allows for the determination of the Estuarine Health Index (EHI) Score (Table 4.5).

**Table 4.5 Estuarine Health Score results for the Present Ecological State of the Thukela Estuary**

| Variable | Weight | Score | Weighted score |
|---|---|---|---|
| Hydrology | 25 | 87 | 22 |
| Hydrodynamics and mouth condition | 25 | 80 | 20 |
| Water quality | 25 | 54 | 14 |
| Physical habitat alteration | 25 | 80 | 20 |
| **Habitat health score** | | | **75** |
| Microalgae | 20 | 65 | 13 |
| Macrophytes | 20 | 60 | 12 |
| Invertebrates | 20 | 60 | 12 |
| Fish | 20 | 70 | 14 |
| Birds | 20 | 70 | 14 |
| Biotic health score | | | 65 |
| **ESTUARINE HEALTH SCORE** | | | **70** |

The EHI score for the Thukela Estuary, based on its Present Ecological State, is 70, translating into a Present Ecological State of C (Table 4.6).

**Table 4.6 Recommended guidelines for the classification of the Present Ecological State (PES)**

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

## 4.5 IMPORTANCE OF THUKELA ESTUARY

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

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

Each of the above can be categorised as measures of rarity, abundance or ecological function. The rationale for selecting these variables, as well as further details on the estuarine importance index are discussed in detail Appendix E4 of the *Resource Directed Measures for Protection of Water Resources: Estuarine Ecosystem Component, Version 1.1* (www-dwaf.pwv.gov.za/idwaf/Documents).

For this study, the Ecological importance determination of the Thukela Estuary was obtained from the *Estuarine Prioritisation for RDM* project (Turpie *et al.* 2002). The *Functional Importance* score, however, was derived at the Specialist Workshop held in Port Elizabeth on 5 and 6 June 2002.

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

*Estuary Size*

| SCORE | MOTIVATION |
|---|---|
| 80 | Estuary size is defined as the total area (ha) within the geographical boundaries of the estuarine resource unit. Size is then converted to a measure of importance using scoring guidelines, which is based on 10% rank percentiles of estuaries of known size. With an area between 50.1 - 100ha, the Thukela Estuary is assigned a score of 80. |

*Zonal Type Rarity*

| SCORE | MOTIVATION |
|---|---|
| 70 | The estuary is one of four river mouths within the Subtropical biogeographical zone. The Zonal Type Rarity index is thus 1/4 = 25. The score assigned is thus 70. |

*Habitat Diversity*

| SCORE | MOTIVATION |
|---|---|
| 50 | This score is calculated on the basis of the amount of each habitat type present in the estuary in relation to the total area of this habitat in South African estuaries. The score (x ha/x ha) for each habitat is summed to obtain the rarity value. The value obtained falls within the second 10% percentile for the scores generated. |

*Biodiversity Importance*

| SUB-COMPONENTS | SCORE | MOTIVATION |
|---|---|---|
| Plants | 20 | This score is calculated by adding rarity scores for each species present in the estuary, where rarity scores for each species are calculated as 1/number of estuaries in which the species occurs in South Africa (based on actual records of presence). The summed value obtained falls within the eighth percentile for the scores generated from all South African estuaries, and is thus assigned a score of 20. |
| Invertebrates | 90 | This score is calculated by adding rarity scores for each species present in the estuary, where rarity scores for each species are calculated as 1/number of estuaries in which the species occurs in South Africa (based on interpolated presence records from species distributions). The summed value obtained falls within the eighth percentile for the scores generated from all South African estuaries, and is thus assigned a score of 90. |
| Fish | 70 | This score is calculated by adding rarity scores for each species present in the estuary, where rarity scores for each species are calculated as 1/number of estuaries in which the species occurs in South Africa (based on actual records of presence). The summed value obtained falls within the second percentile for the scores generated from all South African estuaries, and is thus assigned a score of 70. |
| Bird | 90 | This score is calculated by adding rarity scores for each species present in the estuary, where rarity scores for each species are calculated as 1/number of estuaries in which the species occurs in South Africa (based on actual records of presence). The summed value obtained falls within the second percentile for the scores generated from all South African estuaries, and is thus assigned a score of 90. |
| **Biodiversity score** | **76.5** | |

*Functional Importance*

| SUB-COMPONENTS | SCORE | SCORING GUIDELINES |
|---|---|---|
| Outwelling of detritus and nutrients to the coastal zone | 20 | None = 0<br>Little = 20<br>Some = 40<br>Important = 60<br>Very important = 80<br>Extremely important =100 |
| Nursery function for marine fish and crustacea | 20 | |
| Movement corridor for river invertebrates that breed in marine environment | 100 | |
| Stop-over function for migratory birds | 40 | |
| Roosting area for marine or coastal birds | 100 | |
| **Functional score** | **100*** | |

* Using the maximum score of the above

The individual scores obtained above are incorporated into the final Estuarine Importance Score (Table 4.7).

**Table 4.7 Estuarine Importance scores for the Thukela Estuary**

| Criterion | Score | Weight | Weighted score |
|---|---|---|---|
| Estuary Size | 80 | 15 | 12 |
| Zonal Rarity Type | 70 | 10 | 7 |
| Habitat Diversity | 50 | 25 | 13 |
| Biodiversity Importance | 76.5 | 25 | 19 |
| Functional Importance | 100 | 25 | 25 |
| **ESTUARINE IMPORTANCE SCORE** | | | **76** |

The Estuarine Importance Score for the Thukela Estuary, based on its Present Ecological State, is 76, indicating that the estuary is important (Table 4.8).

**Table 4.8 Interpretation of Estuarine Importance scores for estuaries**

| Importance score | Description |
|---|---|
| 81 – 100 | Highly important |
| **61 – 80** | **Important** |
| 0 – 60 | Of low to average importance |

## 4.6 RECOMMENDED ECOLOGICAL RESERVE CATEGORY FOR THE THUKELA ESTUARY

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

For estuaries the first step is to determine the 'minimum' ERC of an estuary, based on its Present Ecological State (PES). The relationship between EHI Score, PES and ERC is set out in Table 4.9.

**Table 4.9 Relationship between PES and minimum ERC**

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

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

The degree to which the minimum ERC, based on its PES, needs to be modified to assign a recommended ERC depends on:

- Importance of the estuary (determined in Section 4.4 above).
- Modifying determinants, i.e. protected area status and desired protected area status.
- A status of "area requiring high protection" should be assigned to estuaries that are identified as vital for the full and most efficient representation of estuarine biodiversity.
- Reversibility of change resulting in the PES (i.e. the concept of best attainable state (BAS)).

The proposed rules for allocation of the recommended ERC are set out in Table 4.10.

**Table 4.10 Proposed rules for allocation of recommended ERC**

| Current/Desired protection status and Estuary importance | ERC | Policy Basis | Corresponding Management Class |
|---|---|---|---|
| Protected area | A or BAS | Protected and desired protected areas should be restored to and maintained in the best possible state of health. | Natural |
| Desired Protected Area (based on complementarity) | A or BAS | | |
| Highly important | PES + 1, min B, or BAS | Highly important estuaries should be in an A or B category. | Good |
| Important | PES + 1, min C, or BAS | Important estuaries should be in an A, B or C category. | Fair |
| Of low to average importance | PES, min D | The remaining estuaries can be allowed to remain in a D category. | Fair |

According to the rules, the recommended ERC for the Thukela Estuary should be:

- Because the Thukela Estuary is rated 'important' (reflected by the estuarine importance score of 76), the recommended Ecological Reserve Category should be '*Present Ecological State Category (i.e. C) +1*', which implies a Category B or, if not possible,
- Best attainable state, with Category C the minimum requirement.

Results of the workshop indicated that non-flow related anthropogenic activities (such as human disturbance of birds, over-fishing and removal of wetlands for agriculture) have had a significant influence on the present state of the estuary (refer to Section 4.3). As some of the changes caused by these activities would be difficult to reverse, the specialist team suggested that the Present Ecological State corresponding to a PES of C be selected as the recommended ERC, which still remains within the recommended ERC allocation rules proposed for an 'Important' estuary (Table 4.10).

Thus, the **recommended ERC for Thukela Estuary is a Category C (Confidence = Medium).** However, it should be noted that the PES of the estuary corresponds to a high C (scored 70 in the range 61 – 75). This, together with the estuary being rated in the higher range of 'Important' estuaries (scored 76 in the range 60 - 80), is considered reasonable motivation to manage the estuary to maintain a high C category.

# 5 QUANTIFICATION OF ECOLOGICAL RESERVE SCENARIOS

## 5.1 SIMULATED RUNOFF SCENARIOS

The methodology for the determination of the Ecological Reserve for Estuaries uses a 'top down' approach, i.e. for the quantification of Ecological Reserve simulated flows for a range of future scenarios are required. Scenarios are typically simulated over a 50 - 70 year period and are presented as average monthly flows and should represent inflows at the head of the estuary. Two sets of scenarios had to be assessed, namely:

- Initial Scenarios (assessed at a workshop held in June 2002)
- Yield Scenarios (assessed at a workshop in January 2003).

### 5.1.1 Initial Scenarios

After liaison meetings between the Reserve team (river and estuary specialists) and the Water Resources Evaluation and Systems Analysis team, the Institute of Water Research, Rhodes University (Prof Denis Hughes) provided simulated data on several initial scenarios of possible inflows into the Thukela Estuary.

The following approach was agreed upon:

- The Water Resources team (WRP) would provide three scenarios i.e. natural flow, present day (1995 development) and a 'worst case' scenario based on full development of the system (including Jana and Mielietuin Dam) without provision for the Reserve.
- The IFR hydrologist of the rivers Reserve team would then generate several additional scenarios based on a simulation of conditions that could occur if **an estimated** IFR 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 Ecological State – Hydrology' method which has already been used in the Thukela study to determine the present hydrological state of all the resource units (Hughes and O'Keeffe, 2001).

The 'Present Ecological 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 initial scenarios are listed below:

| Scenario | MAR ($m^3 \times 10^6$) | % 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 |

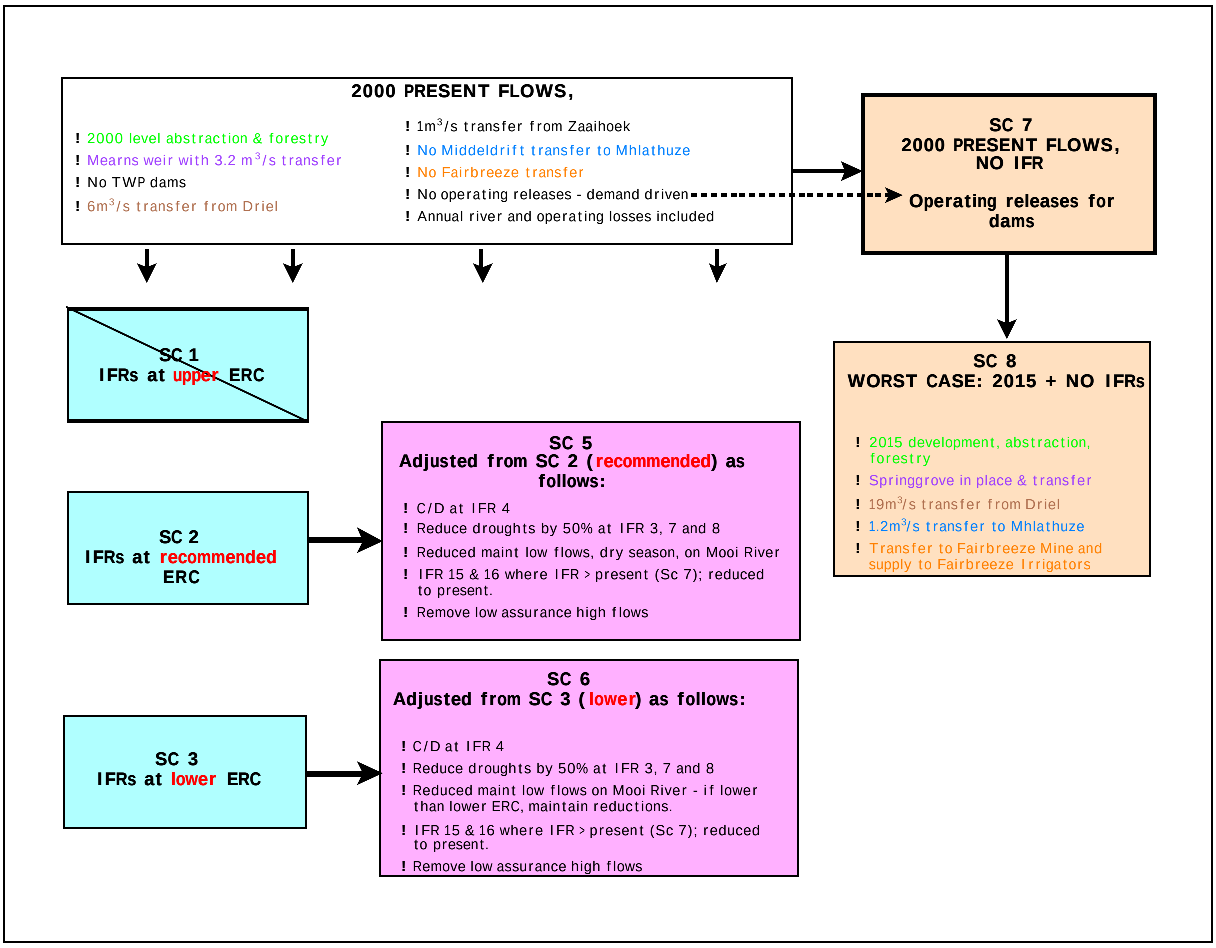
The method that has been used to generate the Reserve scenarios appears to have generated reasonably realistic results, without having to expend the resources that would have been necessary to configure the systems model with Reserve requirements at a large number of points at this stage of the project. 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 some 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).

The flow scenarios were devised by the client, the Reserve team and the system hydrologists (Water Resources Planning (WRP)). These scenarios are fully described in WRP documentation, report no PBV000-00-127/02 (WRP 2002).

As provided by WRP, the scenarios are described below and illustrated in Figure 5.1.

**Fig. 5.1 Description of scenarios**




## 5.2 PRESENT DAY (2000 DEVELOPMENT)

Each Scenario will be analysed for the Present Day (2000 development) except Scenario 7 and 8, which will be analysed at the 2015 development. The Present Day development level is described below:

- 2000 Development level abstractions and aforestation usage.
- Mearns Weir is in place (No Springrove Dam present) with a maximum transfer from Mearns to Midmar Dam of 3.2m$^3$/s.
- No TWP dams in place.
- 6 m$^3$/s being transferred from Driel Barrage to the Vaal River catchment, with no support from the Clifford Chambers weir.
- 1 m$^3$/s transfer from the Zaaihoek Dam to the Vaal River catchment and Majuba Power Station.
- No transfer from Middeldrift to the Mhlathuze River catchment.
- No transfers to Fairbreeze Mine.

- Annual river losses of 23.0 $10^6$ $m^3$ and an operating loss component of 11.5 $10^6$ $m^3$ are included. These losses were not simulated in the original Operating Rule 1 scenario.
- No operating releases from reservoirs, releases will be demand driven.

## 5.3 SCENARIO 1

IFRs were assessed for the recommended ERC, the ERC higher than the recommended and one category lower than the recommended ERC. The combination of Upper, Lower and Recommended ERCs are illustrated in Table 5.2.

Sc 1 models the Present Day as described above and supplies the IFRs as a priority at the Upper ERC level.

## 5.4 SCENARIO 2

This scenario is the same as Sc 1; however all IFRs are supplied at the Recommended ERC level.

## 5.5 SCENARIO 3

This scenario is the same as Sc 1; however all IFRs are supplied at the ERC lower than the recommended**.**

## 5.6 SCENARIO 4

This scenario is modeled using the 2000 Present day as described under 5.2. The scenario is in essence a modification of Sc 2, i.e. all IFRs are supplied for the Recommended ERC with the following changes:

- Use the lowest category (C/D) at IFR site 4.
- Reduce drought flows at IFR site 3, (Little Thukela River) 7 and 8 (Sundays River) by half.
- Reduce maintenance low flows in June, July and August for all sites on the Mooi River (Sites 10, 11 and 12).
- For IFR sites 15 and 16 where scenario requirements exceed Present Day Sc 7 flows, flows were reduced to present day flows.

## 5.7 SCENARIO 5

This scenarios is essentially the same as scenario 4 with the following additional change:

- Remove low assurance high flow (floods) from all sites.

## 5.8 SCENARIO 6

This scenario is the same as for IFR 5 but all the Reserves (apart from IFR 4 which is still applied at a C/D category) are supplied at the lower ERCs.

## 5.9 SCENARIO 7

This scenario represents a different version of present day than the present day described under 5.2. The Sc 7 description is similar than the 2000 Present Day, however, the operating releases are now incorporated as in Table 5.1. Operation of the dams will therefore not be demand driven.

**Table 5.1 Operating Rule releases for Scenario 7**

| | |
|---|---|
| Driel release | 2.0 $m^3/s$ |
| Spioenkop release | 2.4 $m^3/s$ |
| Wagendrift release | 2.5 $m^3/s$ |
| Chelmsford release | 0.8 $m^3/s$ |

## 5.10 SCENARIO 8

Sc 8 is a theoretical scenario to serve as a worst-case scenario. It represents 2015 development with NO IFR releases. The characteristics of the 2015 development level is as follows:

- 2015 Development level abstractions and aforestation usage.
- A maximum transfer of 3.2$m^3/s$ from Mearns weir, with the proposed Springrove Dam in place. An allowance for an additional transfer from Springrove Dam to Midmar Dam of a maximum of 1.3$m^3/s$, allowing for a total maximum transfer capacity of 4.5$m^3/s$.
- No TWP dams in place.
- 19 $m^3/s$ being transferred from Driel Barrage, with support from Clifford Chambers weir.
- 1.2$m^3/s$ transfer from Middeldrift to the Mhlathuze River catchment.
- Transfer to Fairbreeze Mine of 0.417$m^3/s$ and to Fairbreeze Irrigators of 0.521$m^3/s$, the supply to the irrigators will be supplied from run of river and will not be supported from storage.
- 1 $m^3/s$ transfer from Zaaihoek Dam to the Vaal River catchment and the Majuba Power Station.
- Annual river losses of 23.0 $10^6 m^3$ and an operating loss component of 11.5 $10^6$ $m^3$ are included.
- The releases from the reservoirs will be based on current operating rules and is summarised in Table 5.1.

## 5.11 RESERVE ASSESSMENT PROCESS

To derive the water quantity component of the Reserve, runoff scenarios (refer to Section 5.1), 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.

A summary of the results from the assessments of the initial and yield scenarios is provided in Tables 5.2 and 5.3, respectively. A detailed assessment is provided in Appendix I.

## 5.12 ECOLOGICAL RESERVE CATEGORIES ASSOCIATED WITH DIFFERENT SCENARIOS

The individual EHI scores, as well as the corresponding ERC for the different scenarios are provided in Table 5.4.

According to general rule in the methodology for estuaries, Scenario: River D should have been the recommended 'Reserve' in terms of all the scenarios examined, i.e. the scenario representing the largest modification in flow, but that would still keep the estuary in the recommended ERC, in this case C. However, the workshop was concerned that the April/May flow reduction of this scenario could be problematic, particularly in light of recent research (Coastal Research Unit of Zululand, University of Zululand) indicating that there is a narrow window period for larval recruitment of the crab *Varuna litterata* during late autumn each year. This freshwater species has an obligate marine phase during its lifecycle.

Also, the PES of the estuary corresponds to a high C (scored 70 in the range 61 – 75). This, together with the estuary being rated in the higher range of 'Important' estuaries (scored 76 in the range 60 - 80), is considered reasonable motivation to manage the estuary to maintain a high C category.

Therefore, Scenario: River B is selected as the **recommended Reserve** for the Thukela Estuary, which would be required to keep it in an ERC of a high C (with flow distributions as summarised for in Scenario: River Category B in Appendix I.).

In terms of the initial scenarios only River Category A and River Category B are acceptable (i.e. they result in a C+ or higher category), while in terms of the yield scenarios, Scenarios 1 to 6 are acceptable. A full comparison of the initial and yield scenarios relative to the recommended ERC are illustrated in Table 5.5.

**Table 5.2 A summary of the assessment of the Initial Scenarios (using the Estuarine Health Index). (Confidence: H = high; M = medium; L = low)**

| *Hydrology* | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **VARIABLE** | **RIVER CATEGORY A** | | **RIVER CATEGORY B** | | **RIVER CATEGORY C** | | **RIVER CATEGORY D** | | **WORST CASE 1** | | **WORST CASE 2** | |
| | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. |
| a. % similarity in period of low flows. | 100 | M | 83 | M | 75 | M | 67 | M | 67 | M | 67 | M |
| b. % similarity in the magnitude of major floods (e.g. 1:20, 1:50 and 1:100) in comparison with the reference condition. | 73 | H | 73 | H | 73 | H | 73 | H | 73 | H | 73 | H |
| **Hydrology score** | **89** | | **79** | | **74** | | **69** | | **69** | | **69** | |

| *Hydrodynamics and mouth condition* | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **VARIABLE** | **RIVER CATEGORY A** | | **RIVER CATEGORY B** | | **RIVER CATEGORY C** | | **RIVER CATEGORY D** | | **WORST CASE 1** | | **WORST CASE 2** | |
| | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. |
| Change in mean duration of closure over a 70-year period. | 100 | L | 100 | L | 95 | L | 95 | L | 20 | L | 20 | Low |
| **Hydrodynamic score** | **100** | | **100** | | **95** | | **95** | | **20** | | **20** | |

| *Water quality* | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **VARIABLE** | **RIVER CATEGORY A** | | **RIVER CATEGORY B** | | **RIVER CATEGORY C** | | **RIVER CATEGORY D** | | **WORST CASE 1** | | **WORST CASE 2** | |
| | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. |
| 1. Change in longitudinal salinity gradient (%) and vertical salinity stratification. | 100 | M | 80 | M | 70 | M | 50 | M | 40 | L | 40 | L |
| 2a. Nitrate/phosphate concentration in the estuary. | 70 | L | 70 | L | 70 | L | 70 | L | 50 | L | 50 | L |
| 2b. Suspended solids present in inflowing freshwater. | 50 | L | 50 | L | 50 | L | 50 | L | 50 | L | 50 | L |
| 2c. Dissolved oxygen (DO) in estuary. | 80 | L | 80 | L | 80 | L | 80 | L | 60 | L | 60 | L |
| 2d. Levels of toxins. | 100 | M | 100 | M | 100 | M | 100 | M | 100 | M | 100 | M |
| **Water quality score** | **70** | | **62** | | **58** | | **50** | | **46** | | **46** | |

| *Physical habitat alteration* | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **VARIABLE** | **RIVER CATEGORY A** | | **RIVER CATEGORY B** | | **RIVER CATEGORY C** | | **RIVER CATEGORY D** | | **WORST CASE 1** | | **WORST CASE 2** | |
| | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. |
| 1. Resemblance of intertidal sediment structure and distribution to reference condition. | | | | | | | | | | | | |
| 1a. % similarity in intertidal area exposed. | 60 | H | 60 | H | 60 | H | 60 | H | 60 | H | 60 | H |
| 1b. % similarity in sand fraction relative to total sand and mud. | 60 | H | 60 | H | 60 | H | 60 | H | 60 | H | 60 | H |
| 2. Resemblance of subtidal estuary to reference condition: depth, bed or channel morphology. | 75 | H | 75 | H | 75 | H | 75 | H | 75 | H | 75 | H |
| **Physical habitat score** | **67.5** | | **67.5** | | **67.5** | | **67.5** | | **67.5** | | **67.5** | |

**Table 5.2 continued...**

| *Microalgae* | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **VARIABLE** | **RIVER CATEGORY A** | | **RIVER CATEGORY B** | | **RIVER CATEGORY C** | | **RIVER CATEGORY D** | | **WORST CASE 1** | | **WORST CASE 2** | |
| | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. |
| *Phytoplankton* | | | | | | | | | | | | |
| 1. Species richness. | 65 | M | 65 | M | 65 | M | 65 | M | 50 | M | 50 | M |
| 2a. Abundance. | 80 | M | 75 | M | 70 | M | 65 | M | 50 | M | 50 | M |
| 2b. Community composition. | 80 | M | 75 | M | 70 | M | 65 | M | 50 | M | 50 | M |
| *Benthic microalgae* | | | | | | | | | | | | |
| 1. Species richness. | 80 | M | 80 | M | 80 | M | 80 | M | 35 | M | 35 | M |
| 2a. Abundance. | 90 | M | 90 | M | 90 | M | 90 | M | 80 | M | 80 | M |
| 2b. Community composition. | 90 | M | 90 | M | 90 | M | 90 | M | 60 | M | 60 | M |
| **Microalgae score** | **65** | | **65** | | **65** | | **65** | | **35** | | **35** | |

| *Macrophytes* | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **VARIABLE** | **RIVER CATEGORY A** | | **RIVER CATEGORY B** | | **RIVER CATEGORY C** | | **RIVER CATEGORY D** | | **WORST CASE 1** | | **WORST CASE 2** | |
| | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. |
| 1. Species richness. | 75 | M | 75 | M | 75 | M | 75 | M | 65 | M | 65 | M |
| 2a. Abundance. | 62 | M | 64 | M | 67 | M | 67 | M | 60 | M | 60 | M |
| 2b. Community composition. | 80 | M | 80 | M | 78 | M | 78 | M | 70 | M | 70 | M |
| **Macrophyte score** | **62** | | **64** | | **67** | | **67** | | **60** | | **60** | |

| *Invertebrates* | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **VARIABLE** | **RIVER CATEGORY A** | | **RIVER CATEGORY B** | | **RIVER CATEGORY C** | | **RIVER CATEGORY D** | | **WORST CASE 1** | | **WORST CASE 2** | |
| | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. |
| *Zooplankton* | | | | | | | | | | | | |
| 1. Species richness. | 100 | L | 80 | L | 65 | L | 65 | L | 65 | M | 65 | H |
| 2a. Abundance. | 80 | L | 75 | L | 70 | L | 70 | L | 50 | M | 50 | M |
| 2b. Community composition. | 100 | L | 80 | L | 50 | L | 50 | L | 50 | M | 50 | H |
| *Macroinvertebrates* | | | | | | | | | | | | |
| 1. Species richness. | 80 | M | 65 | M | 25 | M | 25 | M | 17 | M | 17 | M |
| 2a. Abundance. | 70 | M | 70 | M | 60 | M | 60 | M | 55 | M | 55 | M |
| 2b. Community composition. | 70 | M | 70 | M | 60 | M | 60 | M | 60 | M | 60 | M |
| ***Macrocrustaceans*** | | | | | | | | | | | | |
| 1. Species richness. | 65 | M | 65 | M | 50 | M | 50 | M | 35 | M | 35 | M |
| 2a. Abundance. | 75 | M | 75 | M | 65 | M | 65 | M | 55 | M | 55 | M |
| 2b. Community composition. | 75 | M | 75 | M | 65 | M | 65 | L | 55 | M | 55 | M |
| **Invertebrate score** | **65** | | **65** | | **25** | | **25** | | **17** | | **17** | |

Table 5.1 continued on next page…

**Table 5.2 continued…**

*Fish*

| VARIABLE | RIVER CATEGORY A | | RIVER CATEGORY B | | RIVER CATEGORY C | | RIVER CATEGORY D | | WORST CASE 1 | | WORST CASE 2 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. |
| 1. Species richness. | 90 | M | 90 | M | 80 | M | 80 | M | 70 | M | 70 | M |
| 2a. Abundance. | 80 | L | 80 | L | 90 | L | 90 | L | 60 | L | 60 | L |
| 2b. Community composition. | 70 | L | 70 | L | 60 | M | 60 | M | 40 | L | 40 | L |
| **Fish score** | **70** | | **70** | | **60** | | **60** | | **40** | | **40** | |

*Birds*

| VARIABLE | RIVER CATEGORY A | | RIVER CATEGORY B | | RIVER CATEGORY C | | RIVER CATEGORY D | | WORST CASE 1 | | WORST CASE 2 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. |
| 1. Species richness. | 80 | M | 80 | M | 80 | M | 80 | M | 25 | M | 25 | M |
| 2a. Abundance. | 70 | M | 70 | M | 70 | M | 70 | M | 50 | M | 50 | M |
| 2b. Community composition. | 80 | M | 80 | M | 90 | M | 90 | M | 40 | M | 40 | M |
| **Bird score** | **70** | | **70** | | **70** | | **70** | | **25** | | **25** | |

**Table 5.3 A summary of the assessment of the Yield Scenarios (using the Estuarine Health Index). (Confidence: H = high; M = medium; L = low)**

*Hydrology*

| VARIABLE | SCENARIO 1 | | SCENARIO 2 | | SCENARIO 3 | | SCENARIO 4 | | SCENARIO 5 | | SCENARIO 6 | | SCENARIO 7 | | SCENARIO 8 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. |
| a. % similarity in period of low flows. | 83 | M | 83 | M | 83 | M | 83 | M | 83 | M | 83 | M | 83 | M | 83 | M |
| b. % similarity in the magnitude of major floods (e.g. 1:20, 1:50 and 1:100) in comparison with the reference condition. | 93 | H | 93 | H | 93 | H | 93 | H | 93 | H | 93 | H | 93 | H | 93 | H |
| **Hydrology score** | **87** | | **87** | | **87** | | **87** | | **87** | | **87** | | **87** | | **87** | |

*Hydrodynamics and mouth condition*

| VARIABLE | SCENARIO 1 | | SCENARIO 2 | | SCENARIO 3 | | SCENARIO 4 | | SCENARIO 5 | | SCENARIO 6 | | SCENARIO 7 | | SCENARIO 8 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. |
| Change in mean duration of closure over a 70-year period. | 100 | M | 100 | M | 100 | M | 95 | M | 95 | M | 95 | M | 90 | M | 85 | M |
| **Hydrodynamic score** | **100** | | **100** | | **100** | | **95** | | **95** | | **95** | | **90** | | **85** | |

*Water quality*

| VARIABLE | SCENARIO 1 | | SCENARIO 2 | | SCENARIO 3 | | SCENARIO 4 | | SCENARIO 5 | | SCENARIO 6 | | SCENARIO 7 | | SCENARIO 8 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. |
| 1. Change in longitudinal salinity gradient (%) and vertical salinity stratification. | 80 | M | 75 | M | 70 | M | 65 | M | 65 | M | 60 | M | 60 | M | 50 | L |
| 2a. Nitrate/phosphate concentration in the estuary. | 70 | L | 70 | L | 70 | L | 70 | L | 70 | L | 70 | L | 70 | L | 65 | L |
| 2b. Suspended solids present in inflowing freshwater. | 50 | L | 50 | L | 50 | L | 50 | L | 50 | L | 50 | L | 50 | L | 50 | L |
| 2c. Dissolved oxygen (DO) in estuary. | 80 | L | 80 | L | 80 | L | 80 | L | 80 | L | 80 | L | 80 | L | 75 | L |
| 2d. Levels of toxins. | 100 | M | 100 | M | 100 | M | 100 | M | 100 | M | 100 | M | 100 | M | 100 | M |
| **Water quality score** | **62** | | **60** | | **58** | | **56** | | **56** | | **56** | | **54** | | **50** | |

**Table 5.3 continued...**

| *Physical habitat alteration* | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **VARIABLE** | **SCENARIO 1** | | **SCENARIO 2** | | **SCENARIO 3** | | **SCENARIO 4** | | **SCENARIO 5** | | **SCENARIO 6** | | **SCENARIO 7** | | **SCENARIO 8** | |
| | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. |
| 1. Resemblance of intertidal sediment structure and distribution to reference condition. | | | | | | | | | | | | | | | | |
| 1a. % similarity in intertidal area exposed. | 70 | M | 70 | M | 70 | M | 70 | M | 70 | M | 70 | M | 70 | M | 70 | M |
| 1b. % similarity in sand fraction relative to total sand and mud. | 70 | M | 70 | M | 70 | M | 70 | M | 70 | M | 70 | M | 70 | M | 70 | M |
| 2. Resemblance of subtidal estuary to reference condition: depth, bed or channel morphology | 90 | H | 90 | H | 90 | H | 90 | H | 90 | H | 90 | H | 90 | H | 90 | H |
| **Physical habitat score** | **80** | | **80** | | **80** | | **80** | | **80** | | **80** | | **80** | | **80** | |

| *Microalgae* | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **VARIABLE** | **SCENARIO 1** | | **SCENARIO 2** | | **SCENARIO 3** | | **SCENARIO 4** | | **SCENARIO 5** | | **SCENARIO 6** | | **SCENARIO 7** | | **SCENARIO 8** | |
| | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. |
| *Phytoplankton* | | | | | | | | | | | | | | | | |
| 1. Species richness. | 70 | M | 70 | M | 70 | M | 70 | M | 70 | M | 70 | M | 65 | M | 60 | M |
| 2a. Abundance. | 75 | M | 75 | M | 75 | M | 75 | M | 75 | M | 75 | M | 70 | M | 65 | M |
| 2b. Community composition. | 70 | M | 70 | M | 70 | M | 70 | M | 70 | M | 70 | M | 70 | M | 65 | M |
| *Benthic microalgae* | | | | | | | | | | | | | | | | |
| 1. Species richness. | 90 | H | 90 | H | 90 | H | 90 | H | 90 | H | 90 | M | 80 | M | 65 | M |
| 2a. Abundance. | 90 | H | 90 | H | 90 | H | 90 | H | 90 | H | 90 | M | 85 | M | 80 | M |
| 2b. Community composition. | 90 | H | 90 | H | 90 | H | 90 | H | 90 | H | 90 | M | 90 | M | 80 | M |
| **Microalgae score** | **70** | | **70** | | **70** | | **70** | | **70** | | **70** | | **65** | | **60** | |

| *Macrophytes* | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **VARIABLE** | **SCENARIO 1** | | **SCENARIO 2** | | **SCENARIO 3** | | **SCENARIO 4** | | **SCENARIO 5** | | **SCENARIO 6** | | **SCENARIO 7** | | **SCENARIO 8** | |
| | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. |
| 1. Species richness. | 80 | M | 80 | M | 80 | M | 80 | M | 80 | M | 80 | M | 80 | M | 75 | M |
| 2a. Abundance. | 60 | M | 60 | M | 60 | M | 60 | M | 60 | M | 60 | M | 60 | M | 60 | M |
| 2b. Community composition. | 75 | M | 75 | M | 75 | M | 75 | M | 75 | M | 75 | M | 75 | M | 70 | M |
| **Macrophyte score.** | **60** | | **60** | | **60** | | **60** | | **60** | | **60** | | **60** | | **60** | |

**Table 5.3 continued…**

| *Invertebrates* | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **VARIABLE** | **SCENARIO 1** | | **SCENARIO 2** | | **SCENARIO 3** | | **SCENARIO 4** | | **SCENARIO 5** | | **SCENARIO 6** | | **SCENARIO 7** | | **SCENARIO 8** | |
| | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. |
| *Zooplankton* | | | | | | | | | | | | | | | | |
| 1. Species richness. | 100 | M | 100 | M | 100 | M | 100 | M | 100 | M | 100 | M | 100 | M | 80 | M |
| 2a. Abundance. | 80 | M | 80 | M | 80 | M | 80 | M | 80 | M | 80 | M | 80 | M | 65 | M |
| 2b. Community composition. | 100 | M | 100 | M | 100 | M | 100 | M | 100 | M | 100 | M | 100 | M | 80 | M |
| *Macroinvertebrates* | | | | | | | | | | | | | | | | |
| 1. Species richness. | 80 | H | 80 | H | 80 | H | 80 | M | 80 | M | 80 | M | 80 | M | 50 | M |
| 2a. Abundance. | 80 | M | 80 | M | 80 | M | 80 | M | 80 | M | 80 | M | 80 | M | 70 | M |
| 2b. Community composition. | 65 | M | 65 | M | 65 | M | 65 | M | 65 | M | 65 | M | 60 | M | 60 | M |
| ***Macrocrustaceans*** | | | | | | | | | | | | | | | | |
| 1. Species richness. | 80 | M | 80 | M | 80 | M | 65 | M | 65 | M | 65 | M | 65 | M | 42 | M |
| 2a. Abundance. | 85 | M | 85 | M | 85 | M | 75 | M | 75 | M | 75 | M | 75 | M | 60 | M |
| 2b. Community composition. | 85 | M | 85 | M | 85 | M | 75 | M | 75 | M | 75 | M | 75 | M | 60 | M |
| **Invertebrate score** | **65** | | **65** | | **65** | | **65** | | **65** | | **65** | | **60** | | **42** | |

| *Fish* | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **VARIABLE** | **SCENARIO 1** | | **SCENARIO 2** | | **SCENARIO 3** | | **SCENARIO 4** | | **SCENARIO 5** | | **SCENARIO 6** | | **SCENARIO 7** | | **SCENARIO 8** | |
| | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. |
| 1. Species richness. | 90 | H | 90 | H | 90 | H | 90 | H | 90 | H | 90 | H | 90 | H | 80 | M |
| 2a. Abundance. | 80 | M | 80 | M | 80 | M | 70 | M | 70 | M | 70 | M | 70 | M | 70 | M |
| 2b. Community composition. | 90 | M | 90 | M | 90 | M | 80 | M | 80 | M | 80 | M | 80 | M | 60 | M |
| **Fish score** | **80** | | **80** | | **80** | | **70** | | **70** | | **70** | | **70** | | **60** | |

| *Birds* | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **VARIABLE** | **SCENARIO 1** | | **SCENARIO 2** | | **SCENARIO 3** | | **SCENARIO 4** | | **SCENARIO 5** | | **SCENARIO 6** | | **SCENARIO 7** | | **SCENARIO 8** | |
| | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. | Score | Conf. |
| 1. Species richness. | 80 | M | 80 | M | 80 | M | 80 | M | 80 | M | 80 | M | 80 | M | 50 | M |
| 2a. Abundance. | 70 | M | 70 | M | 70 | M | 70 | M | 70 | M | 70 | M | 70 | M | 60 | M |
| 2b. Community composition. | 80 | M | 80 | M | 80 | M | 80 | M | 80 | M | 80 | M | 80 | M | 65 | M |
| **Bird score** | **70** | | **70** | | **70** | | **70** | | **70** | | **70** | | **70** | | **50** | |

**Table 5.4 EHI score and corresponding ERC for the different initial and yield scenarios**

| EHI SCORING FOR DIFFERENT INITIAL AND YIELD SCENARIOS | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **COMPONENT** | **INITIAL SCENARIO** | | | | | | | **YIELD SCENARIOS** | | | | | | | |
| | **Present state** | **River Category A** | **River Category B** | **River Category C** | **River Category D** | **Worst Case 1** | **Worst Case 2** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| Hydrology | 87 | 89 | 79 | 74 | 69 | 69 | 69 | 87 | 87 | 87 | 87 | 87 | 87 | 87 | 87 |
| Hydrodynamics | 80 | 100 | 100 | 95 | 95 | 20 | 20 | 100 | 100 | 100 | 95 | 95 | 95 | 90 | 85 |
| Water quality | 54 | 70 | 62 | 58 | 50 | 46 | 46 | 62 | 60 | 58 | 56 | 56 | 56 | 54 | 50 |
| Physical habitat | 80 | 68 | 68 | 68 | 68 | 68 | 68 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 |
| **HABITAT HEALTH SCORE** | **75** | **82** | **77** | **74** | **70** | **51** | **51** | **82** | **82** | **81** | **80** | **80** | **80** | **78** | **76** |
| Microalgae | 65 | 65 | 65 | 65 | 65 | 35 | 35 | 70 | 70 | 70 | 70 | 70 | 70 | 65 | 60 |
| Macrophytes | 60 | 62 | 64 | 67 | 67 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 |
| Invertebrates | 60 | 65 | 65 | 25 | 25 | 17 | 17 | 65 | 65 | 65 | 65 | 65 | 65 | 60 | 42 |
| Fish | 70 | 70 | 70 | 60 | 60 | 40 | 40 | 80 | 80 | 80 | 70 | 70 | 70 | 70 | 60 |
| Birds | 70 | 70 | 70 | 70 | 70 | 25 | 25 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 50 |
| **BIOTA HEALTH SCORE** | **65** | **66** | **67** | **57** | **57** | **35** | **35** | **69** | **69** | **69** | **67** | **67** | **67** | **65** | **54** |
| **EHI SCORE** | **70** | **74** | **72** | **66** | **64** | **43** | **43** | **76** | **75** | **75** | **73** | **73** | **73** | **71** | **65** |
| **CORRESPONDING ERC** | **C+** | **C+** | **C+** | **C-** | **C-** | **D-** | **D-** | **B-** | **C+** | **C+** | **C+** | **C+** | **C+** | **C+** | **C-** |

## Table 5.5 Initial and Yield Scenarios in relation to the Recommended ERC (C+)

| Scenario | State | | Improved from Recommended ERC | | | | | | | | | Worse than Recommended ERC | | | | | | | | | same as for recommended ERC | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | H | HD | WQ | PH | MI | MA | IV | F | B | H | HD | WQ | PH | MI | MA | IV | F | B | H | HD | WQ | PH | MI | MA | IV | F | B |
| **River A** | C+ | ? | ? | | ? | | | | | | | | | | | | ? | | | | | ? | | ? | ? | | ? | ? | ? |
| **River B** | C+ | ? | | | | | | | | | | | | | | | | | | | ? | ? | ? | ? | ? | ? | ? | ? | ? |
| **River C** | C- | ? | | | | | | ? | | | | ? | ? | ? | | | | ? | ? | | | | | ? | ? | | | | ? |
| **River D** | C- | ? | | | | | | ? | | | | ? | ? | ? | | | | ? | ? | | | | | ? | ? | | | | ? |
| **Worst 1** | D- | ? | | | | | | | | | | ? | ? | ? | | | ? | ? | ? | ? | | | | ? | ? | | | | |
| **Worst 2** | D- | ? | | | | | | | | | | ? | ? | ? | | | ? | ? | ? | ? | | | | ? | ? | | | | |
| **Yield 1** | B- | ? | ? | | | ? | | | | ? | | | | | | ? | ? | | | | | ? | ? | | | | ? | | ? |
| **Yield 2** | C+ | ? | ? | | | ? | | | | ? | | | | ? | | ? | ? | | | | | ? | | | | | ? | | ? |
| **Yield 3** | C+ | ? | ? | | | ? | ? | | | ? | | | | ? | | | ? | | | | | ? | | | | | ? | | ? |
| **Yield 4** | C+ | ? | ? | | | ? | ? | | | | | | ? | ? | | | ? | | | | | | | | | | ? | ? | ? |
| **Yield 5** | C+ | ? | ? | | | ? | ? | | | | | | ? | ? | | | ? | | | | | | | | | | ? | ? | ? |
| **Yield 6** | C+ | ? | ? | | | ? | ? | | | | | | ? | ? | | | ? | | | | | | | | | | ? | ? | ? |
| **Yield 7** | C+ | ? | ? | | | ? | | | | | | | ? | ? | | | ? | ? | | | | | | | ? | | | ? | ? |
| **Yield 8** | C- | ? | ? | | | ? | ? | | | | | | ? | ? | | | ? | ? | ? | ? | | | | | | | | | |

H = Hydrology
PH = Physical habitat alteration
IV = Invertebrates
HD = Hydrodynamics/Mouth Conditions
MI = Micoalgae
F = Fish
WQ = Water quality
MA = Macrophytes;
B = Birds

? No change from Present State
? Less modified than Present State
? More modified than Present State

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