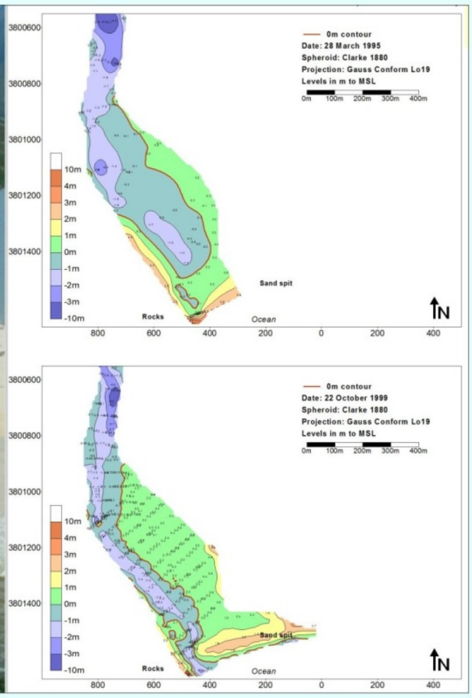
Report No: P WMA 19/G10/00/2413/2

DEPARTMENT OF WATER AFFAIRS
DIRECTORATE : OPTIONS ANALYSIS

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

## Report No 1 : Ecological Water Requirement Assessments

## Volume 2 : Rapid Determination of the Environmental Water Requirements of the Palmiet River Estuary




**Final**

**June 2012**

**Department of Water Affairs**
**Directorate: Options Analysis**

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

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## APPROVAL

| | | |
|---|---|---|
| **Title** | : | Ecological Water Requirement Assessments<br>Rapid Determination of the Environmental Water Requirements of the Palmiet River Estuary |
| **Consultants** | : | Western Cape Water Consultants Joint Venture |
| **Report status** | : | Final |
| **Date** | : | June 2012 |

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This report is to be referred to in bibliographies as:

Department of Water Affairs, South Africa. 2012. *Report No.1 : Ecological Water Requirement Assessments, Volume 2 – Rapid Determination of the Environmental Water Requirements of the Palmiet River Estuary.* Prepared by Western Cape Water Consultants Joint Venture, as part of the Pre-feasibility and Feasibility Studies for Augmentation of the Western Cape Water Supply System by Means of Further Surface Water Developments.

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## STUDY REPORT LIST

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| 1 | **ECOLOGICAL WATER REQUIREMENT ASSESSMENTS** | Vol 1 | PWMA19 G10/00/2413/1 | **Riverine Environmental Water Requirements** |
| | | | | Appendix 1: EWR data for the Breede River |
| | | | | Appendix 2: EWR data for the Palmiet River |
| | | | | Appendix 3: EWR data for the Berg River |
| | | | | Appendix 4: Task 3.1: Rapid Reserve assessments (quantity) for the Steenbras, Pombers and Kromme Rivers |
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| | | Vol 2 | PWMA19 G10/00/2413/2 | **Rapid Determination of the Environmental Water Requirements of the Palmiet River Estuary** |
| | | | | Appendix A: Summary of data available for the RDM investigations undertaken during 2007 and 2008 |
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| | | Vol 3 | PWMA19 G10/00/2413/3 | **Berg Estuary Environmental Water Requirements** |
| | | | | Appendix A: Available information and data |
| | | | | Appendix B: Measurement of streamflows in the Lower Berg downstream of Misverstand Dam |
| | | | | Appendix C: Specialist Report – Physical dynamics and water quality |
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| | | | | Appendix 6: Voëlvlei Dam Water Quality Assessment |
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| | | | | Appendix 4: Dispersion Modelling in Voëlvlei Dam from Berg River Water Transfers for the Berg River-Voëlvlei Augmentation Scheme |
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| 4 | **RECORD OF IMPLEMENTATION DECISIONS** | | PWMA19 G10/00/2413/7 | |

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Riverine Environmental Water Requirements
*PWMA19 G10/00/2413/1*
- Data (Electronic format)
- Rapid Reserves (Steenbras, Pombers, Kromme Rivers)
- Habitat Integrity (Breede River)

Rapid Determination of the Environmental Water Requirements of the Palmiet River Estuary
*PWMA19 G10/00/2413/2*
- Existing Data Availability
- Baseline Data Requirements and Monitoring Programme
- Abiotic Assessment

Berg Estuary Environmental Water Requirements
*PWMA19 G10/00/2413/3*
- Available Information and Data
- Measurement of Streamflows in the Lower Berg
- Physical Dynamics and Water Quality
- Modelling
- Microalgae
- Invertebrates
- Fish
- Birds
- Economic Value of the Estuary

**PRELIMINARY ASSESSMENT OF OPTIONS**
*PWMA19 G10/00/2413/4*
- Scheme Yield Assessments and Diversion Functions
- Unit Reference Value Calculation Sheets
- Yield Analysis and Dam Size Optimization
- Dam Design Inputs
- Diversion Weir Layout Drawings
- Voëlvlei Dam Water Quality Assessment
- Botanical Considerations
- Heritage Considerations
- Agricultural Economic Considerations

### PHASE 2: FEASIBILITY STUDIES

**BERG RIVER VOËLVLEI AUGMENTATION SCHEME**
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- Ecological Water Requirements Summary
- Geotechnical Investigations
- Aerial Survey
- Conveyance Infrastructure Design
- Diversion Weirs Design
- Cost Estimates

### IMPLEMENTATION DECISION SUPPORT

**RECORD OF IMPLEMENTATION DECISIONS**
*PWMA19 G10/00/2413/7*

## ACKNOWLEDGEMENTS

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# EXECUTIVE SUMMARY

The Palmiet Estuary is a small system located 75 km south east of Cape Town.

The estuary is in a good condition, although mean annual run-off has been reduced by 36.1% relative to natural.

The **Present Ecological Status** of the estuary is a **C**. Major drivers of change in the system were a significant reduction in river inflow (floods and baseflows), increased mouth closure; reduced sediment scouring and an increased nutrient load from the catchment. Of special concern were the occurrence of macrophytes blooms in the estuary as a result of increase nutrients, reduce baseflow and closed (or semi-closed) mouth conditions. Die-off of these macrophyte blooms causes hypoxic or anoxic conditions in the estuary, which in turn puts the rest of the ecosystem under stress. An additional concern was the long periods of artificial droughts the estuary were currently experiencing and the impact this would have on fish recruitment.

The overall **Estuarine Importance Score** for the Palmiet Estuary, based on its present state, is **58**, signifying that the estuary is of **average importance**.

The Palmiet Estuary abuts the Kogelberg Biosphere, and is included in a core set of estuaries that needs to be protected to meet biodiversity targets in South Africa.

The pressures currently contributing to the degraded health of the Palmiet Estuary are poor water quality and reduction in river inflow in summer, which can be easily mitigated. Thus, the **REC for the Palmiet Estuary is a Category B.**

Hydrological data were provided by Aurecon Consulting Engineers for the Reference Conditions, Present State and Scenarios 1 to 4. Scenario 5 and 6 were generated at the EWR workshop and represent minor changes to the Present State.

| Scenario name | MAR (million $m^3$) | % Remaining | Description |
|---|---|---|---|
| Reference Condition | 256.3 | 100 | Natural (~ 100 to 150 years ago) |
| Present State | 163.7 | 63.9 | Current level of catchment development |
| Scenario 1 | 185.2 | 72.2 | Minimum Degradation - Campanula Dam |
| Scenario 2 | 161.3 | 62.9 | Different pump rates |
| Scenario 3 | 148.7 | 58.0 | No EWR releases and Lower Steenbras raised |
| Scenario 4 | 111.18 | 43.4 | Lower Steenbras raised, Campanula Dam and no EWR releases |
| Scenario 5 | 163.7 | 63.9 | Similar to Present State, with a 66 % reduction in nutrient input from the catchment |
| *Scenario 6 | 161.3 | 62.9 | Similar to Scenario 2, but elevate base flows, with flows <1.0 $m^3s^{-1}$ occurring for 22 % of the time, i.e. flows not less than 1.0 $m^3s^{-1}$ for longer than 3 months in a year. |

The recommended Ecological Water Requirement is defined as the runoff scenario (or a slight modification thereof) that represents the highest reduction in river inflow that will still protect the aquatic ecosystem of the estuary and keep it in the recommended EC.

In evaluating Scenarios 1 to 4, it was assumed that only river inflow from the Palmiet Catchment would be modified and that other related anthropogenic activities (e.g. fishing, bait collection and human disturbance) will remain at present levels.

| Variable | Weight | Present | Future Runoff Scenario | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 |
| Score | | 67 | 69 | 66 | 66 | 59 | 68 | 76 |
| Category | | C | C | C | C | D | C | B |

**Scenario 6 was selected as the recommended Ecological Water Requirement for the Palmiet Estuary**. A summary of flow distributions for the recommended ecological flow scenario (Scenario 6) is provided below.

| | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 99%ile | 20.44 | 8.79 | 3.58 | 2.81 | 2.35 | 2.44 | 6.71 | 12.85 | 25.23 | 43.50 | 36.36 | 27.49 |
| 90%ile | 10.43 | 3.90 | 1.43 | 0.82 | 0.83 | 1.05 | 3.53 | 7.91 | 19.45 | 22.70 | 26.15 | 17.93 |
| 80%ile | 6.61 | 2.52 | 1.00 | 0.57 | 0.68 | 0.81 | 2.06 | 5.38 | 12.39 | 17.16 | 19.62 | 13.37 |
| 70%ile | 5.89 | 1.98 | 1.00 | 0.52 | 0.54 | 0.56 | 1.50 | 4.34 | 9.39 | 13.35 | 16.73 | 11.27 |
| 60%ile | 4.52 | 1.66 | 1.00 | 0.52 | 0.52 | 0.51 | 1.19 | 3.78 | 8.25 | 11.40 | 15.80 | 9.75 |
| 50%ile | 3.66 | 1.47 | 1.00 | 0.52 | 0.49 | 0.44 | 1.00 | 3.12 | 7.03 | 9.91 | 13.54 | 7.91 |
| 40%ile | 3.17 | 1.36 | 1.00 | 0.45 | 0.34 | 0.33 | 1.00 | 2.56 | 5.46 | 8.88 | 11.20 | 6.58 |
| 30%ile | 2.81 | 1.20 | 1.00 | 0.35 | 0.32 | 0.30 | 1.00 | 2.13 | 4.14 | 6.64 | 9.94 | 6.05 |
| 20%ile | 2.40 | 1.00 | 1.00 | 0.32 | 0.29 | 0.27 | 1.00 | 1.60 | 3.57 | 5.43 | 8.43 | 5.67 |
| 10%ile | 1.76 | 1.00 | 1.00 | 0.28 | 0.26 | 0.25 | 1.00 | 1.30 | 2.56 | 4.63 | 7.01 | 5.05 |
| 1%ile | 1.22 | 1.00 | 1.00 | 0.10 | 0.08 | 0.12 | 1.00 | 1.00 | 1.27 | 3.00 | 5.02 | 3.95 |

Note that an increase in river inflow in itself (i.e. Scenario 6) would not be sufficient to ensure the recommended level of estuarine functioning. The following restoration measures are required to improve the present health of the Palmiet Estuary:

- Manage anthropogenic nutrient and organic matter inputs to the estuary through improved agricultural and urban landscape management;
- Improve the compliance monitoring of fishing and bait collection activities on the estuary. This will assist in controlling illegal harvesting of the estuarine living resources. At present recreational angling (and the occasional gillnetting) accounts for approximately 0.2 tonne annually. This includes the requirement for improved control of the harvesting of eels from the catchment.
- Restrict bait collection when the mouth is closed, since recruitment cannot occur during extended periods of mouth closure as it leads to the depletion of important food resources in the estuary.
- Install a fish ladder at the gauging weir and an eelway at the dams to facilitate migration of fishes into the lower river reaches.

Any assessment of future water-resource developments should also include an evaluation of the success of the implementation of these non-flow related mitigation measures in restoring the habitat and protecting biota.

The setting and achievement of national management objectives for the Palmiet Estuary will require a high level of co-operative governance between the various management authorities.

Lastly, it is recommended that a Palmiet Estuarine Management Plan be developed.

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# GLOSSARY AND ABBREVIATIONS

| | |
|---|---|
| CCT | |
| CD | Chief Directorate |
| CSIR | Centre of Scientific and Industrial Research |
| DAFF | Department of Agriculture, Forestry and Fisheries |
| DEA | Department of Environmental Affairs |
| DIN | Dissolved Inorganic Nitrogen |
| DRP | Dissolved Reactive Phosphate |
| DRS | Dissolved Reactive Silicate |
| DWA | Department of Water Affairs |
| EHI | Estuarine Health Index |
| ERC | Ecological Reserve Category |
| MAR | Mean Annual Runoff |
| MCM | Million Cubic Metres |
| MCM/a | Million Cubic Metres per annum |
| MSL | Mean Sea Level |
| NMMU | Nelson Mandela Metropolitan University |
| PES | Present Ecological Status |
| ppt | part per thousand |
| PSP | Professional Service Provider |
| RDM | Resource Directed Measures |
| REI | River Estuary Interface |
| RQO | Resource Quality Objectives |

# 1 INTRODUCTION

## 1.1 BACKGROUND

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

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

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

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

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

Southern Waters sub-consulted CSIR, on behalf of the JV, to undertake a rapid Ecological Water Requirement (EWR) determination for the Palmiet River Estuary.

### *1.1.1 Ecological Water Requirements and the Ecological Reserve*

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

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

## 1.2 OBJECTIVES OF THE REPORT

This report provides the background data and deliberations for the preliminary Ecological Water Requirement (EWR) study on the Palmiet Estuary. The study was done at a **RAPID** level.

## 1.3 ESTUARINE SPECIALIST TEAM

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

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

| Role/Expertise | Lead specialists | Contact details |
|---|---|---|
| Workshop coordination, Report preparation and hydrodynamics | Ms Lara van Niekerk | CSIR, Stellenbosch, lvnieker@csir.co.za |
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| Water quality | Ms Susan Taljaard | CSIR, Stellenbosch, staljaar@csir.co.za |
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| Birds | Dr Jane Turpie | Anchor Environmental Consultants jane.turpie@uct.ac.za |

## 1.4 OVERVIEW OF THE PROCESS FOR DETERMINATION OF THE ECOLOGICAL RESERVE FOR ESTUARIES

The preliminary determination of the EWRs for estuaries can be conducted on different levels, namely:

- Comprehensive;
- Intermediate; and
- Rapid.

The procedures are discussed in detail in *Resource directed measures for protection of water resources: Methodology for the Determination of the Ecological Water Requirements for Estuaries, Version 2* (DWAF 2004). The procedure for the Rapid level determination for estuaries is summarised in the Figure 1.1.

A summary of the human resource requirements to conduct a Rapid level determination is illustrated in Figure 1.2.

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## 1.5 ASSUMPTIONS AND LIMITATIONS OF THE STUDY

The following assumptions and limitations should be taken into account:

- No new data were collected as part of this study. All assumptions made as part of this assessment are based on historical data and expert opinion.
- The overall confidence in the hydrological data provided to the estuarine team by Aurecon Consulting Engineers was high.
- The accuracy of the predicted abiotic states for the Palmiet Estuary and the distribution of these states under the reference condition, present state and future flow scenarios depend largely on the accuracy of the simulated runoff data and measured flow data.

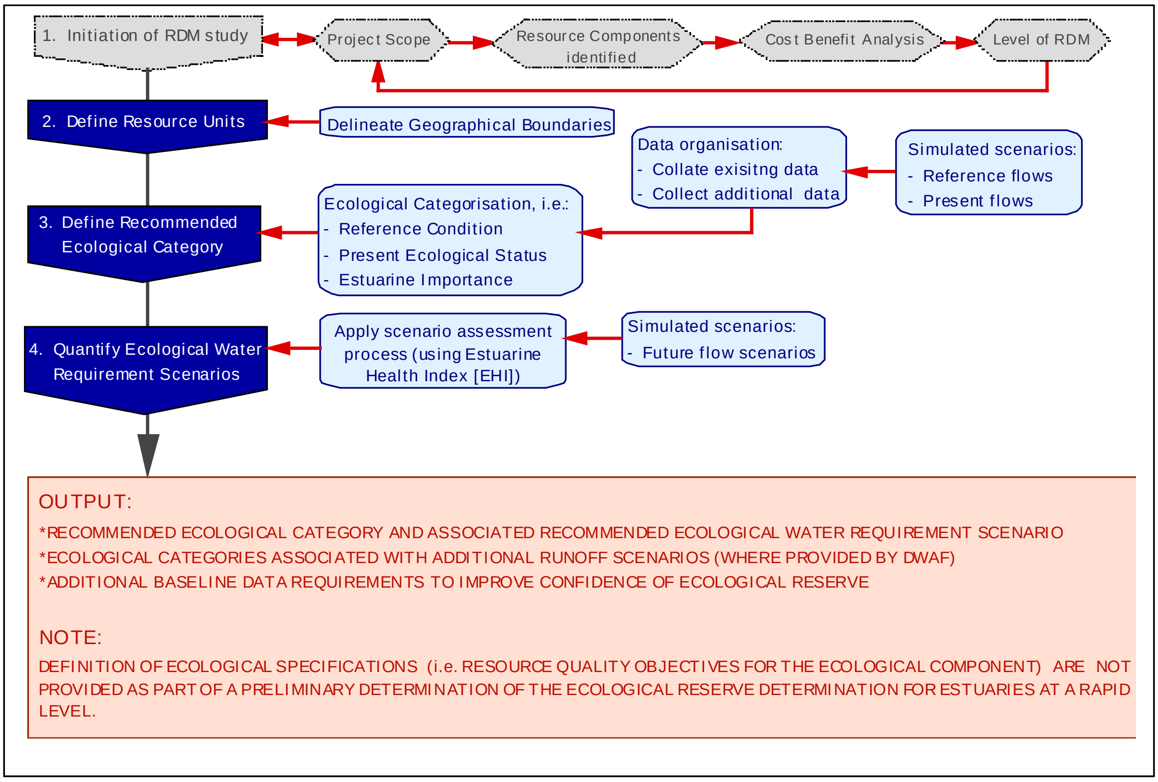



**Figure 1.1 Procedures for a rapid EWR determination for estuaries, in context of the broader RDM process (components not addressed as part of the ecological reserve determination process are indicated by hatched line boxes) (DWAF 2004)**

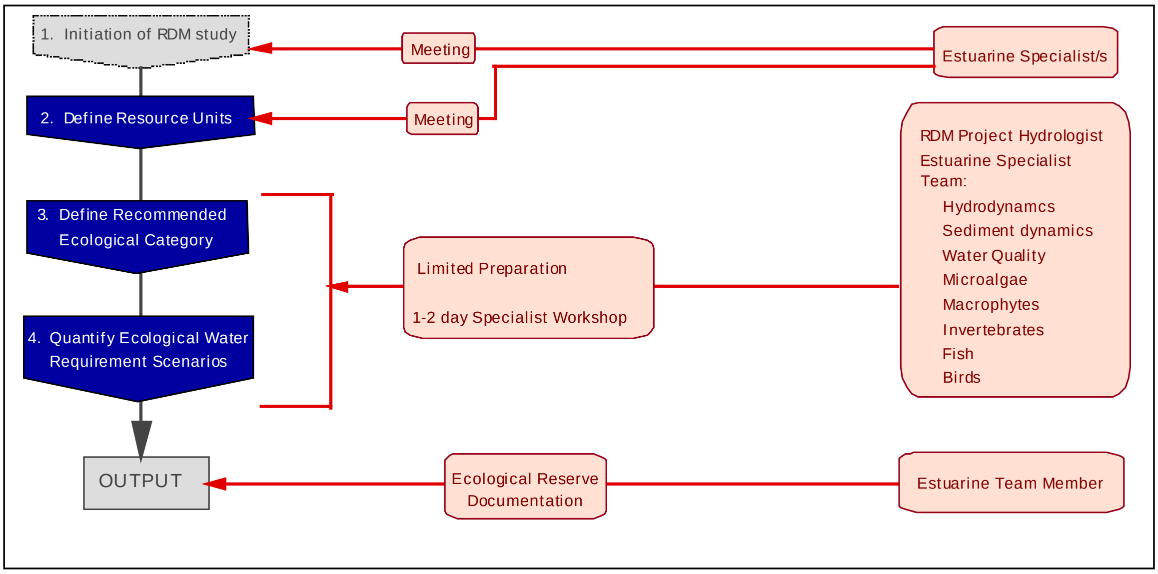



**Figure 1.2 Indication of human resource requirements for a rapid EWR determination for estuaries (DWAF 2004)**

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

**Table 1.2 Confidence limits for an estuarine EWR study**

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

## 1.6 REPORT OUTLAY

The Palmiet Estuary EWRs report is divided into following chapters:

- **Chapter 2: Definition of Resource Unit.** This chapter provides a brief description of the Palmiet Estuary and the area covered by the study.
- **Chapter 3: Ecological Reserve Categorisation.** Chapter three discusses the dominant abiotic states associated with the estuary and links these states to the various flow rates experienced within the estuary. The chapter further describes the present state of the system in comparison to the reference condition. This chapter concludes with scoring the Present Ecological Status (PES) of the estuary using the Estuarine Health Index. This score gives a measure of how healthy the estuary is in its present state.
- **Chapter 4: Recommended Ecological Category for Palmiet Estuary.** Chapter 4 uses a range of measures to establish how important the Palmiet Estuary is from a biological and conservation point of view. The final score determines the Recommended Ecological Category of the estuary. It should be noted that this Recommended Ecological Category (REC) is a biological recommendation only and does NOT take into consideration the socio-economic factors associated with integrated water management and therefore the final reserve.
- **Chapter 5: Quantification of Ecological Reserve Scenarios.** In this chapter a range of flow scenarios are examined to establish the impact that they will have on the Estuarine Health Indices (EHI) score. As outlined in the 2004 RDM estuary methods it is imperative that a full range of water resources development scenarios are reviewed to ensure that the correct sensitivity in analysis is achieved. Where possible operational scenarios are used, i.e., scenarios that are plausible and which have been motivated by water resource planners. However in order to achieve a full spread of scenarios some hypothetical options are also included (normally associated with extreme abstraction scenarios) to secure the required spread.
- **Chapter 6: Recommended Ecological Flow Requirements for the Palmiet Estuary.** This chapter discusses all of the scenarios and recommends the Ecological Flow Requirement for the system as well as outlining key non-flow related activities which impact on the health of the estuary.
- **Chapter 7: Cooperative Governance.** Chapter 7 highlights the importance of Co-operative governance in achieving the REC. It also briefly touch on the various roles and responsibilities of the authorities mandated with estuarine resource management with regards to the Palmiet.
- **Chapter 8: Ecological Specifications.** In this chapter Ecological Specifications and Thresholds of potential concern (TPC) are defined for the various abiotic and biotic components to prompts management action if required.
- **Chapter 9: Monitoring Requirements.** This chapter highlights the baseline data requirements to increase the overall confidence of the study and the long-term monitoring needs to identify change and trends in ecosystem processes and function of the Palmiet Estuary.
- **Chapter 10: Long-term Monitoring Decision Support System (DSS).** Chapter 10 provides a brief summary of the proposed monitoring decision support system for the Palmiet Estuary

# 2 DEFINITION OF RESOURCE UNIT

## 2.1 INTRODUCTION

The Palmiet Estuary, located 75 km south east of Cape Town, is a small system 1.67-km long and *c*. 300 m at its widest point (Figure 2.1). The head of the estuary is marked by a series of rocky sills. The channel meanders between steep rocky banks in the upper reaches of the estuary, and scour holes (4-5 m) are located on the outer bends of these meanders. From *c*. 700 m upstream of the mouth, the channel hugs the west bank and there are broad, shallow tidal flats on the eastern side (CSIR 1992).

The mouth is located close to a rocky bank on the western side. Prevailing westward longshore currents and the SSW and WSW high-energy waves result in an extensive mobile sand spit on th eastern side of the mouth.

The estuary is in a good condition. However, based on the simulated run-off data provided for this project, it is estimated that the mean annual run-off has been reduced by 36.1%, from 256.3 x $10^6$ $m^3a^{-1}$ under natural conditions to 163.7 x $10^6$ $m^3a^{-1}$ in 2009. The runoff from the catchment shows strong seasonal variations with high flows and major floods during the winter months, and low flows during the summer months.


**Figure 2.1 Google image showing the boundaries of the Palmiet Estuary**

## 2.2 GEOGRAPHICAL BOUNDARY

For the purposes of this rapid level EWR determination for the Palmiet Estuary, the geographical boundaries were defined as follows (Figure 2.1):

| | |
|---|---|
| **Downstream boundary:** | Estuary mouth (34°20'43.55"S 18°59'40.29"E) |
| **Upstream boundary:** | 1.67 km from the mouth (34°19'53.67"S 18°59'28.42" E) to the extent of tidal influence |
| **Lateral boundaries:** | 5-m contour above Mean Sea Level (MSL) along each bank |

# 3 ECOLOGICAL RESERVE CATEGORISATION

## 3.1 TYPICAL ABIOTIC STATES

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

**Table 3.1 Summary of the abiotic states that can occur in the Palmiet Estuary**

| State | Name | Flow range ($m^3s^{-1}$) |
|---|---|---|
| 1 | Closed mouth: No exchange through the mouth (usually during the dry season) | < 0.15 |
| 2 | Semi-open mouth: No seawater intrusion, but with water flowing out to sea (usually during the dry season) | 0.15 -1.0 |
| 3 | Highly stratified, with significant marine influence: Open mouth with extensive seawater intrusion (usually during the dry season); | 1.0 – 10.0 |
| 4 | Highly stratified, with significant freshwater influence: Open mouth with limited seawater intrusion and strong river influence (usually during the wet season) | 10.0 – 20.0 |
| 5 | Freshwater dominated: Open mouth with no seawater intrusion and very strong river influence (i.e. river or fluvially dominated) (usually during the wet season) | > 20.0 |

The transitions between the different states are gradual.

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

- Colour coding for the full tables of simulated monthly river flow reaching the estuary for each scenario to highlight the occurrences of the different abiotic states related to the different flow ranges.
- Separate summary tables of the occurrences of different flows at increments of the 10%ile to provide a quick comprehensive overview.
- the median (50%ile) and drought flows (10%ile) monthly flows used to provide a conceptual overview of the annual distribution of abiotic states under the different scenarios.

The abiotic characteristics for the different states are summarised in Table 3.2. For a more detailed discussion refer to the Abiotic Specialist Report (Appendix B).

The five characteristic abiotic states identified for the Palmiet Estuary, related to tidal exchange, salinity distribution and water quality.

A schematic representation of the circulation features of each of the states is provided in **Figure 3.1**.

## Table 3.2 Summary of typical physical and water quality characteristics of different abiotic states in the Palmiet Estuary

| PARAMETER | STATE 1 | STATE 2 | STATE 3 | STATE 4 | STATE 5 |
|---|---|---|---|---|---|
| ***River flow ($m^3s^{-1}$)*** | **< 0.05** | **Usually when flows < 1**<br>(refer to **Table 3.5**) | **1 - 10** | **10 - 20** | **> 20** |
| ***Mouth condition*** | **Closed** | **Semi-closed** | **Open**<br>**(**with extensive sea water intrusion) | **Open**<br>(with limited seawater intrusion on the flood tide and strong river influence) | **Open**<br>(with no seawater intrusion and very strong river influence) |
| ***Water level variation*** | **None** | **None** | **0.3** m<br>(could drop up to 0,5 m lower during low tide after freshet) | **0.3** m<br>(could drop up to 0,5 m lower during low tide after freshet) | **Backing up effect** |
| ***Inundation*** | **Limited inundated** | **Intertidal area inundated** | **None** | **None** | **Intertidal and Floodplain inundated during peak flows** |
| ***Circulation*** | **Wind mixing** | **Entrainment** | **Tidal** | **Freshwater flushing and Tidal** | **Freshwater flushing** |
| ***Salinity (ppt)**** | After storm<br>15, 15<br>30, 30<br>or<br>5, 5<br>5, 10<br>After state 2 | < 1 month<br>15, 15<br>20, 25<br>or<br>5, 5<br>5, 15<br>> 1 month | 20, 15<br>35, 30 | 0, 0<br>25, 10 | 0, 0<br>0, 0 |
| ***Temperature ($^oC$)*** | **8 – 26**<br>(usually summer) | **18 – 26**<br>(usually summer) | **12 – 26**<br>(usually summer, lower range saline waters during occasional upwelling) | **12 -17**<br>(usually winter) | **13 – 15**<br>(usually winter) |
| ***pH*** | **7 - 8** | **7 – 8** | **7 - 8** | **<6 – 8** | **< 6** |
| ***DO ($mg.l^{-1}$)*** | >6, >6<br>2-6, <2 | Reference<br>>6, >6<br>2-6, <2<br>or<br>>6, >6<br>2-6, 2-6<br>Present, persists >2 months | >6, >6<br>>6, >6 | >6, >6<br>>6, >6 | >6, >6<br>>6, >6 |
| ***Transparency** (Sechhi depth in m)*** | 1-2, 1-2<br>1-2, 1-2 | 1-2, 1-2<br>1-2, 1-2 | >2, 1-2<br>>2, >2 | 1-2, 1-2<br>1-2, 1-2 | 1-2, 1-2<br>1-2, 1-2 |

| PARAMETER | STATE 1 | STATE 2 | STATE 3 | STATE 4 | STATE 5 |
|---|---|---|---|---|---|
| ***DIN (μg.l$^{-1}$)*** | Reference<br>**<50 · <50**<br>**<50 · <50**<br>**or**<br>**<50 · 50-300**<br>**<50 · <50**<br>Present | Reference<br>**<50 · <50**<br>**<50 · <50**<br>**or**<br>**50-300 · 50-300**<br>**<50 · <50**<br>Present (higher levels linked to river input) | Reference (higher levels linked to upwelling)<br>**50-300 · <50**<br>**50-300 · 50-300**<br>**or**<br>**50-300 · □0-300**<br>**50-300 · 50-300**<br>Present ((higher levels linked to upwelling and river input) | Reference<br>**<50 · <50**<br>**<50 · <50**<br>**or**<br>**>300 · >300**<br>**<50 · >300**<br>Present (high levels linked to river input) | Reference<br>**<50 · <50**<br>**<50 · <50**<br>**or**<br>**>300 · >300**<br>**>300 · >300**<br>Present (high levels linked to river input) |
| ***DIP (μg.l$^{-1}$)*** | **<10 · <10**<br>**<10 · <10** | **<10 · <10**<br>**<10 · <10** | **10-50 · <10**<br>**10-50 · 10-50**<br>(higher levels linked to upwelling) | Reference<br>**<50 · <50**<br>**<50 · <50**<br>**or**<br>**10-50 · 10-50**<br>**<10 · 10-50**<br>Present (high levels linked to river input) | Reference<br>**<50 · <50**<br>**<50 · <50**<br>**or**<br>**10-50 · 10-50**<br>**10-50 · 10-50**<br>Present (high levels linked to river input) |
| ***DRS (μg.l$^{-1}$)*** | **500-1000 · 500-1000**<br>**<500 · <500** | **500-1000 · 500-1000**<br>**<500 · <500** | **500-1000 · 500-1000**<br>**<500 · <500** | **>1000 · >1000**<br>**<500 · >1000**<br>(high levels linked to river input) | **>1000 · >1000**<br>**>1000 · >1000**<br>(high levels linked to river input) |

* *For the purposes of summarising typical salinity distributions, the system was sub-divided into 4 sections representing the lower (0-800 m) and upper (800 – 1 800 m) estuary (moving upstream from the mouth left to right) and into surface (water depth < 1.5 m) and bottom (water depth > 1.5 m) waters (top, left also represents the intertidal area – sand flats)*

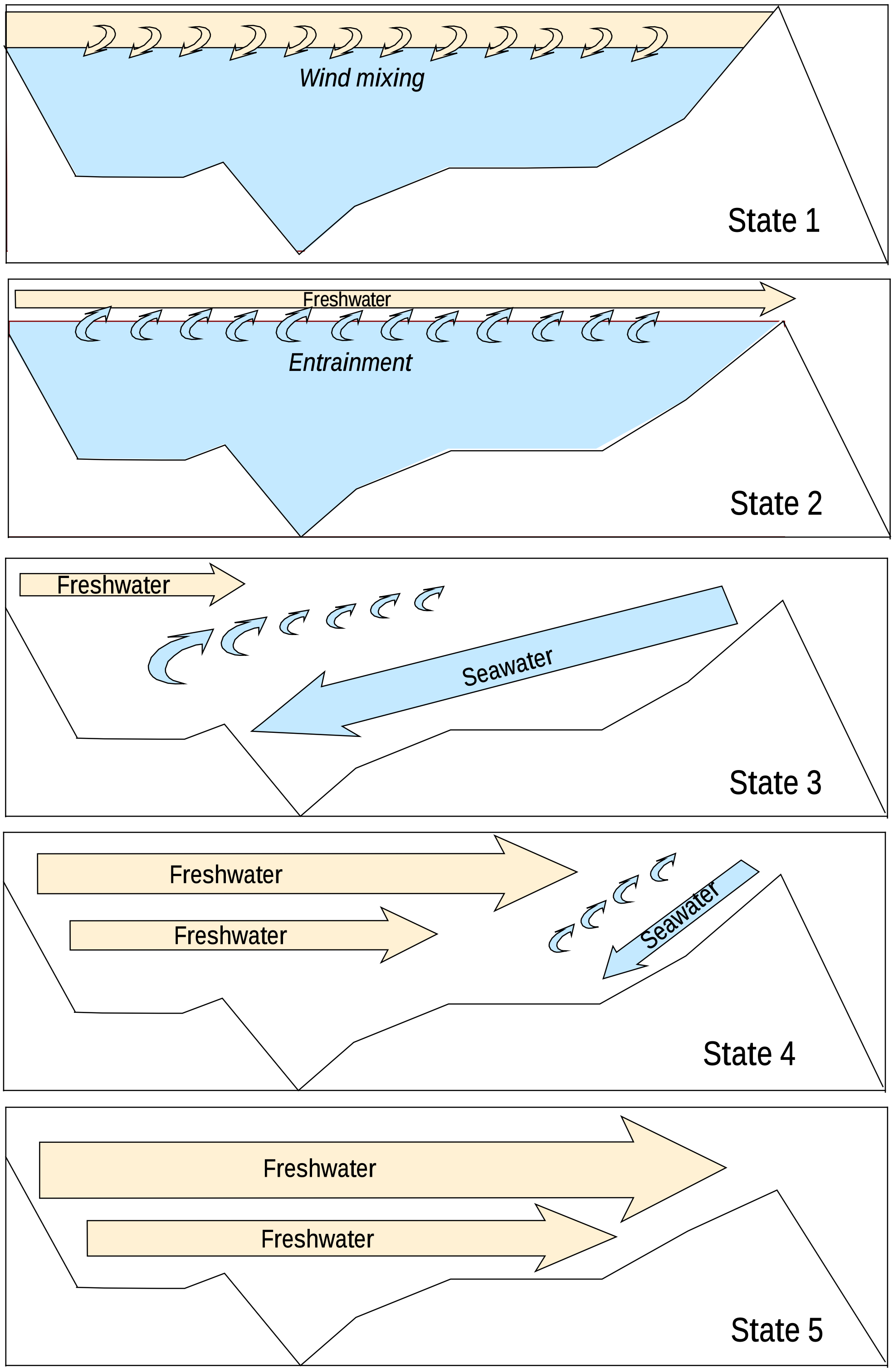



Figure 3.1 Schematic representation of the key circulation features of the five abiotic states of the Palmiet Estuary (after Van Ballegooyen et al. 2004)

## 3.2 DESCRIPTION OF THE PRESENT STATE

### *3.2.1 Abiotic Components*

#### 3.2.1.1 Seasonal variability in river inflow

The mean annual runoff (MAR) into the Palmiet Estuary is, according to the hydrological data provided for this study 163.7 million $m^3$. This is a reduction of 36.1% compared with the natural MAR of 256.3 million $m^3$.

The occurrences of flow distributions (mean monthly flows in $m^3s^{-1}$) for the present state of the Palmiet Estuary, derived from a 77-year simulated data set are provided in Table 3.3. The full 77-year series of simulated monthly runoff data for the present state is provided in Table 3.4. A graphic representation of the occurrence of the various abiotic states is presented in Figure 3.2.

**Table 3.3 A summary of the monthly flow ($m^3s^{-1}$) distribution under the Present State**

| | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 99%ile | 20.44 | 8.79 | 3.58 | 2.81 | 2.35 | 2.44 | 6.71 | 12.85 | 25.58 | 43.56 | 36.36 | 27.49 |
| 90%ile | 11.40 | 3.90 | 1.43 | 0.82 | 0.83 | 1.05 | 3.53 | 7.91 | 19.69 | 23.38 | 26.15 | 18.69 |
| 80%ile | 6.84 | 2.52 | 0.86 | 0.57 | 0.68 | 0.81 | 2.06 | 5.38 | 12.63 | 17.56 | 20.33 | 13.41 |
| 70%ile | 5.89 | 1.98 | 0.74 | 0.52 | 0.54 | 0.57 | 1.50 | 4.34 | 9.39 | 13.56 | 16.77 | 12.18 |
| 60%ile | 4.52 | 1.66 | 0.67 | 0.52 | 0.52 | 0.52 | 1.19 | 3.78 | 8.25 | 11.61 | 16.08 | 9.89 |
| 50%ile | 3.66 | 1.47 | 0.60 | 0.52 | 0.50 | 0.44 | 0.97 | 3.12 | 7.03 | 9.91 | 13.54 | 8.30 |
| 40%ile | 3.17 | 1.36 | 0.56 | 0.46 | 0.34 | 0.33 | 0.74 | 2.56 | 5.46 | 8.88 | 11.20 | 6.70 |
| 30%ile | 2.81 | 1.20 | 0.54 | 0.35 | 0.32 | 0.30 | 0.57 | 2.13 | 4.14 | 6.74 | 9.94 | 6.10 |
| 20%ile | 2.40 | 1.00 | 0.52 | 0.32 | 0.29 | 0.27 | 0.48 | 1.61 | 3.57 | 5.43 | 8.64 | 5.67 |
| 10%ile | 1.82 | 0.89 | 0.44 | 0.28 | 0.26 | 0.25 | 0.33 | 1.33 | 2.56 | 4.63 | 7.23 | 5.05 |
| 1%ile | 1.22 | 0.61 | 0.33 | 0.10 | 0.08 | 0.12 | 0.25 | 0.70 | 1.32 | 3.00 | 5.02 | 3.95 |

**Table 3.4 Simulated monthly flows to the Palmiet Estuary for the Present State ($m^3s^{-1}$)**

| YEAR | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1928 | 2.41 | 0.96 | 0.70 | 0.52 | 0.52 | 0.26 | 1.52 | 2.72 | 3.39 | 10.94 | 12.33 | 6.11 |
| 1929 | 1.24 | 0.73 | 0.52 | 0.39 | 0.47 | 0.50 | 0.48 | 0.53 | 1.36 | 2.73 | 5.79 | 13.43 |
| 1930 | 6.50 | 1.81 | 0.78 | 0.31 | 0.34 | 0.28 | 2.67 | 3.36 | 2.00 | 5.84 | 15.72 | 13.32 |
| 1931 | 11.21 | 2.07 | 0.70 | 0.46 | 0.86 | 0.55 | 0.33 | 3.18 | 7.72 | 9.88 | 8.39 | 13.22 |
| 1932 | 5.90 | 1.07 | 0.51 | 0.33 | 0.31 | 0.29 | 0.32 | 1.43 | 10.09 | 12.23 | 18.19 | 6.36 |
| 1933 | 2.84 | 0.97 | 0.39 | 0.26 | 0.33 | 0.32 | 0.30 | 1.57 | 2.13 | 4.44 | 10.70 | 8.98 |
| 1934 | 8.51 | 1.99 | 0.52 | 0.27 | 0.27 | 0.48 | 1.32 | 4.35 | 5.92 | 6.76 | 5.60 | 6.03 |
| 1935 | 2.42 | 1.64 | 0.74 | 0.99 | 0.74 | 0.58 | 0.53 | 2.91 | 3.65 | 5.44 | 10.54 | 6.76 |
| 1936 | 2.89 | 1.85 | 1.38 | 0.71 | 0.34 | 0.38 | 0.97 | 2.82 | 16.62 | 24.00 | 15.07 | 5.66 |
| 1937 | 2.79 | 1.07 | 0.54 | 0.52 | 0.52 | 0.37 | 1.68 | 4.10 | 2.87 | 4.18 | 7.88 | 12.28 |
| 1938 | 4.95 | 1.37 | 0.57 | 0.31 | 0.80 | 0.65 | 1.15 | 3.28 | 2.09 | 5.23 | 12.15 | 6.03 |
| 1939 | 1.62 | 1.23 | 0.65 | 0.34 | 1.15 | 0.84 | 2.94 | 4.28 | 9.00 | 7.08 | 5.82 | 8.32 |
| 1940 | 2.39 | 2.52 | 0.87 | 0.61 | 0.51 | 0.30 | 4.27 | 11.09 | 23.39 | 20.49 | 16.95 | 30.52 |
| 1941 | 12.44 | 2.33 | 0.80 | 0.57 | 0.52 | 0.52 | 0.57 | 3.95 | 19.96 | 9.74 | 13.54 | 6.28 |
| 1942 | 1.54 | 0.64 | 0.54 | 2.38 | 1.61 | 0.62 | 1.45 | 1.95 | 4.53 | 8.92 | 16.38 | 8.08 |
| 1943 | 3.98 | 1.45 | 0.58 | 0.33 | 0.32 | 0.28 | 0.49 | 4.21 | 21.41 | 22.70 | 25.72 | 22.43 |
| 1944 | 6.63 | 1.63 | 0.85 | 0.52 | 0.32 | 0.24 | 0.70 | 10.37 | 24.19 | 42.41 | 29.31 | 5.97 |
| 1945 | 6.17 | 1.98 | 0.60 | 0.52 | 0.30 | 0.97 | 1.37 | 1.66 | 2.87 | 4.66 | 8.32 | 12.08 |
| 1946 | 2.99 | 0.90 | 0.37 | 0.26 | 0.26 | 0.92 | 0.96 | 1.98 | 3.81 | 18.08 | 9.14 | 5.42 |
| 1947 | 1.86 | 1.01 | 0.44 | 0.28 | 0.30 | 0.48 | 0.64 | 1.36 | 4.03 | 9.01 | 7.35 | 7.46 |
| 1948 | 10.57 | 2.53 | 0.54 | 0.52 | 0.52 | 0.25 | 1.40 | 2.43 | 3.93 | 5.62 | 10.08 | 7.13 |
| 1949 | 2.79 | 1.64 | 0.73 | 0.33 | 0.28 | 0.24 | 2.37 | 2.31 | 1.73 | 13.83 | 6.94 | 7.09 |
| 1950 | 5.83 | 7.89 | 2.38 | 0.73 | 0.52 | 0.52 | 3.76 | 4.34 | 19.41 | 22.99 | 15.76 | 26.53 |
| 1951 | 7.11 | 2.76 | 0.79 | 0.52 | 0.50 | 0.43 | 0.53 | 2.16 | 2.34 | 6.61 | 16.59 | 11.81 |
| 1952 | 6.87 | 1.82 | 0.83 | 0.35 | 0.29 | 0.27 | 3.38 | 7.87 | 5.80 | 12.46 | 15.16 | 4.00 |
| 1953 | 1.99 | 1.98 | 0.65 | 0.52 | 0.31 | 0.33 | 1.07 | 10.81 | 17.46 | 37.69 | 36.06 | 13.79 |
| 1954 | 3.24 | 1.67 | 0.58 | 0.37 | 4.20 | 2.28 | 1.39 | 1.32 | 3.03 | 17.12 | 30.18 | 15.51 |
| 1955 | 10.40 | 2.99 | 0.87 | 0.52 | 0.54 | 0.41 | 0.56 | 4.84 | 9.39 | 11.09 | 12.21 | 5.94 |
| 1956 | 3.24 | 1.24 | 0.54 | 0.52 | 0.69 | 0.80 | 1.19 | 7.96 | 20.46 | 30.08 | 26.88 | 12.88 |
| 1957 | 19.73 | 3.77 | 0.56 | 0.52 | 0.80 | 1.12 | 0.86 | 5.51 | 7.44 | 3.19 | 9.48 | 9.82 |
| 1958 | 3.47 | 1.31 | 0.48 | 0.34 | 0.33 | 0.36 | 5.23 | 18.42 | 9.67 | 4.78 | 20.46 | 8.81 |
| 1959 | 4.03 | 1.44 | 0.54 | 0.52 | 0.29 | 0.34 | 0.48 | 2.79 | 8.95 | 5.32 | 5.07 | 3.79 |
| 1960 | 1.89 | 0.73 | 0.61 | 1.28 | 0.81 | 0.30 | 0.33 | 1.09 | 4.06 | 5.25 | 13.11 | 11.06 |
| 1961 | 3.66 | 1.07 | 0.39 | 0.28 | 0.36 | 0.51 | 1.49 | 1.28 | 17.04 | 14.67 | 26.29 | 12.28 |
| 1962 | 16.13 | 4.17 | 0.70 | 0.54 | 0.52 | 0.52 | 0.54 | 1.36 | 3.91 | 13.24 | 25.08 | 7.22 |

| YEAR | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1963 | 1.96 | 1.27 | 0.70 | 0.52 | 0.56 | 0.57 | 0.73 | 1.60 | 7.03 | 8.57 | 21.51 | 9.72 |
| 1964 | 4.55 | 4.10 | 0.97 | 0.52 | 0.57 | 1.15 | 1.67 | 3.83 | 4.70 | 6.40 | 9.60 | 4.18 |
| 1965 | 3.20 | 1.30 | 0.92 | 0.53 | 0.34 | 0.93 | 1.01 | 2.32 | 3.00 | 11.28 | 17.50 | 12.01 |
| 1966 | 2.18 | 0.79 | 0.52 | 0.52 | 0.27 | 0.33 | 4.78 | 4.08 | 9.41 | 9.06 | 8.94 | 5.40 |
| 1967 | 5.61 | 1.49 | 0.57 | 0.49 | 0.55 | 0.33 | 0.78 | 5.39 | 9.38 | 11.64 | 17.04 | 5.03 |
| 1968 | 6.63 | 1.70 | 0.55 | 0.57 | 0.58 | 0.74 | 1.19 | 1.34 | 4.29 | 5.43 | 7.69 | 6.37 |
| 1969 | 5.88 | 1.86 | 0.51 | 0.28 | 0.35 | 0.30 | 0.27 | 1.88 | 7.15 | 9.89 | 19.79 | 8.78 |
| 1970 | 3.77 | 1.40 | 0.94 | 0.54 | 0.33 | 0.29 | 0.31 | 1.05 | 2.70 | 8.86 | 13.23 | 6.42 |
| 1971 | 2.13 | 0.96 | 0.44 | 0.36 | 0.55 | 0.48 | 2.01 | 4.79 | 5.24 | 4.58 | 8.95 | 6.32 |
| 1972 | 1.75 | 0.65 | 0.47 | 0.34 | 0.29 | 0.25 | 0.32 | 0.78 | 1.18 | 8.22 | 9.18 | 6.81 |
| 1973 | 2.81 | 0.89 | 0.44 | 0.32 | 0.29 | 0.27 | 0.26 | 2.93 | 4.22 | 3.93 | 37.30 | 21.87 |
| 1974 | 12.01 | 2.61 | 0.58 | 0.52 | 0.52 | 0.27 | 0.68 | 4.25 | 6.41 | 13.81 | 22.78 | 5.72 |
| 1975 | 3.55 | 1.38 | 0.54 | 0.52 | 0.32 | 0.39 | 0.75 | 1.87 | 11.60 | 14.62 | 11.75 | 10.44 |
| 1976 | 4.46 | 8.99 | 3.80 | 0.86 | 0.66 | 0.82 | 2.37 | 10.20 | 29.35 | 33.90 | 31.90 | 14.78 |
| 1977 | 3.23 | 1.00 | 0.68 | 0.35 | 0.35 | 0.45 | 0.72 | 0.97 | 1.52 | 4.17 | 10.81 | 9.65 |
| 1978 | 5.37 | 1.40 | 0.55 | 0.44 | 1.77 | 1.00 | 0.33 | 5.16 | 7.94 | 7.60 | 7.65 | 6.65 |
| 1979 | 11.68 | 2.64 | 0.54 | 0.35 | 0.49 | 0.32 | 1.01 | 3.56 | 8.33 | 5.01 | 4.85 | 5.06 |
| 1980 | 2.94 | 6.52 | 3.51 | 4.17 | 1.73 | 0.81 | 3.17 | 1.85 | 2.78 | 14.30 | 22.50 | 22.99 |
| 1981 | 3.84 | 1.23 | 0.65 | 0.52 | 0.52 | 0.27 | 1.70 | 1.59 | 4.16 | 4.67 | 7.06 | 5.17 |
| 1982 | 2.27 | 0.95 | 0.88 | 0.57 | 1.49 | 1.30 | 0.62 | 6.27 | 19.51 | 24.30 | 15.01 | 18.37 |
| 1983 | 3.67 | 0.89 | 0.52 | 0.52 | 0.30 | 0.44 | 0.84 | 10.40 | 8.17 | 9.91 | 5.88 | 16.61 |
| 1984 | 12.69 | 2.45 | 2.79 | 1.19 | 1.57 | 2.94 | 4.35 | 2.42 | 5.79 | 17.67 | 21.00 | 8.30 |
| 1985 | 4.48 | 1.62 | 0.54 | 0.52 | 0.57 | 1.26 | 1.90 | 2.29 | 6.71 | 12.25 | 32.25 | 16.27 |
| 1986 | 2.65 | 1.23 | 0.58 | 0.52 | 0.54 | 0.52 | 1.38 | 5.34 | 7.89 | 10.58 | 16.59 | 13.04 |
| 1987 | 3.15 | 1.53 | 0.95 | 0.30 | 0.09 | 0.29 | 1.13 | 2.53 | 6.72 | 10.37 | 7.80 | 10.88 |
| 1988 | 2.66 | 1.41 | 0.22 | 0.08 | 0.18 | 1.98 | 4.61 | 4.89 | 9.39 | 11.49 | 19.76 | 22.90 |
| 1989 | 6.75 | 2.81 | 0.81 | 0.52 | 0.72 | 0.88 | 3.17 | 7.67 | 10.79 | 23.95 | 18.07 | 6.06 |
| 1990 | 1.23 | 1.02 | 0.52 | 0.16 | 0.18 | 0.03 | 0.33 | 3.56 | 9.85 | 19.78 | 16.29 | 16.37 |
| 1991 | 8.41 | 2.50 | 0.68 | 0.52 | 0.37 | 0.33 | 2.07 | 7.72 | 24.39 | 21.29 | 14.83 | 12.88 |
| 1992 | 17.14 | 3.42 | 0.66 | 0.52 | 0.74 | 0.28 | 11.40 | 7.68 | 12.89 | 47.18 | 16.40 | 5.25 |
| 1993 | 1.22 | 0.53 | 0.83 | 0.10 | 0.06 | 0.19 | 0.33 | 1.37 | 20.07 | 13.50 | 10.03 | 4.57 |
| 1994 | 2.83 | 0.73 | 0.37 | 0.22 | 0.17 | 0.14 | 0.48 | 2.92 | 8.07 | 12.63 | 16.33 | 5.29 |
| 1995 | 9.19 | 2.39 | 3.29 | 1.17 | 0.54 | 0.52 | 0.52 | 2.23 | 9.02 | 15.00 | 14.16 | 19.16 |
| 1996 | 22.68 | 8.72 | 2.63 | 0.80 | 0.52 | 0.63 | 0.94 | 3.12 | 15.65 | 8.99 | 12.32 | 4.89 |
| 1997 | 1.21 | 5.36 | 1.50 | 0.57 | 0.52 | 0.25 | 1.08 | 8.77 | 9.08 | 13.08 | 10.22 | 4.35 |
| 1998 | 1.54 | 5.40 | 2.06 | 0.76 | 0.52 | 0.52 | 0.71 | 2.60 | 6.40 | 8.51 | 10.14 | 9.93 |
| 1999 | 3.64 | 1.07 | 0.39 | 0.47 | 0.09 | 0.71 | 0.40 | 1.77 | 5.22 | 6.65 | 8.57 | 12.16 |
| 2000 | 2.71 | 0.91 | 0.54 | 0.26 | 0.39 | 0.16 | 0.29 | 5.71 | 4.75 | 22.35 | 26.07 | 23.23 |
| 2001 | 2.88 | 1.35 | 0.65 | 1.82 | 0.79 | 0.52 | 1.63 | 3.70 | 8.30 | 11.56 | 16.31 | 5.15 |
| 2002 | 4.74 | 1.47 | 0.44 | 0.32 | 0.29 | 1.12 | 0.78 | 3.14 | 3.55 | 3.08 | 10.83 | 6.02 |
| 2003 | 4.71 | 1.11 | 0.60 | 0.48 | 0.24 | 0.27 | 0.22 | 0.75 | 3.81 | 6.47 | 9.41 | 4.80 |
| 2004 | 6.26 | 1.63 | 0.49 | 0.35 | 0.27 | 0.16 | 4.87 | 5.31 | 13.81 | 7.91 | 16.72 | 6.33 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| State 1 | <0.15 | State 2 | 0.15-1 | State 3 | 1-10 | State 4 | 10 - 20 | State 5 | > 20 |

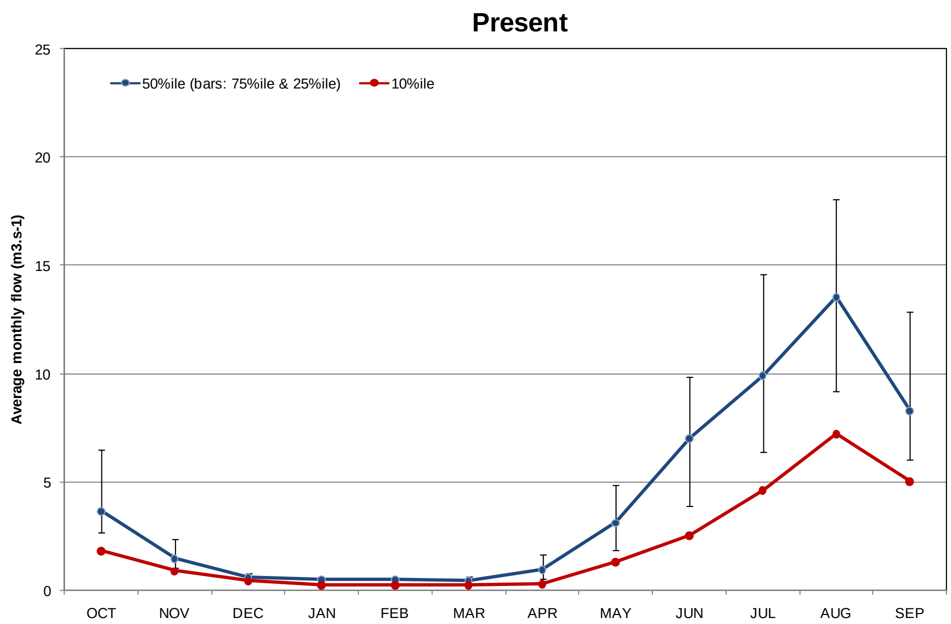



**Figure 3.2 Graphic representations of the occurrence of the abiotic states under the Present State**

#### 3.2.1.2 Present flood regime

As the Palmiet Estuary is a relatively small estuary, the underlying assumption for the flood analyses was that small floods would reset the sediment processes in the estuary, but that the frequency with which these events occur was important as this drives the rate at which the deposition/erosion cycles of the sediments occur.

To undertake a first assessment of the effects of the present level of development on the incidence of floods, the occurrences and magnitudes of the highest average monthly flows are listed in Table 3.5 for the period October 1928 until September 2005 for which data for all scenarios are available.

**Table 3.5 Highest monthly flows (in $m^3s^{-1}$) in the Palmiet River simulated data for October 1928 to September 2005 for the Reference Condition and Present State**

| Year | Month | SIMULATED HIGHEST AVERAGE MONTHLY FLOWS ($m^3s^{-1}$) | |
|---|---|---|---|
| | | Reference | Present |
| 1974 | Aug | 50.11 | 37.30 |
| 1993 | Jul | 46.92 | 47.18 |
| 1944 | Jun | 42.29 | 21.41 |
| 1945 | Jul | 41.73 | 42.41 |
| 1994 | Jun | 39.07 | 20.07 |
| 1954 | Jul | 38.77 | 37.69 |
| 1992 | Jun | 38.39 | 24.39 |
| 1945 | Jun | 36.43 | 24.19 |
| 2001 | Jul | 36.38 | 22.35 |
| 1955 | Aug | 35.82 | 30.18 |
| 1986 | Aug | 35.67 | 32.25 |
| 1954 | Aug | 35.03 | 36.06 |
| 1959 | May | 34.08 | 18.42 |
| 1937 | Jul | 33.52 | 24.00 |
| 1977 | Jun | 33.23 | 29.35 |
| 1977 | Jul | 32.92 | 33.90 |
| 1957 | Jun | 32.01 | 20.46 |
| 1942 | Jun | 31.55 | 19.96 |
| 1951 | Jun | 31.37 | 19.41 |
| 1977 | Aug | 30.99 | 31.90 |
| 1963 | Aug | 30.57 | 25.08 |
| 1976 | Jun | 30.12 | 11.60 |
| **Average of the 22 events** | | **36.23** | **27.71** |
| **% Similar to Reference** | | **76** | |

Simulated daily flow data for the period October 1963 to September 2005 were also analysed to estimate the effects of the different scenarios on the occurrence of floods, the occurrences and magnitudes (Table 3.6).

**Table 3.6 Palmiet highest daily flows (in $m^3s^{-1}$) simulated data for October 1928 to September 1963 for the Reference Condition and Present State**

| Flow ($m^3s^{-1}$) | Natural | Present |
|---|---|---|
| Average | 8.147 | 5.184 |
| Occurrence of floods exceeding: | | |
| >150<br>100-150<br>75 – 100<br>50 -75 | 3<br>31<br>82<br>137 | 1<br>8<br>25<br>81 |
| Total | 253 | 115 |
| % Occurrence in relation to Reference Condition | | |
| >150<br>100-150<br>75 – 100<br>50 -75 | -<br>-<br>-<br>- | 33<br>26<br>30<br>59 |
| Average | - | 45 |

The simulated runoff data shows that for present conditions the highest monthly flow was 47 $m^3s^{-1}$ in July 1993. For the 77-year period, an average monthly flow higher than 30 $m^3s^{-1}$ was exceeded 9 times. These exceedances occurred 4 times in July, and 5 times in August. Such events therefore occur later in the year compared to natural conditions.

An analysis of the simulated daily flow data indicates that the occurrence of daily flows higher than 75 $m^3s^{-1}$ have been reduced between 67 to 74%, depending on the size class. As the Palmiet Estuary is a relative small system, smaller events (flows higher than 50 $m^3s^{-1}$) may also assist in maintaining the sediment equilibrium, i.e. removing sediment from the mouth region and basin. Daily flows between 50 $m^3s^{-1}$ and 75 $m^3s^{-1}$ have been reduced by 41%. The total reduction in the occurrence for daily flows higher than 50 $m^3s^{-1}$ is 55%. In general, compared to the natural conditions, a reduction in the occurrence and magnitude of major floods is observed, but such floods are still occurring.

Thus the flood analysis indicates that there is about a 40% reduction in the occurrence of large and intermediate floods to the Palmiet Estuary relative to the Reference Condition. The hydrological data indicate that the magnitude and occurrence of major floods have been reduced significantly.

*Confidence: Medium*

3.2.1.3 Anthropogenic influences, other than modification of river inflow, that are presently affecting abiotic characteristics in the estuary:

| **Type** | **Activity** | **Present** | **Describe impact** |
|---|---|---|---|
| **Land-use and development** | Weirs | ✓ | Weir upstream prevent migration of fish |
| | Bridge(s) | ✓ | Bridges over the Palmiet presents no obstruction to flow |
| | Artificial breaching | × | |
| | Mouth stabilisation | × | |
| | Bank stabilisation and destabilisation | ✓ | Retaining wall near the mouth |
| | Causeway | × | |
| | Marina development | × | |
| | Dredging | × | |
| | Mining (e.g. sand winning) | × | |

| Type | Activity | Present | Describe impact |
|---|---|---|---|
| | Poor agricultural practices (e.g. causing siltation) | ✓ | On a limited scale |
| | Exceedance of carrying capacity resulting from boating, bathers etc. | × | |
| | Low-lying developments | × | |
| | Lack of maintenance of infrastructure (e.g. roads and bridges) | × | |
| | Migration barrier in river | × | |
| | Other … | × | |
| **Water Quality and Quantity** | Agricultural and pastoral run-off containing fertilisers, pesticides and herbicides | ✓ | Yes |
| | Waste water treatment works | × | |
| | Municipal waste (including sewage disposal) | × | |
| | Industrial effluent (including cooling water) discharges | × | |
| | Litter | ✓ | Limited |
| | Mariculture waste products | × | |
| | Pollution related to shipping activities in harbours | × | |
| | Septic and conservancy tank seepage | × | |
| | The inflow of contaminated storm-water or groundwater | × | |
| | Lack of maintenance of infrastructure (e.g. sewage works) | × | |
| | Other water quality activity | × | |
| | Waste water treatment works | × | |

#### 3.2.1.4 Present sediment processes

If the period between flood events increases, this leads to infilling of the lower regions by marine sand through wave action during such a period. The net result is reduced inter and sub-tidal habitat in the lower reaches as this is smothered by sediments between floods.

The Palmiet catchment has a naturally low sediment yield. Under present conditions, however, what little sediment would have came down is trapped in upstream dams, which in turn reduces the infilling of some of the rocky areas in the upper reaches. The net result are markedly more rocky upper reaches than would have occurred under natural conditions.

*Confidence: Medium*

#### 3.2.1.5 Droughts

Hydrological drought conditions in the Palmiet Estuary are defined as years in which the annual inflow (million $m^3$) falls below the Reference Condition 10%ile, i.e. 175 million $m^3$. Under the Present State, annual flows are less than 175 million $m^3$ for approximately 65% of the time. An analysis of the 77-year period also highlights the occurrence of extended drought periods varying between 4 to 10 years in a row (Figure 3.3).

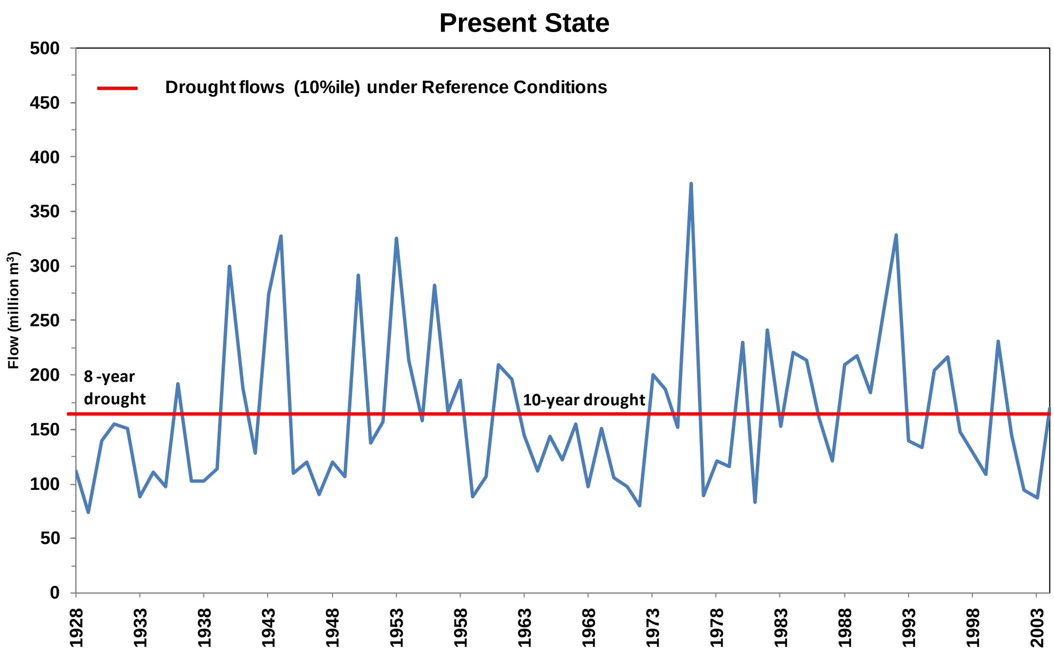
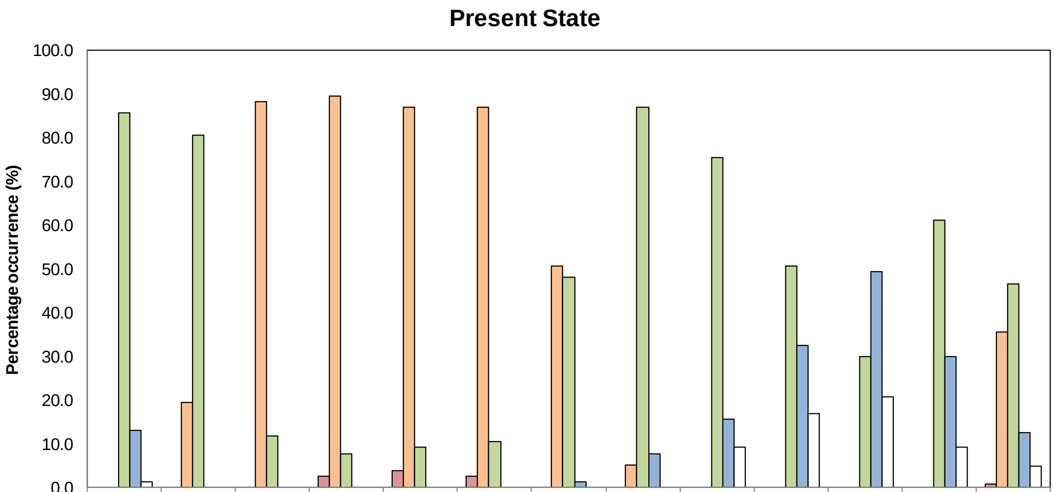



**Figure 3.3 Occurrence of 'drought' conditions in the Palmiet Estuary under the Present State**




| | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| State 1 | 0.0 | 0.0 | 0.0 | 2.6 | 3.9 | 2.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 |
| State 2 | 0.0 | 19.5 | 88.3 | 89.6 | 87.0 | 87.0 | 50.6 | 5.2 | 0.0 | 0.0 | 0.0 | 0.0 | 35.6 |
| State 3 | 85.7 | 80.5 | 11.7 | 7.8 | 9.1 | 10.4 | 48.1 | 87.0 | 75.3 | 50.6 | 29.9 | 61.0 | 46.4 |
| State 4 | 13.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.3 | 7.8 | 15.6 | 32.5 | 49.4 | 29.9 | 12.4 |
| State 5 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 9.1 | 16.9 | 20.8 | 9.1 | 4.8 |

### *3.2.2 Biotic Components*

#### 3.2.2.1 Response of biotic components

Table 3.7 summarises the effect of abiotic characteristics and processes, as well as other biotic components on the biota of the Palmiet Estuary.

**Table 3.7 The effect of abiotic drivers (and other biotic components) on the biota of the Palmiet Estuary**

| | |
|---|---|
| **Microalgae** | **Mouth condition (provide temporal implications where applicable):** The condition of the mouth can affect intertidal benthic microalgal biomass because the intertidal habitat is lost when the mouth closes and the water level rises. Intertidal microalgae (generally the more mobile microalgal taxa) would be absent from the estuary for States 1 and 2.<br>Turbulent currents associated with tidal exchange limit benthic microalgal growth in the flood tide delta. Tidal exchange during open mouth conditions – States 3 and 4 - introduces marine species of microalgae and nutrients. |
| | **Exposure of intertidal areas during low tide:** A large sand flat on the western side of the lower estuary (11 ha) is an important habitat for benthic microalgae. Taxa adapted to tidal exposure are lost if the mouth closes and the sand flat is flooded. |
| | **Subtidal, intertidal and supratidal habitat:** The total area of the estuary has been estimated to be 23 ha with a high tide volume of 360 000 m$^3$. The total area of water increased to 26.4 ha when the mouth of the estuary was closed (2009 Google Earth image).<br>The 11 ha sand flat provides an important habitat for intertidal microalgae when the estuary mouth is open and the estuary tidal; highest benthic microalgal chl-a (239 mg m$^{-2}$) was measured just above the mid-tide mark.<br><br>Less than 12 ha of the estuary is subtidal. The sediment is coarse and the tannin-stained water limit subtidal benthic microalgal biomass. |
| | **Sediment characteristics (including sedimentation):** The sediment in the estuary is unusually coarse; 65% gravel and 34% sand (0.63 to 2 mm particle size). As a result, the sediment has a low organic content (<0.6%), limiting benthic microalgal biomass. The sediment does support a healthy population of sand prawn and these are an essential source of nutrients for microalgae. |
| | **Retention times of water masses:** The estuary is small, making the retention times of water masses very short, as a result of tidal exchange as well as river inflow. This is a major factor limiting phytoplankton biomass. The strong salinity gradient developed in state 3 provide conditions most suited to phytoplankton growth. |
| | **Flow velocities (e.g. tidal velocities or river inflow velocities):** The strong salinity gradient developed in state 3 provide conditions most suited to phytoplankton growth.<br>Turbulent tidal and river inflow velocities limit subtidal benthic microalgal biomass at the head and mouth of the estuary. River flows typical of State 3 are ideal for microalgal growth. River flows lower than this support macrophyte growth and flows greater than this mobilise the sediment. |
| | **Total volume and/or estimated volume of different salinity ranges:** Shortly after a flood event the volume of the estuary should be at its lowest on the spring low tide; water surface area <12 ha. The volume is highest when the estuary is closed and the water perched behind a well developed sandbar; water surface area >23 ha. This provides almost double the amount of available habitat for phytoplankton and subtidal benthic microalgae. |
| | **Salinity**: Salinity stays within the fresh to marine range and is unlikely to affect microalgal growth. However, when the mouth is closed the saline water at depth is likely to accelerate the decomposition of macroalgae and result in local hypoxic/anoxic conditions. This could provide suitable habitat for cyanophytes. |
| | **Other water quality variables (see above):** Nutrient concentrations in the estuary probably limit microalgal growth. Microalgae will be competing with macroalgae for nutrients when there is limited tidal exchange and low river inflow (States 1 and 2). |
| | **Other biotic components:** Microalgae will be competing with macroalgae for nutrients during States 1 and 2. Invertebrates, sand prawns in particular, are capable of accumulating organic material in the burrows and will be an important source of nutrients for microalgae and macroalgae. |
| **Macrophytes** | **Mouth condition (provide temporal implications where applicable):** Open mouth and intertidal conditions maintain the small salt marsh area. When the mouth is closed, there would be an increase in the growth of filamentous macroalgae. Blooms of macroalgae could become a problem if decomposition led to anoxic conditions and noxious odours. Prolonged inundation (greater than 3 months) because of mouth closure and increased water levels can reduce the growth of salt marsh plants, particularly during the growing season (spring, summer).<br><br>An increase in semi-closed mouth conditions would result in inundation of the salt marsh area. Prolonged closure of the mouth and low river water input would deprive the estuary of a high proportion of organic material that would have an adverse effect on secondary production. |

| | |
|---|---|
| | **Exposure of intertidal areas during low tide:** The intertidal habitat available for colonisation by estuarine macrophytes (i.e. salt marsh, reed and sedge communities) is very small because of the predominately rock lined banks. Intertidal habitat is lost when the mouth closes. |
| | **Subtidal, intertidal and supratidal habitat:** Intertidal and supratidal habitat is limited in the Palmiet Estuary because of the steep banks and small estuary size. This limits the area colonised by salt marsh and reeds and sedges. |
| | **Sediment characteristics (including sedimentation):** Sedimentation and reduced flooding will result in macrophyte encroachment and an increase in the area occupied by salt marsh and reeds and sedges. |
| | **Retention times of water masses:** Macroalgae are abundant when the mouth of the estuary is closed and there is greater water retention. Increased nutrient concentrations from the reference to present condition would increase macroalgal growth. |
| | **Flow velocities (e.g. tidal velocities or river inflow velocities):** High flow and open mouth conditions flush out macroalgae. |
| | **Salinity:** Macroalgae: *Cladophora* spp can tolerate wide fluctuations in salinity and has been found growing in the Seekoei and Kabeljous estuaries in salinity of 15-43 ppt.<br><br>Salt marsh: the grass *Sporobolus virginicus* and the rush *Juncus kraussii,* indicate brackish (< 15 ppt) conditions.<br><br>Reeds and sedges: A number of grass, rush and sedge species grow on the rocky banks below the road bridge at freshwater seepage sites. |
| | **Other water quality variables (see above):** High nutrients increase macrophyte abundance. Blooms of macroalgae (particularly species of *Ulva, Enteromorpha* and *Cladophora*) have long been associated with nutrient enrichment. Filamentous algae depend on water column nutrients and, when they form mats on the bottom, they take up nutrients regenerated by microbial processes in the sediment. Robinson and Hawkes (1986) concluded that phosphate was the limiting nutrient for *Cladophora* growth. They further concluded that the critical phosphate level was 0.098 mg $l^{-1}$ (critical nutrient level is the minimum concentration of an element required for maximal growth of the algal cells). Wong and Clark (1976) gave a value of 0.06 mg $l^{-1}$. |
| | **Other biotic components:** Because *in situ* primary production is low, secondary production within the estuary may be dependant on **imports of organic material** from the river (Palmiet reed) and sea (kelp).<br><br>There are no rooted submerged macrophytes (e.g. *Zostera capensis, Ruppia cirrhosa*) in the Palmiet Estuary. This can be attributed to the high flows, unstable substrate and low light permeability of the estuary. |
| **Invertebrates** | **Mouth condition (provide temporal implications where applicable):**<br>An open mouth is a critical driver of invertebrate health in the Palmiet. Tidal ebb and flow ensures a regular input of fresh seawater across the bottom and this ensures well- oxygenated bottom waters and relatively high salinity values for benthic organisms, particularly the sandprawn *Callianassa kraussi* and two species of amphipods – *Grandidierella* and *Corophium*. These three species are probably the most important invertebrates in the system, playing major roles in the foodweb and the breakdown of macrophyte debris. Their combined biomass (dry mass) probably exceeds 95% of total biomass in the estuary, including faecal matter produced by sandprawns. If the mouth closes, there is the potential for anoxic conditions to develop, particularly in summer because of higher water temperatures. Such conditions are likely to develop even within weeks of closure. Collectively, this will impact negatively on the benthic invertebrates, particularly below about 2 m water depth. |
| | **Exposure of intertidal areas during low tide:** Exposure of the large sandbank in the lower estuary during low tide is an important pumping mechanism that leads to the exchange of interstitial water, and hence maintains oxygen levels. Sandprawns will also actively pump water through burrows when the bank is covered, adding to the exchange of water and oxygen through the sediment. |
| | **Subtidal, intertidal and supratidal habitat:** Supratidal is limited for invertebrate (steepness of the banks) colonisation. The most important habitat is the subtidal, followed by the large sandbank in the lower estuary. If this sandbank is covered by water for long periods (weeks to months), *Callianassa* density may increase, due to migration of individuals from deeper areas as ogygen levels decrease in these channel areas. However, density of *Callianassa* will not remain high if salinity values decline and remain below above 17 ppt (*Callianassa* unable to breed successfully). |

| | |
|---|---|
| | **Sediment characteristics (including sedimentation):** The sandy sediment forms the most important habitat for invertebrates, although increasing sediment particle size in an upstream direction leads to lower abundance or biomass levels. |
| | **Retention times of water masses:** Increasing retention time will increase the probability of low oxygen conditions developing. If the system becomes stagnant for periods that exceed 1-2 months (particularly in summer), it is likely that water below ca 1 m depth (wind mixing) will become anoxic, causing major die-backs in the invertebrate fauna. Species richness is also likely to decline. |
| | **Flow velocities (e.g. tidal velocities or river inflow velocities):**<br>Increased flow velocities will lead to an increase in average particle size of the sediment. If the sediment becomes too course, abundance/biomass of invertebrates will decrease. |
| | **Total volume and/or estimated volume of different salinity ranges:**<br>It is important that salinity values remain above ca 17 ppt at least for 4-5 months during summer. This is the threshold required for *Callianassa* to produce new recruits into the population. The amphipods are less-affected, as their tolerance levels are much wider. If freshwater conditions persist throughout the water column, amphipods will not be able to breed successfully. |
| | **Salinity:** Salinity values should not fall below 15-20 ppt during late winter and spring, as this is the main breeding season for *Callianassa.* |
| | **Other water quality variables (see above):** |
| | **Other biotic components:** Expansion of the macrophyte beds in the estuary will decrease available habitat for species such as *Callianassa* that utilise non-vegetated areas particularly. Increasing macrophyte coverage will also lead to a change in the invertebrate species mix. |
| **Fish** | **Mouth condition (provide temporal implications where applicable):**The mouth needs to be open during the peak recruitment period of August to December. Semi-closed conditions are also sufficient for recruitment. The semi-closed (and limited closed) conditions that persist for much of December-March result in low oxygen conditions in the deeper areas. Consequently, benthic fish species such as *Caffrogobius* spp. and *Solea bleekeri* are limited throughout the system. The only benthic fish in any quantity is *Psammogobius Knysnaensis*, which occurs predominantly in the shallower, over-washed, sandy reaches near the mouth.<br><br>This said, low salinities due to closed, semi-closed and high flow conditions are likely to drive benthic invertebrates, notably *Callianassa kraussi*, deeper into the sediment in search of higher salinities. This will reduce prey availability for the benthic feeding *Lithognathus lithognathus*, *Rhabdosargus globiceps* and *R. holubi*. Consequently, these species can be expected to be in low numbers in the estuary.<br><br>Microalgae biomass is the dominant food source of the 5 Mugillidae species in the estuary and also important to *G. aestuaria* and *A. breviceps* declines during states 1 and 2. Macroalgal biomass increases during states 1 and 2 benefiting *Rhabdosargus holubi* and *Syngnathus temminckii* but, if these states persist, low oxygen conditions could arise from decomposition and night time respiration. |
| | **Exposure of intertidal areas during low tide:** This is important for mullet. Compared to other systems, limited benthic microalgae production increases the importance of detritus from upstream and from resuspension of faecal and other material during high tide. |
| | **Subtidal, intertidal and supratidal habitat:** The subtidal habitat is fairly homogenous but due to the high tannin levels in the water column, the entire subtidal is an ideal refuge. Fish will forage in the intertidal during high tide and find limited refuge in the supratidal inundated during floods. |
| | **Sediment characteristics (including sedimentation):** Low organic content of the sediment and limited benthic microalgae accounts for low numbers of detritivores. Anoxic sediments, especially during states 1 and 2, limit benthic fish species and their invertebrate prey. Sandy sediments result in dominance by the Knysna sand-goby *Psammogobius knysnaensis*. Numbers of this species will also be enhanced by *C, kraussi* burrows with which it appears to have a symbiotic/commensal relationship’ |
| | **Retention times of water masses:** High retention times result in benthic anoxia and low numbers of benthic species. |
| | **Flow velocities (e.g. tidal velocities or river inflow velocities):** Unlikely to be an issue except during floods when the homogenous nature of the system will limit standing-waves, eddies and other flow related refugia. |

| | |
|---|---|
| | **Total volume and/or estimated volume of different salinity ranges:** The fish assemblage is typical of a blackwater system and able to withstand low salinities for prolonged periods. The impacts of low salinities on fish are likely to be more due to the knock on effects of invertebrates and algae. Overall, volume dictates the dispersal of fish throughout the system and their vulnerability to predation. |
| | **Salinity**: The fish assemblage is dominated by species with a preference for (e.g. *Monodactylus falciformis*, *Myxus capensis*, *Gilchristella aestuaria*) or tolerant (e.g. *Liza richardsonii*, *Atherina breviceps*) of low salinities. The 5-25 ppt range experienced throughout most of states should be ideal for most estuarine associated species which, coupled with state 3 during summer, should see an influx of these and marine species, thereby increasing diversity. |
| | **Other water quality variables (see above):** Hypoxic or anoxic conditions during states 1 and 2 may negate many benefits of ideal salinity ranges in the estuary. It also needs to be noted that there is extensive crop spraying in the middle and upper reaches of the catchment and that water levels rise and fall daily according to hydro requirements (check). |
| | **Other biotic components:** Catadromous eels *Anguilla mossambica* recruit via the estuary into the freshwater reaches of the catchment, as do the facultative catadromous *Myxus capensis* and freshwater loving *M. falciformis* and *M. cephalus*. High densities of, and predation by, the introduced smallmouth bass *Micropterus dolomieu* immediately after the head of the estuary may compromise recruitment. In turn, although easily overcome by *A. mossambica*, the weir immediately upstream of the estuary completely blocks all recruitment by *M. falciformis*, *Myxus capenis* and *Mugil cephalus* into the freshwater reaches. |
| **Birds** | **Mouth condition (provide temporal implications where applicable):** Little direct effect, only indirect, through impacts on habitat and food. Main effect is on terns, with open mouth providing suitable feeding conditions. |
| | **Exposure of intertidal areas during low tide:** Tidal exposure is essential for many estuarine bird species, with the majority of estuarine species depending on these habitats for food, and several more using intertidal areas for roosting. |
| | **Subtidal, intertidal and supratidal habitat:** Subtidal habitat is not directly important except where <30cm. Intertidal habitat is the most important, and supratidal habitat may also be important, especially for non-feeding activiites, though not in the case of the Palmiet. |
| | **Sediment characteristics (including sedimentation):** Sediment characteristics affect the food and feeding methods of estuarine birds, with different species being adapted to different conditions. Thus a change in characteristics is likely to affect bird community composition. |
| | **Retention times of water masses:** No direct impact. |
| | **Flow velocities (e.g. tidal velocities or river inflow velocities):** Can affect foraging by piscivorous birds, but only at very high velocities |
| | **Total volume:** No direct impact. Inundation of intertidal habitats would lead to reduction in bird numbers. |
| | **Salinity**: Most estuarine birds tolerate a wide range of salinities, but a few species are typical of more freshwater or marine habitats, and the abundances of these species would be affected by change. |
| | **Other water quality variables (see above):** Sediment particle size is important in determining species composition and bird densities, with muddy (not silty) habitats being important for foraging. Increased nutrient loading would lead to increased bird biomass due to increased food supplies |
| | **Other biotic components:** Since estuarine bird species comprise herbivores, invertebrate feeders and piscivores, the abundance of other biotic components is critical in terms of food availability. Abundance in certain size classes is also a key factor. |

Table 3.8 summarises the living resources utilisation and how it is affecting the biota in the Palmiet Estuary.

### Table 3.8 Summary of the living resources utilisation in the Palmiet Estuary

| Activity | Present | Describe impact |
|---|---|---|
| Recreational fishing | Yes | **Number of anglers:** Similar to adjacent coastline, approximately 1 $km^{-1}.day^{-1}$. Increase in fly-fishing in recent years. There is angling for *M. dolomieu* at the head of the estuary and illegal fishing for eels further upstream.<br>**Number of boats:** None, occasional angling from canoes and kayaks.<br>**Tonnage harvested:** approximately 200 $kg.yr^{-1}$ due to angling and castnetting.<br>**Species targeted and their status (e.g. collapsed):** Twelve species caught. Of these, *L. lithognathus* and *R. globiceps* are collapsed, *L. amia, L. richardsonii* and *P. saltatrix* are overexploited and *M. capensis* is regarded as particularly vulnerable to anthropogenic influences other than fishing. |
| Commercial/Subsistence fishing (e.g. gillnet fishery) | No | |
| Traditional fish traps | No | |
| Illegal fishing (Poaching) | Yes | **Number of operators:** Unsubstantiated number of illegal eel fishers in the freshwater reaches immediately above the estuary.<br>**Tonnage harvested:** unknown<br>**Species targeted and their status**: *Anguilla mossambica*, vulnerable due to catchment degradation, overfishing historically, introduced pathogens and collection of recruiting glass eels for mariculture. |
| Bait collection | Yes | **Number of harvesters:** Higher during holiday periods, approximately 10 maximum observed at any one time. Very difficult to pump sandprawn when conditions fresh.<br>**Biomass harvested:** low, < 50 $person^{-1}.hour^{-1}$<br>**Species targeted:** *Callianassa kraussi* |
| Aquarium fish collecting | No | |
| Inappropriate levels of recreational activities (e.g. fishing competitions) | No | |
| Mariculture | No | |
| Harvesting of plants | N/A | |
| Grazing of salt mashes | N/A | |
| Translocated or alien fauna and flora | Yes | **Species:** Smallmouth bass *Micropterus dolomieu*, Largemouth bass *M. salmoides* and bluegill sunfish *Lepomis macrochirus* at the head of the estuary.<br>**Numbers or area (ha) inhabited:** Throughout freshwater reaches of the catchment. |

#### 3.2.2.2 Description of Present State

**MICROALGAE**

At present, the estuary is predominantly in State 2 during the dry summer months (December-April) and in State 3 during the wet winter months (May-November). Based on the simulated flows for the past 77 years, the estuary has a 7.8%, 79.2% and 33.8% chance each year of experiencing States 1, 4 and 5 respectively. As a result, conditions in the Palmiet Estuary can range from closed mouth conditions with very little river inflow to turbulent flood conditions.

Phytoplankton

Branch and Day (1984) measured phytoplankton chl-a that ranged from 2.12 to 7.76 µg $L^{-1}$ in December, and 1.48 to 4.82 µg $L^{-1}$ in April. These concentrations were low when compared to other permanently open estuaries but higher than expected in such a short estuary with a fast flow regime. Measurements suggest that phytoplankton cells were imported from the river and sea. A small dam, just behind the weir above the coastal road, may be the source of the phytoplankton biomass as there was little evidence of phytoplankton in the river upstream of the weir (Branch and Day 1984).

Phytoplankton status is likely to be controlled by the following processes during the various states;

- State 1: Low biomass due to competition for nutrients from macroalgae
- State 2: Low biomass but could increase in short term due to nutrient-rich freshets
- State 3: Intermediate biomass; limited by large tidal exchange
- State 4: Low biomass due to high river flow and short retention time
- State 5: Low biomass due to high river flow and short retention time

Benthic microalgae

The total area of the estuary, during the tidal state, is estimated to be 23 ha. A large sand flat, ~11 ha, on the western side of the estuary becomes exposed during low tides and provides an important available habitat for benthic microalgae. Branch and Day (1984) and Adams and Bate (unpublished data) recorded the highest benthic microalgal chl-a on the sand flat just above the mid-tide level. The estuary was sampled on 11 March 1992 and 22 November 1992 (Adams and Bate, Unpub. data) and intertidal chl-a ranged from 9 to 239 mg $m^{-2}$ (average = 105 ± 71 mg $m^{-2}$) and subtidal chl-a from 0 to 38 mg $m^{-2}$ (average = 22 ± 12 mg $m^{-2}$). These concentrations were similar to the nearby Berg Estuary, but lower than other South African estuaries.

A number of factors could influence benthic microalgal biomass in the Palmiet Estuary;

- The estuary is tannin-stained, limiting light penetration through the water column.
- Sediment in the estuary was dominated by gravel (65%) and sand (34%), which generally has a low organic content (<0.6%) and supports low microalgal biomass (Willis 1981).
- Turbulent tidal currents are capable of mobilising sediments. This is typical of sites near to the head and mouth of the estuary. Large floods (>500 $m^3 s^{-1}$) are capable of completely removing the sand flat area on the west bank.
- Nutrient concentrations are generally low in the estuary (DIN and DIP). However, sand-prawns accumulate organic matter in their burrows, potentially providing nutrients for microalgal and macroalgal growth.
- The condition of the mouth can affect intertidal microalgae because the intertidal habitat is flooded when the mouth is closed (States 1 and 2).

Benthic microalgal status is likely to be controlled by the following processes during the various states;

- State 1: Low biomass due to closed mouth, flooded intertidal zone and competition for resources with macroalgae
- State 2: Low biomass due to closed mouth, flooded intertidal zone and competition for resources with macroalgae
- State 3: Optimal biomass due to adequate tidal exchange and water level fluctuations
- State 4: Low biomass due to turbulent flow resulting in sediment mobilisation
- State 5: Low biomass due to turbulent flow resulting in sediment mobilisation

Confidence: Medium

**MACROPHYTES**

The small area of the Palmiet Estuary and the steep rocky banks restrict the development of estuarine plant communities. There are no rooted submerged macrophytes (e.g. *Zostera capensis, Ruppia cirrhosa*) because of high flows, unstable substrate and low light permeability of the estuary. The only comprehensive botanical survey of the estuary took place in the 1980s (Branch and Day 1984). They reported that the filamentous green algae *Cladophora* and *Enteromorpha* occurred in the estuary between December and April. These macroalgal mats would cover an area of approximately 1 ha. On the central, eastern bank of the estuary a small salt marsh (0.1 ha) exists on a sheltered region of the sandflat. Heydorn and Morant (1989) reported 12 different salt marsh species. Dominant species were the rush, *Juncus kraussii* and the grass *Sporobulus virginicus*. These plants indicate persistent brackish (< 15 ppt) rather than saline conditions. The status of the macrophytes for the different abiotic states would be as follows:

| | State 1 Closed | State 2 Semi - open | State 3 Open | State 4 | State 5 |
|---|---|---|---|---|---|
| Macroalgae | Abundant particularly in summer | Abundant particularly in summer | Present | Absent due to increase in flow | Absent high flow |
| Salt marsh | Die-back after 3 months inundation | Die-back after 3 months inundation | Abundant : tidal conditions | Present | Present : possible removal due to high flow |
| Reeds and sedges | Decreased growth if inundated for > 3 months spring / summer | Decreased growth if inundated for > 3 months spring / summer | Present | Present | Present : possible removal due to high flow |

Confidence: Medium

**INVERTEBRATES**

Zooplankton
No comprehensive study of the zooplankton has been undertaken, but biomass values provided by Branch and Day (1984) indicate a very depauperate fauna. This is typical for black-water systems, and zooplankton is unlikely to play an important part in the functioning of the estuary.

Benthic invertebrates
The number of invertebrate species in the estuary is low (28). Most of these are benthic (>75%), with some associated with rocky substrata (2 species) and about 4-5 insect species spending part of their life cycle in the aquatic medium. The sandprawn is the dominant species from a biomass perspective (ca 50%), followed by the amphipod *Grandidierella* sp. and the gastropod *Hydrobia* sp.

Hyperbenthos
Not known, but it is predicted that the hyperbenthos is extremely low in biomass or abundance.

Intertidal macrofauna
The sandprawn *Callianassa kraussi* colonises the intertidal sandbank in the lower estuary, equating to about 35% of the total surface area of the estuary covered by high tide. The gastropod *Hydrobia* and the polychaete *Ceratonereis* are also important on the intertidal sandbank, although from a biomass perspective, they probably contribute <10% to total intertidal biomass.

Confidence: Medium

**FISH**

A total of 25 fish species representing 16 families have been recorded from the Palmiet Estuary (Lamberth, unpublished, Bennett 1981, 1989a,b, Branch and Day 1984). Five of these are entirely dependent on estuaries to complete their lifecycle. These are *Gilchristella aestuaria,* which breeds only in estuaries, and *Lichia amia*, *Mugil cephalus*, *Myxus capensis* and *Lithognathus lithognathus,* which are dependent on estuaries as nursery areas. A further 14 species, e.g. *Pomatomus saltatrix* and *Solea bleekeri*, are at least partially dependent on estuaries. In all, 90 % of the fish species recorded from the Palmiet can be regarded as either partially or completely dependent on estuaries for their survival. The remaining six species recorded from the estuary are the indigenous freshwater Cape galaxias *Galaxias zebratus* and Cape kurper *Sandelia capensis*, the euryhaline freshwater introduced small and largemouth bass, *Micropterus dolomieu* and *M. salmoides* and bluegill sunfish Lepomis macrochirus, and the indigenous catadromous eel, *Anguilla mossambica*. No purely marine species have been recorded from the Palmiet Estuary.

A list of all species recorded in the Palmiet Estuary by reliable observers (a), by Bennett 1981 (b) and during a 1997-1998 seine and gill-net study (c). The species are classified into five major categories of estuarine-dependence as suggested by Whitfield 1994.

| Family name | Species name | Common name | Recorded by | Dependence category |
|---|---|---|---|---|
| Anabantidae | *Sandelia capensis* | Cape kurper | a | IV |
| Anguillidae | *Anguilla mossambica* | Longfin eel | a | V |
| Ariidae | *Galeichthys feliceps* | Barbel | b | IIb |
| Atherinidae | *Atherina breviceps* | Cape silverside | b,c | Ib |
| Carangidae | *Lichia amia* | Leervis | b,c | IIa |
| Centrarchidae | *Lepomis macrochirus* | Bluegill sunfish | a | IV |
| | *Micropterus dolomieu* | Smallmouth bass | c | IV |
| | *Micropterus salmoides* | Largemouth bass | c | IV |
| Clupeidae | *Gilchristella aestuaria* | Estuarine roundherring | b,c | Ia |
| Galaxiidae | *Galaxias zebratus* | Cape galaxias | a | IV |
| Gobiidae | *Caffrogobius multifasciatus* | Prison goby | b,c | Ib |
| | *Psammogobius knysnaensis* | Knysna sand-goby | b,c | Ib |
| Monodactylidae | *Monodactylus falciformis* | Cape moony | b,c | IIb |
| Mugilidae | *Liza dumerilii* | Groovy mullet | b | IIc |
| | *Liza richardsonii* | Harder | b,c | IIc |
| | *Liza tricuspidens* | Striped mullet | b | IIc |
| | *Mugil cephalus* | Springer mullet | b,c | IIa |
| | *Myxus capensis* | Freshwater mullet | b,c | IIa |
| Pomatomidae | *Pomatomus saltatrix* | Elf | b,c | IIc |
| Soleidae | *Solea bleekeri* | Blackhand sole | b,c | IIb |
| Sparidae | *Lithognathus lithognathus* | White steenbras | b | IIa |
| | *Rhabdosargus globiceps* | White stumpnose | b,c | IIc |
| | *Rhabdosargus holubi* | Cape stumpnose | b | IIc |
| Syngnathidae | *Syngnathus acus* | Pipefish | b | Ib |
| Teraponidae | *Terapon jarbua* | Thornfish | b | IIb |

Excluding the two indigenous and three introduced fish of freshwater origin, the 20 species listed in the Palmiet Estuary compare favourably with those recorded from the nearby, seasonally open Kleinmond Estuary (17 species), and normally closed Bot Estuary (12 species) (Bennett 1989). Entirely estuarine-dependent species compromise 24 % of the Palmiet species, compared to 33 % and 43 % in the Kleinmond and Bot estuaries respectively. Partially estuarine-dependent species comprise 67 % of the Palmiet Estuary fish fauna, which is higher than the 56 % of the Kleinmond and 43 % of the Bot estuaries. The relatively low proportion of entirely estuarine-dependent and high proportion of partially dependent species in the Palmiet compared to the Kleinmond and Bot is related to the duration of mouth closure. The normally closed Bot Estuary favours species that can complete their entire lifecycle in estuaries, whereas the seldom-closed Palmiet Estuary provides more opportunity for species that recruit from the sea. The importance of the Palmiet Estuary to these species is highlighted by the observation that it is the only permanently open estuary along the approximately 650 km between the Berg River in the west and Breede River on the south coast (Branch and Day 1984). During dry years, many of the estuaries in the southwestern Cape close prematurely in spring or remain closed throughout the year, hindering the recruitment of estuarine-dependent species that were spawned at sea. Although small, in some years the normally-open Palmiet may be the only estuary in the region preventing recruitment failure of some species.

Species composition and abundance (catch per haul) in monthly seine net samples from the Palmiet Estuary. Shading indicates months in which new recruits were recorded. After Bennett 1981 and 1989a.

| | Catch per haul | | | | | | | | | | | | Total catch |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | |
| *Liza richardsonii* | 218 | 1329 | 146 | 149 | 1154 | 381 | 295 | 73 | 307 | 54 | 8 | 326 | 9 173 |
| *Atherina breviceps* | | | | 24 | 3900 | | | | 34 | 2 | | 5 | 7 975 |
| *Psammogobius knysnaensis* | 8 | 71 | 31 | 14 | 23 | 26 | 35 | 5 | 7 | 13 | 4 | 3 | 501 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Lithognathus lithognathus* | 7 | 65 | 15 | 4 | | | | | | 11 | 25 | 65 | 389 |
| *Liza dumerilii* | | | | 30 | 7 | | | | | | | | 132 |
| *Myxus capensis* | 1 | | 7 | 8 | 9 | | | | 4 | 1 | 4 | 4 | 88 |
| *Gilchristella aestuaria* | 5 | 26 | 4 | | | | | | | | 5 | | 77 |
| *Rhabdosargus holubi* | 1 | 6 | 5 | 2 | | | | | | | | 2 | 34 |
| *Rhabdosargus globiceps* | 1 | 3 | 2 | 3 | | | | | | | 2 | 3 | 31 |
| *Mugil cephalus* | | | 1 | 2 | | | | | | 1 | 3 | | 16 |
| *Caffrogobius multifasciatus* | | 1 | 2 | 1 | | | | | 1 | 2 | | | 11 |
| *Pomatomus saltatrix* | 1 | | | | | | | | | | | 2 | 5 |
| *Lichia amia* | 1 | 1 | 1 | | | | | | | | | 1 | 5 |
| *Solea bleekeri* | 1 | | 1 | | | | | | | | 1 | | 3 |
| *Liza tricuspidens* | | 1 | | | | | | | | | | | 1 |
| Total | 241 | 1499 | 211 | 236 | 5092 | 407 | 330 | 77 | 352 | 84 | 49 | 408 | 18 441 |
| Number of species | 10 | 9 | 11 | 10 | 5 | 2 | 2 | 2 | 5 | 7 | 8 | 9 | |
| Number of species recruiting | 4 | 4 | 4 | 6 | 3 | 1 | 1 | 2 | 1 | 4 | 3 | 4 | |

### *3.2.3 Distribution and abundance*

A total of 18 442 fish, representing 15 species from 8 families, were caught in 26 seine-net hauls during the period April 1980 – April 1981 (Bennett 1989). In terms of numbers, two species, namely *Liza richardsonii* (50 %) and *Atherina breviceps* (43 %) together provided 93 % of the total catch. However, whereas catches of *L. richardsonii* were fairly consistent and dominant throughout the year, the bulk of the *A. breviceps* catch was made in one haul. A further three species, *Psammogobius knysnaensis* (3 %), *Lithognathus lithognathus* (2 %) and *Liza dumerili* (1 %) comprised most of the remaining catch. Overall catch per unit effort (*cpue*) was 79 fish.haul$^{-1}$ or 3.8 kg.haul$^{-1}$.

*Liza richardsonii* had the highest frequency of occurrence and was caught in all hauls throughout the year. Other species with high frequencies of occurrence were *P. knysnaensis* (88 %), *Myxus capensis* (50 %) and *L. lithognathus* (46 %) (Bennett 1989a). Catch per unit effort varied seasonally, being highest in autumn (May, 5 092 fish.haul$^{-1}$) and midsummer (February 1 499 fish.haul$^{-1}$), and lowest in early summer (November, 49 fish.haul$^{-1}$). The number of species caught was highest in late summer with a maximum of eleven in March, and lowest in winter when only two species were caught from June through to August. Multidimensional classification and ordination grouped these fish catches into winter (June-September), summer (October – February) and autumn (March – April) (Bennett 1989a).

Overall, fish numbers are low. Phytoplankton biomass is low throughout all 5 states, favouring *Atherina breviceps* over *G. aestuaria*, the former being a more accomplished clearwater selective feeder. Low benthic algal biomass accounts for the relatively low numbers of Mugilidae compared to other estuaries. High macroalgal biomass during the summer months can provide habitat for *Syngnathus temminckii* and *Rhabdosargus holubi,* but night-time respiration and eventual decomposition may lower oxygen levels, thus excluding them. Low benthic oxygen conditions during states 1and 2 may account for the low numbers of benthic species such as *Solea bleekeri* and *Caffrogobius* spp. for much of the time.

Of the fourteen sea spawning estuarine-dependent species listed in the table above, ten spawn during winter and/or spring which enables them to enter estuaries in early summer when flows are reduced but the mouths still open. Bennett (1981) recorded nine species recruiting into the Palmiet Estuary, of which seven enter the system during the summer months. One species, *Myxus capensis* recruited during spring and summer, whereas *L. richardsonii* recruited throughout the year. Ripe adults of five species were observed in the Palmiet Estuary from September through to March, none during the winter (Bennett 1981). These were *L. richardsonii*, *M. capensis*, *P. knysnaensis*, *Syngnathus acus* and *G. aestuaria*. No 'ripe and running' fish were observed during Bennett's (1981) study.

Bennett (1989b) found no clear seasonal patterns in food preference for any of the fish species examined from the Palmiet Estuary. It is likely however, that food availability drops during the winter floods when much of it is washed out to sea. In general, small juveniles (< 30 mm) of all species fed almost exclusively on zooplankton before switching to their adult diets. Three species, *L. lithognathus*, *Rhabdosargus globiceps* and *Rhabdosargus holubi* were omnivorous, two; *Lichia amia* and *Pomatomus saltatrix* were piscivorous whereas the five mullet species were detritivorous. The remaining 11 species were carnivorous, feeding largely on small invertebrates.

Confidence: Medium

**BIRDS**

In total the estuary covers an area of about 23 ha, and at high tide has a volume of approximately 360 000$m^3$ (Branch and Day 1984). The intertidal sand flat has an area of about 11 ha. In addition, there is a small area of saltmarsh of less than 1 ha. Due to the scouring action of floods, the estuary's sediments are unusually coarse. Sand makes up most of the sediment of the estuary, and the muddy component is virtually insignificant (Branch and Day 1984).

Run-off is highly seasonal, with high flows and major floods occurring during winter months and low flows during summer. Strong stratification occurs throughout the year. Clear sea water penetrates almost to the head of the estuary during summer, but does not penetrate far during winter. This salt water is overlaid by dark humic-acid stained fresh water (Branch and Day 1984).

The Palmiet River estuary contains relatively few waterbird species relative to other estuaries in the region. A total of 24 waterbird species have been recorded on the estuary, of which at least three (African Penguin, Arctic Tern and Sand Martin) are probably not very frequent visitors to the estuary. A total of 30 birds were counted on the estuary in 1981, and 474 were counted in 1997, including a flock of 400 terns. For the sake of comparison, the top 10, 20 and 40 estuaries in the country for waterbirds contain at least 43, 34 and 21 species, and at least 13 000, 2200 and 580 birds, respectively (Turpie 1995).

Waterbird species recorded on the Palmiet Estuary (Underhill and Cooper 1984, Clarke 1989, this study), and the numbers recorded in January 1981 (Underhill and Cooper 1984) and December 1997 (Turpie 1998) include:

| **Species** | **January 1981** | **December 1997** |
|---|---|---|
| African Penguin* | | |
| Whitebreasted Cormorant | 2 | 15 |
| Cape Cormorant | 1 | |
| Reed Cormorant | | 4 |
| Darter | | |
| Little Egret | | 1 |
| African Spoonbill | | |
| Egyptian Goose | | |
| Cape Shoveller# | | 2 |
| Osprey | 1 | 1 |
| African Black Oystercatcher# | | 1 |
| Whitefronted Plover | | 2 |
| Sanderling | | |
| Common Sandpiper | 11 | |
| Greenshank | 2 | |
| Kelp Gull | | 18 |
| Hartlaub's Gull# | 10 | 29 |
| Common Tern | | 330 |
| Arctic Tern | | |
| Sandwich Tern | | 30 |
| Swift Tern | | 40 |
| Pied Kingfisher | | |
| Sand Martin | | |
| Cape Wagtail# | 3 | 1 |

* Red Data Species (Brooke 1984).
# Endemic to southern Africa.

In addition, the estuary does not support important populations of any species of conservation significance. The only Red Data species recorded in the area, the African Penguin (Barnes 2000), is likely to have been recorded on the beach in front of the estuary, and is certainly not in anyway dependent on the estuary. Thus the estuary is not of particular importance in terms of its waterbirds.

The estuary's avifauna is dominated by terns and gulls. Terns were not recorded during the 1981 survey, but fairly high numbers were recorded in 1997, and several were present during a site visit in September 2009. The presence of terns in the estuary is probably highly variable on a tidal as well as a seasonal basis. These terns probably forage mainly at sea, but they also forage to some extent in the lower estuary. Terns roost on the intertidal flats within the estuary at low tide, as well as on the sand spit at the mouth at high tide. Gulls are relatively common on the estuary, and their increase in numbers probably reflects their general population increases in the south-western Cape to some extent. Kelp Gulls use the estuary as a roosting site, concentrating mainly on the sand spit near the mouth, but also using the intertidal flats at low tide. Hartlaub's Gulls, on the other hand, feed in the estuary on the sandflats at low tide.

Waders are conspicuously absent from the estuary, in spite of a relatively large area of intertidal flats, which have a reasonably high invertebrate biomass per unit area (Branch and Day 1984). In 1981, waders were virtually absent from the count, except for Common Sandpipers and Greenshank. Common Sandpipers prefer rocky and relatively fresh-water habitats, where they forage solitarily and usually occur at very low densities. The number recorded was thus probably a communal roost of birds from the estuary and areas beyond.

African Black Oystercatchers are primarily coastal, rather than estuarine, birds, and breed and feed mainly on the rocky and sand shores on either side of the estuary. Although the conservation of African Black Oystercatchers in this area is currently of considerable concern due to the escalating threats of human and vehicle disturbance, it is unlikely that the Palmiet River Estuary is important for this species, owing to the paucity of suitable prey species such as pencilbait (*Solen* spp.) (Branch and Day 1984). The estuary may, however, provide a refuge for the birds when disturbed from their coastal territories. Similarly, Whitefronted Plovers, which generally prefer sandy habitats, were recorded on the sand spit at the mouth, and probably do not enter the estuary much beyond this area.

Despite the fact that several suitable prey species, such as polychaete worms (*Ceratonereis*) exist on the estuary, there is also an almost total absence of small waders such as Curlew Sandpipers, which are normally common on predominantly open estuaries. The absence of larger waders could be explained by a lack of large surface-active macroinvertebrates such as crabs, although the cryptic *Hymenosoma* crabs were recorded in low numbers (Branch and Day 1984). The absence of these birds may not be due to the lack of food *per se*, but could be due to other limiting factors, such as the lack of a suitable high tide roost site on the estuary.

The low overall numbers of birds on the estuary have been ascribed to the small size of the estuary, and possibly to human disturbance (Clarke 1989). Apart from the influence of overall size of the estuary, the low numbers and diversity of birds on the Palmiet River estuary can probably be ascribed to its low nutrient status and lack of habitat diversity and resultant lack availability of food in the system.

The low diversity of habitats is partly ascribed to the steep-sided nature of most of the estuary, as well as the surrounding vegetation. There is a notable absence of emergent and overhanging vegetation, and even of intertidal saltmarsh. These habitats, particularly the first two, would ordinarily attract additional species to the area because they provide cover, roost sites and hunting perches. The saltmarsh vegetation is too restricted in area to be of any significance to the avifaunal community.

The diversity of food available in the estuary for birds is relatively low. There is very little in the way of vegetation or algae in the estuary (at least during summer), and no herbivorous species have been recorded. Probably largely due to the coarse, sandy sediments of the estuary, the diversity of invertebrates is relatively low. However, the invertebrate community is characterised by relatively high densities of a few dominant species, and biomass reaches $35 g.m^{-2}$ at the mid-tide level on the sand flats (Branch and Day 1984). *Callianassa* densities are also high, but generally not available to birds. Fish diversity is relatively high compared to other estuaries in the region, and juvenile abundance is high. It is thus not surprising that piscivorous birds, such as terns, cormorants, kingfisher and osprey dominate the estuary avifauna.

Confidence: High

## 3.3 REFERENCE CONDITION

### *3.3.1 Abiotic Components*

#### 3.3.1.1 Seasonal variability in river inflow

Under the Reference Condition, the mean annual runoff (MAR) into the Palmiet Estuary was *c*. 256.3 million $m^3$.

The flow distributions (mean monthly flows in $m^3s^{-1}$) under the Reference Condition, derived from a 77-year simulated data set is provided in Table 3.9. The full 77-year series of simulated monthly runoff data for the Reference Condition is provided in Table 3.10. A graphic representation of the percentage occurrence of the various abiotic states is presented in Figure 3.3.

**Table 3.9 A summary of the monthly flows ($m^3s^{-1}$) distribution under the Reference Condition**

| | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 99%ile | 20.75 | 12.24 | 8.20 | 7.55 | 6.28 | 6.35 | 17.60 | 26.86 | 39.84 | 42.97 | 39.25 | 27.57 |
| 90%ile | 13.94 | 7.61 | 4.33 | 2.70 | 2.45 | 2.85 | 9.03 | 18.82 | 30.62 | 28.02 | 27.31 | 21.39 |
| 80%ile | 11.14 | 5.75 | 2.38 | 1.71 | 1.80 | 1.88 | 5.47 | 12.09 | 23.02 | 24.86 | 23.17 | 16.63 |
| 70%ile | 9.18 | 4.90 | 2.12 | 1.47 | 1.53 | 1.47 | 4.15 | 10.03 | 18.64 | 22.68 | 20.43 | 15.54 |
| 60%ile | 7.01 | 4.53 | 1.89 | 1.19 | 1.13 | 1.23 | 3.03 | 8.61 | 15.99 | 19.08 | 19.09 | 13.76 |
| 50%ile | 6.41 | 3.80 | 1.80 | 1.14 | 1.07 | 1.09 | 2.40 | 6.99 | 12.31 | 17.07 | 16.47 | 12.65 |
| 40%ile | 5.97 | 3.44 | 1.65 | 1.07 | 0.99 | 0.96 | 1.93 | 5.35 | 10.30 | 15.22 | 14.88 | 10.51 |
| 30%ile | 5.43 | 3.13 | 1.57 | 1.02 | 0.94 | 0.86 | 1.60 | 4.68 | 7.92 | 12.81 | 13.29 | 9.19 |
| 20%ile | 4.94 | 2.70 | 1.47 | 0.92 | 0.89 | 0.80 | 1.41 | 4.20 | 6.63 | 10.92 | 11.57 | 7.73 |
| 10%ile | 4.13 | 2.33 | 1.28 | 0.84 | 0.82 | 0.75 | 1.02 | 2.91 | 5.17 | 7.93 | 10.08 | 6.54 |
| 1%ile | 2.61 | 1.69 | 1.04 | 0.57 | 0.55 | 0.35 | 0.79 | 1.88 | 2.43 | 4.40 | 7.32 | 4.55 |

#### 3.3.1.2 Reference flood regime

Floods would have been about 25% greater and occurred about 55% more frequently under the Reference Conditions.

*Confidence: Medium.*

#### 3.3.1.3 Reference sediment processes

Under natural conditions, catchment-derived sediments (mostly coarse grained sand) albeit in limited amounts would have been dispersed amongst the larger rocks in the upper reaches. The upper reaches would therefore have comprised a mixed rocky-sandy area versus the current rocky substrate.

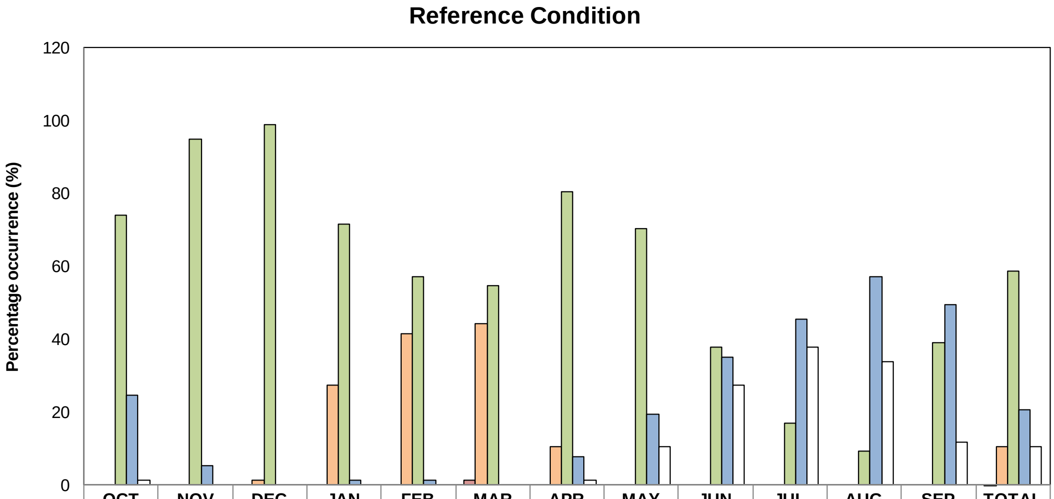
As floods would have occurred significant more frequently, there would have been less frequent build-up of marine sediment in the lower reaches with a related increase in inter- and subtidal habitat.

*Confidence: Low.*

## Table 3.10 Simulated monthly flows to the Palmiet Estuary for the Reference Condition ($m^3s^{-1}$)

| YEAR | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1928 | 6.19 | 2.69 | 1.84 | 1.14 | 0.92 | 0.79 | 4.66 | 4.69 | 5.78 | 23.06 | 23.19 | 8.81 |
| 1929 | 3.42 | 2.13 | 1.58 | 1.18 | 1.37 | 1.41 | 1.40 | 1.59 | 2.44 | 4.45 | 10.40 | 27.01 |
| 1930 | 11.07 | 4.80 | 2.18 | 1.02 | 1.01 | 0.82 | 7.58 | 6.99 | 5.09 | 8.92 | 22.57 | 17.93 |
| 1931 | 12.68 | 5.45 | 2.09 | 1.39 | 2.46 | 1.61 | 1.11 | 8.27 | 12.20 | 17.30 | 10.74 | 16.64 |
| 1932 | 8.21 | 3.19 | 1.57 | 1.06 | 0.98 | 0.87 | 0.97 | 4.19 | 22.63 | 22.64 | 19.41 | 9.72 |
| 1933 | 5.38 | 2.97 | 1.27 | 0.83 | 1.00 | 0.94 | 0.86 | 4.48 | 6.63 | 7.21 | 15.09 | 16.62 |
| 1934 | 10.86 | 4.72 | 1.56 | 0.86 | 0.83 | 1.52 | 3.86 | 11.25 | 12.19 | 13.49 | 8.92 | 9.23 |
| 1935 | 4.92 | 4.37 | 2.20 | 3.10 | 2.08 | 1.50 | 1.44 | 8.38 | 8.07 | 13.46 | 14.85 | 11.38 |
| 1936 | 6.15 | 4.66 | 4.29 | 2.13 | 1.12 | 1.19 | 2.60 | 5.45 | 27.16 | 33.52 | 14.92 | 8.43 |
| 1937 | 6.03 | 3.26 | 1.44 | 1.24 | 1.12 | 1.10 | 4.46 | 7.72 | 6.13 | 6.21 | 11.56 | 17.82 |
| 1938 | 8.52 | 3.75 | 1.74 | 0.97 | 2.39 | 1.75 | 3.41 | 6.52 | 5.23 | 7.89 | 16.65 | 8.85 |
| 1939 | 4.04 | 2.96 | 1.83 | 1.06 | 3.22 | 2.30 | 9.05 | 8.27 | 19.12 | 13.94 | 6.75 | 9.23 |
| 1940 | 5.15 | 5.03 | 2.55 | 1.85 | 1.53 | 0.94 | 12.51 | 23.78 | 29.70 | 20.01 | 16.47 | 29.37 |
| 1941 | 14.00 | 4.66 | 2.35 | 1.69 | 1.22 | 0.89 | 1.56 | 10.00 | 31.55 | 15.76 | 14.20 | 7.66 |
| 1942 | 3.99 | 2.03 | 1.28 | 6.51 | 4.01 | 1.71 | 2.65 | 3.85 | 5.39 | 15.27 | 24.91 | 13.01 |
| 1943 | 5.94 | 3.96 | 1.83 | 1.10 | 0.97 | 0.87 | 1.41 | 10.17 | 42.29 | 23.01 | 24.90 | 21.96 |
| 1944 | 10.69 | 4.24 | 2.06 | 1.14 | 0.86 | 0.72 | 1.99 | 20.68 | 36.43 | 41.73 | 28.65 | 9.56 |
| 1945 | 8.22 | 5.21 | 1.89 | 1.07 | 0.94 | 2.28 | 2.60 | 3.16 | 4.73 | 7.74 | 14.86 | 17.19 |
| 1946 | 6.80 | 2.66 | 1.21 | 0.82 | 0.78 | 2.54 | 2.53 | 5.24 | 5.81 | 27.75 | 17.76 | 7.06 |
| 1947 | 4.27 | 2.67 | 1.37 | 0.90 | 0.88 | 1.45 | 1.88 | 4.40 | 7.50 | 15.19 | 10.11 | 16.93 |
| 1948 | 14.08 | 5.79 | 1.65 | 1.09 | 0.98 | 0.77 | 4.13 | 5.28 | 6.55 | 10.85 | 14.14 | 13.61 |
| 1949 | 6.32 | 4.73 | 2.34 | 1.16 | 0.91 | 0.73 | 7.19 | 4.03 | 2.38 | 23.41 | 11.35 | 15.79 |
| 1950 | 10.01 | 10.68 | 5.40 | 2.31 | 1.36 | 0.96 | 9.02 | 7.09 | 31.37 | 25.03 | 15.43 | 25.57 |
| 1951 | 11.98 | 5.57 | 2.38 | 1.02 | 0.86 | 1.21 | 1.53 | 6.12 | 5.71 | 13.25 | 22.35 | 16.14 |
| 1952 | 7.03 | 4.87 | 2.36 | 1.09 | 0.94 | 0.79 | 11.18 | 15.96 | 10.26 | 16.92 | 14.84 | 6.57 |
| 1953 | 4.19 | 3.72 | 1.98 | 1.04 | 0.96 | 1.03 | 3.45 | 24.58 | 23.99 | 38.77 | 35.05 | 14.84 |
| 1954 | 5.84 | 3.27 | 1.87 | 1.14 | 11.23 | 5.01 | 2.23 | 1.97 | 7.31 | 21.36 | 35.82 | 15.47 |
| 1955 | 12.89 | 6.22 | 2.11 | 1.05 | 0.95 | 1.23 | 1.44 | 9.35 | 18.52 | 16.41 | 15.45 | 7.74 |
| 1956 | 5.64 | 3.20 | 1.61 | 1.05 | 2.20 | 2.24 | 2.47 | 23.14 | 32.01 | 29.58 | 26.16 | 13.64 |
| 1957 | 19.96 | 7.91 | 1.59 | 0.84 | 2.47 | 2.26 | 2.22 | 8.84 | 12.31 | 6.70 | 20.24 | 10.29 |
| 1958 | 5.44 | 3.48 | 1.55 | 1.07 | 1.00 | 1.06 | 15.39 | 34.08 | 15.69 | 7.96 | 20.25 | 11.19 |
| 1959 | 6.53 | 3.47 | 1.37 | 0.92 | 0.88 | 1.09 | 1.45 | 5.89 | 17.90 | 10.88 | 7.50 | 7.01 |
| 1960 | 4.47 | 2.29 | 1.77 | 3.92 | 2.31 | 0.94 | 1.05 | 3.10 | 7.59 | 11.09 | 20.40 | 15.23 |
| 1961 | 6.91 | 3.16 | 1.28 | 0.93 | 1.12 | 1.46 | 4.55 | 3.40 | 27.82 | 17.76 | 28.17 | 13.42 |
| 1962 | 16.60 | 7.78 | 2.01 | 1.49 | 1.20 | 0.88 | 1.13 | 3.14 | 9.70 | 26.17 | 30.57 | 12.25 |
| 1963 | 4.53 | 2.99 | 1.90 | 1.14 | 1.66 | 1.32 | 1.82 | 2.80 | 15.49 | 20.63 | 26.47 | 12.65 |
| 1964 | 9.64 | 6.96 | 2.79 | 1.17 | 1.78 | 2.43 | 4.25 | 8.55 | 7.95 | 11.31 | 13.35 | 7.25 |
| 1965 | 5.57 | 3.59 | 2.72 | 1.58 | 1.08 | 2.98 | 2.97 | 4.90 | 6.77 | 18.98 | 21.73 | 14.29 |
| 1966 | 5.55 | 2.35 | 1.16 | 0.84 | 0.81 | 0.97 | 13.33 | 8.77 | 17.50 | 16.92 | 12.69 | 7.28 |
| 1967 | 7.69 | 4.35 | 1.80 | 1.46 | 1.55 | 1.01 | 2.36 | 12.16 | 19.34 | 19.14 | 18.15 | 8.29 |
| 1968 | 9.13 | 4.33 | 1.74 | 1.71 | 1.69 | 1.32 | 2.55 | 2.16 | 7.80 | 8.30 | 11.99 | 12.09 |
| 1969 | 11.15 | 5.10 | 1.54 | 0.91 | 1.05 | 0.86 | 0.79 | 6.67 | 16.04 | 19.77 | 22.74 | 13.83 |
| 1970 | 6.47 | 3.77 | 2.59 | 1.55 | 1.03 | 0.86 | 0.91 | 2.86 | 6.65 | 14.77 | 19.74 | 9.03 |
| 1971 | 4.30 | 2.60 | 1.41 | 1.15 | 1.53 | 1.34 | 6.12 | 9.37 | 8.54 | 10.13 | 13.05 | 7.84 |
| 1972 | 4.02 | 2.06 | 1.40 | 1.06 | 0.89 | 0.77 | 0.96 | 2.33 | 2.87 | 17.07 | 12.99 | 12.79 |
| 1973 | 6.35 | 2.80 | 1.49 | 1.03 | 0.92 | 0.79 | 0.79 | 8.39 | 11.69 | 11.06 | 50.11 | 26.47 |
| 1974 | 14.84 | 5.98 | 1.84 | 1.24 | 1.07 | 0.80 | 1.72 | 11.80 | 11.76 | 26.44 | 23.82 | 9.23 |
| 1975 | 6.26 | 3.80 | 1.57 | 0.87 | 0.85 | 1.15 | 2.27 | 4.37 | 30.12 | 25.04 | 11.63 | 11.52 |
| 1976 | 6.36 | 12.24 | 7.72 | 2.62 | 1.94 | 1.91 | 4.98 | 21.70 | 33.23 | 32.92 | 30.99 | 14.53 |
| 1977 | 5.27 | 2.91 | 1.71 | 1.12 | 1.09 | 1.30 | 2.28 | 2.64 | 2.96 | 7.39 | 17.64 | 16.07 |
| 1978 | 9.80 | 4.63 | 2.30 | 1.84 | 4.18 | 3.23 | 1.14 | 12.11 | 18.07 | 12.92 | 11.38 | 10.85 |
| 1979 | 17.08 | 6.44 | 1.59 | 1.58 | 1.77 | 0.99 | 3.07 | 9.00 | 15.66 | 8.46 | 9.63 | 6.11 |
| 1980 | 5.17 | 10.54 | 7.34 | 10.86 | 4.72 | 2.78 | 5.31 | 4.45 | 4.82 | 21.20 | 23.63 | 24.69 |
| 1981 | 7.43 | 2.76 | 1.90 | 1.37 | 1.05 | 0.86 | 5.89 | 5.17 | 9.12 | 8.03 | 8.43 | 7.72 |
| 1982 | 5.42 | 2.61 | 3.16 | 1.71 | 4.43 | 3.71 | 1.71 | 15.92 | 29.87 | 26.03 | 14.67 | 17.91 |
| 1983 | 8.23 | 2.43 | 1.42 | 0.99 | 1.06 | 1.22 | 1.86 | 24.21 | 12.17 | 16.47 | 8.74 | 16.15 |
| 1984 | 13.90 | 5.24 | 5.56 | 3.42 | 2.24 | 7.37 | 7.09 | 4.25 | 10.14 | 24.17 | 20.53 | 9.22 |
| 1985 | 6.41 | 4.04 | 1.71 | 0.97 | 1.68 | 2.96 | 4.85 | 4.73 | 13.41 | 17.60 | 35.67 | 16.24 |
| 1986 | 4.55 | 3.39 | 1.46 | 1.25 | 1.60 | 1.11 | 3.64 | 12.89 | 18.32 | 14.20 | 18.91 | 12.93 |
| 1987 | 5.38 | 1.78 | 3.04 | 0.93 | 0.56 | 1.00 | 3.90 | 6.90 | 13.23 | 16.95 | 10.02 | 15.03 |
| 1988 | 4.66 | 3.85 | 0.82 | 0.48 | 0.53 | 6.03 | 12.19 | 11.66 | 17.91 | 18.41 | 21.23 | 22.34 |
| 1989 | 11.51 | 7.13 | 2.00 | 1.01 | 1.81 | 1.54 | 8.06 | 17.58 | 20.96 | 27.67 | 17.79 | 6.49 |
| 1990 | 2.87 | 2.70 | 1.57 | 0.69 | 0.64 | 0.11 | 0.92 | 10.33 | 21.29 | 28.42 | 16.49 | 15.97 |
| 1991 | 9.36 | 6.18 | 1.65 | 0.60 | 0.93 | 0.79 | 5.51 | 12.73 | 38.39 | 22.87 | 14.41 | 12.69 |
| 1992 | 17.53 | 7.50 | 1.79 | 0.83 | 1.13 | 0.80 | 24.57 | 12.00 | 22.89 | 46.92 | 16.17 | 3.92 |
| 1993 | 2.39 | 1.42 | 2.28 | 0.59 | 0.68 | 0.72 | 1.60 | 5.01 | 39.07 | 20.05 | 9.66 | 5.51 |
| 1994 | 5.03 | 2.01 | 1.28 | 0.86 | 0.67 | 0.43 | 1.54 | 9.46 | 13.98 | 24.03 | 19.22 | 6.29 |
| 1995 | 13.58 | 5.16 | 8.78 | 2.86 | 1.10 | 1.23 | 1.53 | 2.94 | 22.16 | 26.05 | 15.78 | 18.63 |
| 1996 | 23.24 | 12.25 | 8.02 | 2.82 | 1.19 | 0.81 | 1.92 | 8.65 | 23.06 | 11.76 | 12.51 | 5.86 |
| 1997 | 2.68 | 8.66 | 4.39 | 1.81 | 0.95 | 0.98 | 3.18 | 23.78 | 16.81 | 17.80 | 10.60 | 4.74 |
| 1998 | 3.66 | 9.60 | 4.86 | 2.05 | 0.94 | 0.72 | 1.69 | 4.51 | 10.37 | 11.22 | 10.24 | 11.77 |
| 1999 | 5.65 | 2.31 | 1.11 | 1.33 | 0.56 | 1.75 | 1.14 | 4.62 | 10.86 | 17.52 | 12.38 | 21.01 |
| 2000 | 5.83 | 2.43 | 1.22 | 0.85 | 1.08 | 0.52 | 0.93 | 14.43 | 8.12 | 36.38 | 26.73 | 22.72 |
| 2001 | 6.44 | 3.41 | 1.51 | 5.47 | 2.45 | 0.82 | 1.95 | 6.12 | 15.92 | 22.88 | 19.22 | 6.49 |
| 2002 | 6.49 | 3.67 | 1.58 | 1.07 | 0.93 | 3.86 | 2.40 | 5.13 | 4.79 | 4.26 | 19.57 | 13.87 |
| 2003 | 6.97 | 3.26 | 1.81 | 1.53 | 0.88 | 0.83 | 1.25 | 2.11 | 6.68 | 12.39 | 15.02 | 6.89 |
| 2004 | 12.89 | 4.86 | 1.57 | 1.20 | 0.93 | 0.60 | 12.74 | 11.27 | 24.62 | 12.28 | 23.09 | 9.61 |

| State 1 | <0.15 | State 2 | **0.15-1** | State 3 | 1-10 | State 4 | 10 - 20 | State 5 | > 20 |
|---|---|---|---|---|---|---|---|---|---|




| | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| State 1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 |
| State 2 | 0.0 | 0.0 | 1.3 | 27.3 | 41.6 | 44.2 | 10.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 10.4 |
| State 3 | 74.0 | 94.8 | 98.7 | 71.4 | 57.1 | 54.5 | 80.5 | 70.1 | 37.7 | 16.9 | 9.1 | 39.0 | 58.7 |
| State 4 | 24.7 | 5.2 | 0.0 | 1.3 | 1.3 | 0.0 | 7.8 | 19.5 | 35.1 | 45.5 | 57.1 | 49.4 | 20.6 |
| State 5 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.3 | 10.4 | 27.3 | 37.7 | 33.8 | 11.7 | 10.3 |

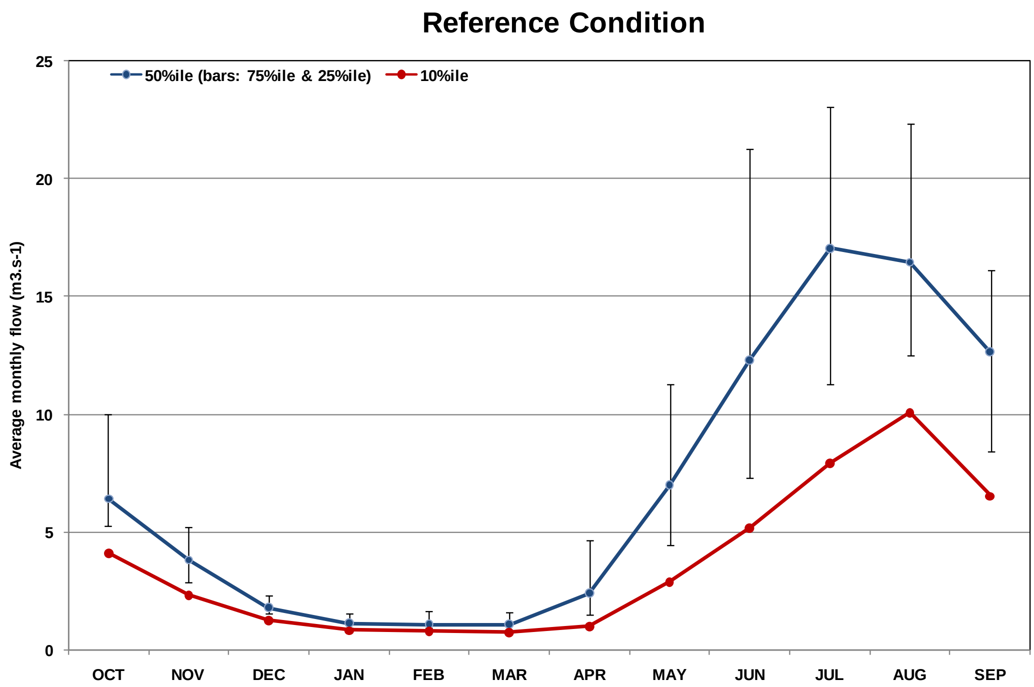



**Figure 3.4 Graphic representations of the occurrence of the abiotic states under the Reference Condition**

### 3.3.1.4 Droughts

Hydrological drought conditions in the Palmiet Estuary are defined as years in which the annual inflow (million $m^3$) falls below the Reference Condition 10%ile, i.e. 175 million $m^3$. Figure 3.5 shows that this condition never occurred for more than a year at a time.

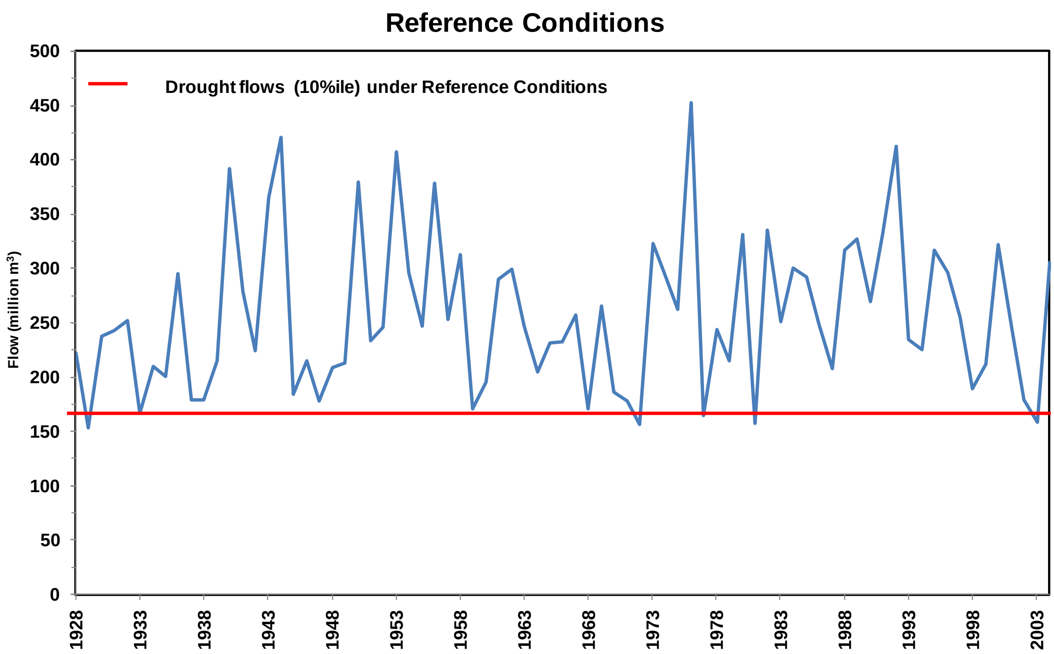



**Figure 3.5 Drought conditions in the Palmiet Estuary under the Reference Condition**

### *3.3.2 Biotic Components*

3.3.2.1 Change in biotic characteristics from the Reference Condition to the Present State

**MICROALGAE**

The largest changes from the reference to present state have been the 36.1% decrease in river flow and the 45% decrease in pulses/floods exceeding 50 $m^3 s^{-1}$. Dams in the catchment trap sediment being transported from the catchment, preventing the infilling of rocky areas in the upper reaches.

Based on the simulated 76 year reference and present flow records (Tables 3.6 and 3.10), there has been a distinct shift in the chance (%) that any particular state will occur in any given year;

State 1: Ref = 1.3%; present = 7.7%
State 2: Ref = 66.6%; present = 100%
State 3: Ref = 100%; present = 100%
State 4: Ref = 94.9%; present = 78.2%
State 5: Ref = 61.5%; present = 33.4%

As river flow has decreased, there has been a decrease in the occurrence of States 4 and 5 and an increase in States 1 and 2. It is important to note that the mouth only closed once in the reference condition simulated flows (Table 3.9), and this increased to six times in 77 years (Table 3.3).

Phytoplankton
River water flowing into the estuary would have been low in nutrients, resulting in the estuary being oligotrophic and microalgal biomass low (<5 µg $L^{-1}$) due to nutrient limited growth. In addition, there was no small dam behind the gauging weir acting as a source of phytoplankton to the estuary. It is unlikely there was specific group dominating the phytoplankton, but there would have been a broad suite of small-celled phytoplankton, probably made up of diatoms, chlorophytes, dinoflagellates and flagellates; the majority imported in the river water. It is unlikely that cyanophytes would have been present for any significant length of time (States 1 and 2).

Benthic microalgae
The mouth of the estuary would have opened more frequently and for longer periods in the reference state,

supporting a higher biomass of intertidal benthic microalgae on the sand flat located on the west side of the lower reaches. However, floods occurred more frequently and with higher intensity, which would have mobilised large loads of sediment and effectively 'reset' the estuary; floods with flows in excess of 500 $m^3 s^{-1}$ would have occurred more frequently and are likely to have scoured away the entire sand flat. Microalgal cells would have been almost entirely dependent on remineralised nutrients from imported organic matter and from the local sand prawn population. Biomass would have been highest above the mid-tide mark in the intertidal zone, but the oligotrophic conditions would have kept the biomass lower than present.

Confidence: Medium

**MACROPHYTES**

The reduction in flooding and extended drought periods would result in stagnant water conditions and an increase in macroalgal growth (e.g. *Cladophora* spp). This is a problem, as decomposition of the organic load leads to anoxic conditions. The increase in the duration of semi-closed mouth conditions would increase macroalgal growth. Higher water levels and closed mouth conditions would result in inundation and die-back of the small area of salt marsh. This reduction in river flow would reduce allochthonous inputs from the river. As a result of this and the increase in semi-closed mouth conditions, the estuary would be cut off from the two main sources that maintain its functional state, i.e. freshwater input and tidal exchange.

Confidence: Medium

**INVERTEBRATES**

<u>Zooplankton</u>
It is unlikely that the zooplankton has ever played an important role in the functioning of the Palmiet Estuary. Under the reference condition, variability in biomass and species would have been greater, but because of their already low numbers/biomass, changes are minimal.

<u>Zoobenthos</u>
Biomass of the sandprawn *Callianassa kraussi* was probably lower under natural conditions, due to the greater magnitude of larger floods (25% higher) and the greater frequency of intermediate and large floods (55%). Sediment particle size would also have been coarser, leading to less dense populations (indicated by the current trend of increasing particle size upstream). Under the reference condition, larger areas of the substrate was also made up of hard rock in the upper reaches, while the intertidal sandbank at the mouth would have been smaller because of the greater frequency of erosion (reduced time to accumulated between floods)

<u>Hyperbenthos</u>
Unknown, but it is likely that species such as *Palaemon capensis* was more common under natural conditions (currently, its habitat is restricted by the weir above the road bridge). It is also possible that *Macrobrachium* sp. was also more common under the natural state for the same reason, but its geographical distribution westwards, as currently recorded, extends as far as the Breede Estuary. Formal documentation indicates the Gamtoos Estuary as the western boundary.

Confidence: Medium

**FISH**

The fish assemblage is unlikely to have changed much from reference conditions. The frequency of occurrence of state 2 conditions would have been sufficient for low oxygen conditions to exclude benthic species from most of the deeper parts of the estuary. Similarly, benthic microalgae biomass may have been higher under reference, favouring the *Mugillidae,* but more frequent flood scouring would have limited these opportunities. An increase in macroalgal biomass since reference may have seen an increase in low oxygen levels through night time respiration and decomposition. Zooplankton levels were and remain low. The fact that zooplankton are at low numbers and the main diet of new recruits into the estuary, may explain the low levels of species such as *L. lithognathus* and *R. holubi*. *Callianassa kraussi* have increased in numbers from reference, but their availability as prey for fish is still likely to be governed by the relationships between freshwater flow and burrow quantity and depth.

Confidence: Low

**BIRDS**

The estuary is depauperate in terms of avifauna, and probably always has been, due to its coarse substrate, lack of habitat diversity, and lack of food availability. Indications are that these factors have not changed significantly relative to the Reference State. The main change is that increased closed or semiclosed conditions will have made the system slightly less attractive to waders, gulls and terns, and more attractive to wading birds and waterfowl. The system has probably always served as a roost site for gulls and terns, but this function may be impacted by human disturbance during peak summer periods. At the same time, numbers of gulls may have increased somewhat due to regional increases in their populations. Thus it is probably reasonable to assume that there have not been any major changes in abundance or community structure, other than those that might have occurred through non-flow related changes (regional population, human disturbance).

Confidence: Medium

## 3.4 PRESENT ECOLOGICAL STATUS OF THE PALMIET ESTUARY

### *3.4.1 Abiotic Components*

#### 3.4.1.1 Hydrology

| VARIABLE | SCORE | MOTIVATION | CONFIDENCE |
|---|---|---|---|
| a.% Similarity in period of low flows OR present MAR as a % of MAR in the reference condition | 74 | For the Palmiet Estuary low flows are defined as months in which river inflow to the estuary is < 1.0 $m^3s^{-1}$ i.e. flows representative of State 1 (closed mouth) and State 2 (semi-closed).<br><br>Months with flows of less than 1.0 $m^3/s$ occurred under the reference condition for 10.5% (~1 month) of the year for the simulated period. Under the present state low flows now occur for 36.4% (~4.5 months) of the year.<br><br>*Formula: (100 – (% Reference -% Present)) DWAF (2004)* | High |
| b.% Similarity in mean annual frequency of floods | 55 | As Palmiet Estuary is a relatively small estuary, comparatively small floods would be able to reset its sediment processes, but the frequency at which these events occur is of great importance, as this drives the rate at which the deposition/erosion cycle in the system occur.<br><br>The flood analysis of the daily flow data indicates that there is about a 55% reduction in the occurrence of large and intermediate floods to the Palmiet Estuary from Reference Condition, while simulated average monthly flow data indicate a 24% reduction in the magnitude of larger floods.<br><br>*Formula: % Change in occurrence (2/3) +% Change in magnitude (1/3)* | Medium |
| **[1]Hydrology score** | **67** | | |

#### 3.4.1.2 Hydrodynamics and mouth condition

| VARIABLE | SCORE | MOTIVATION | CONFIDENCE |
|---|---|---|---|
| Change in mean duration of closure, e.g. over a 5 or 10 year period | 46 | Extended periods of mouth closure (State 1) only occurred for very short periods of the time (0.1%) under the Reference Condition, and increased slightly to 0.8% of the time under the present state.<br><br>While State 2 (semi-closed) increased by 25.2% from the Reference Condition to the Present State.<br><br>Following the scoring guidelines provided in DWAF (2004) allocate a score of 46% (Note: the Reserve method scores mouth closure conservatively). | High |
| **Hydrodynamics and mouth conditions score** | **46** | | |

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

### 3.4.1.3 Water quality

**Salinity**

The change in salinity was calculated based on two conditions, change in the average salinity and change in the structure of the Palmiet.

Change in the average salinity was calculated as the average salinity per state for a zone (lower surface, upper surface, lower bottom and upper bottom) multiplied by the % occurrence of the state. There was an average decrease in salinity of about 3.5%, with the most significant change observed in the bottom water of the lower reaches, which went from 28 ppt to 21 ppt. There was relative little change in the salinity of the surface water in the estuary.

| St | Average salinity (ppt) | | | | | |
|---|---|---|---|---|---|---|
| | Reference | | | Present | | |
| | % | L | U | % | L | U |
| 1 | 0.1 | **15** | 15 | 0.8 | 5 | 5 |
| | | 30 | 30 | | 5 | 15 |
| 2 | 10.4 | **15** | 15 | 35.6 | 5 | 5 |
| | | 20 | 25 | | 5 | 10 |
| 3 | 58.7 | **20** | 15 | 46.4 | 20 | 15 |
| | | 35 | 30 | | 35 | 30 |
| 4 | 20.6 | **0** | 0 | 12.4 | 0 | 0 |
| | | 25 | 10 | | 25 | 10 |
| 5 | 10.3 | **0** | 0 | 4.8 | 0 | 0 |
| | | 0 | 0 | | 0 | 0 |

**Average salinity for 4 sections representing the lower (0-800 m) and upper (800 – 1 800 m) estuary (moving upstream from the mouth left to right) and surface (water depth < 1.5 m) and bottom (water depth > 1.5 m) waters**

| Reference Conditions: | | Present State: | |
|---|---|---|---|
| 13 | 10 | 11 | 9 |
| 28 | 22 | 21 | 19 |

Change in structure was calculated on the loss of State 3 and 4, which represents the highly stratified states. State 3 and 4 decreased from 79% under the Reference Condition, to 59% under the Present State, i.e. 20% change.

**DIN**

DIN concentrations in river inflow during <u>winter</u> (i.e. during States 4 and 5.) increased markedly from Reference (<50 µg.l$^{-1}$) to Present (>500 µg.l$^{-1}$) due to anthropogenic inputs from agriculture. DIN concentrations in river inflow during <u>summer</u> increased somewhat from Reference (<50 µg.l$^{-1}$) to Present (~100 µg.l$^{-1}$) due to agricultural inputs. Occasional DIN input (200-300 µg.l$^{-1}$) from the sea (upwelling) is most significant during State 3 in <u>summer</u>. Considering the above, deviation from the Reference to Present (similar situation assumed for Scenarios) occurs as follows:

- During State 4 (occurring in winter) DIN concentrations are significantly higher in surface waters of the estuary and bottom waters of the upper estuary compared to Reference
- During State 5 (occurring in winter) DIN concentrations are significantly higher in the entire estuary compared to Reference
- During States 1 and 2 (occurring in summer) DIN concentrations are somewhat higher in the surface waters of the estuary compared to Reference
- Reduction in the occurrence of State 3 (occurring in summer) from Reference reduced DIN concentrations in bottom waters of the estuary and surface waters of the lower estuary.

To score similarity to Reference the following approach was followed:

- Estuary has *n* DIN conditions ($C_1$ *to* $C_n$), e.g.oligothropic (<50 µg.l$^{-1}$), mesotrophic (50-300 µg.l$^{-1}$) and eutrophic (>300µg.l$^{-1}$)
- Estuary is sub-divided into *n* zones ($Z_1$ *to* $Z_n$), e.g. lower surface, lower bottom, upper surface, upper bottom (assume zones are of equal volume, each <u>25% of total volume</u>)
- Estuary has *n* abiotic states ($S_1$ *to* $S_n$) each with a specific DIN condition ($C_1$ *to* $C_n$) occurring in a specific zone ($Z_1$ *to* $Z_n$) (see Table 3.2)
- For a particular flow scenario (e.g. Reference, Present, etc.) each abiotic state ($S_1$ *to* $S_n$) has a specific %occurrence *(*$\%S_1$ *to* $\%S_n$*)*
- For a specific flow scenario the fraction occurrence of *a specific DIN Condition (Ci) in a specific zone (Zi)* is determined by:

$$Fraction_{Ci,Zi} = \%S_1Vol_{Zi} + \%S_2Vol_{Zi} + \ldots\ldots + \%S_nVol_{Zi} \text{ (considering only } S_1 \text{ to } S_n \text{ in which } C_i \text{ occurs } Z_i)$$

| | |
|---|---|
| | • Similarity of DIN in Present or any Scenarios relative to Reference is then calculated as follows:<br><br>$Similarity_{DIN} = \sum min(Fraction_{Ci,Zi\ in\ Ref}, Fraction_{Ci,Zi\ in\ Present/Scenario})$ |
| **DIP** | DIP concentrations in river inflow during <u>winter</u> (i.e. during States 4 and 5.) increased somewhat from Reference (<10 µg.l$^{-1}$) to Present (10-50 µg.l$^{-1}$) due to anthropogenic inputs from agriculture. Occasional DIP input (10-50 µg.l$^{-1}$) from the sea (upwelling) is most significant during State 3 in <u>summer</u>. Considering the above, deviation from the Reference to Present (similar situation assumed for Scenarios) occurs as follows:<br>• During State 4 (occurring in winter) DIP concentrations are somewhat higher in surface waters of the estuary and bottom waters of the upper estuary compared to Reference<br>• During State 5 (occurring in winter) DIP concentrations are somewhat higher in the entire estuary compared to Reference<br>• Reduction in the occurrence of State 3 (occurring in summer) from Reference reduced DIP concentrations in bottom waters of the estuary and surface waters of the lower estuary.<br><br>To score similarity to Reference, the following approach was followed:<br><br>• Estuary has *n* DIP conditions ($C_1$ *to* $C_n$), e.g.oligothropic (<10 µg.l$^{-1}$), mesotrophic (10-50 µg.l$^{-1}$) and eutrophic (>50µg.l$^{-1}$)<br>• Estuary is sub-divided into *n* zones ($Z_1$ *to* $Z_n$), e.g. lower surface, lower bottom, upper surface, upper bottom (assume zones are of equal volume, each <u>25% of total volume</u>)<br>• Estuary has *n* abiotic states ($S_1$ *to* $S_n$) each with a specific DIP condition ($C_1$ *to* $C_n$) occurring in a specific zone ($Z_1$ *to* $Z_n$) (see Table 3.2)<br>• For a particular flow scenario (e.g. Reference, Present, etc.) each abiotic state ($S_1$ *to* $S_n$) has a specific % occurrence ($\%S_1$ *to* $\%S_n$)<br>• For a specific flow scenario, the fraction occurrence of *a specific DIP Condition (Ci) in a specific zone (Zi)* is determined by:<br><br>$Fraction_{Ci,Zi} = \%S_1Vol_{Zi} + \%S_2Vol_{Zi} + \ldots + \%S_nVol_{Zi}$ *(considering only* $S_1$ *to* $S_n$ *in which* $C_i$ *occurs* $Z_i$*)*<br><br>• Similarity of DIP in Present or any Scenarios relative to Reference is then calculated as follows:<br><br>$Similarity_{DIP} = \sum \min(Fraction_{Ci,Zi\ in\ Ref}, Fraction_{Ci,Zi\ in\ Present/Scenario})$ |
| **DIN/DIP** | Overall nutrient score = Average [$Similarity_{DIN}, Similarity_{DIP}$] |
| **Transparency** | Palmiet is a black water system, i.e. water is clear but contains dissolved humic acids. Transparency between different states is not considered significantly different (~ 2 m), except during State 3, when strong marine influence increases visibility in bottom waters of both sections and surface waters of lower estuary (i.e. 3 sections out of 4). Reduction in occurrence of State 3 from Reference Condition reduced transparency in these sections.<br><br>To score similarity to Reference the following approach was followed:<br><br>• Estuary has *n* Transparency Conditions ($C_1$ *to* $C_n$), e.g. low (<1 m Secchi depth), medium (1-2 m) and high (>2 m)<br>• Estuary is sub-divided into *n* zones ($Z_1$ *to* $Z_n$), e.g. lower surface, lower bottom, upper surface, upper bottom (assume zones are of equal volume, each <u>25% of total volume</u>)<br>• Estuary has *n* abiotic states ($S_1$ *to* $S_n$) each with a specific Transparency Condition ($C_1$ *to* $C_n$) occurring in a specific zone ($Z_1$ *to* $Z_n$) (see Table 3.2)<br>• For a particular flow scenario (e.g. Reference, Present, etc.) each abiotic state ($S_1$ *to* $S_n$) has a specific %occurrence ($\%S_1$ *to* $\%S_n$)<br>• For a specific flow scenario the fraction occurrence of *a specific Transparency Condition (Ci) in a specific zone (Zi)* is determined by:<br><br>$Fraction_{Ci,Zi} = \%S_1Vol_{Zi} + \%S_2Vol_{Zi} + \ldots + \%S_nVol_{Zi}$ *(considering only* $S_1$ *to* $S_n$ *in which* $C_i$ *occurs* $Z_i$*)* |

| | |
|---|---|
| **DO** | Palmiet is typically oxygenated (>6 $mg.l^{-1}$), except during States 1 and 2, when DO in the bottom water of estuary can be reduced markedly (2-6 $mg.l^{-1}$, even <2 $mg.l^{-1}$). An increase in occurrence of States 1 and 2 from Reference would therefore generally result in reduced DO in bottom waters. However, in instances where State 2 persists for longer than 2 months, entrainment of freshwater into bottom layers, partial re-aeration of bottom waters could occur.<br><br>To score similarity to Reference the following approach was followed:<br><br>• Estuary has *n* Oxygen conditions ($C_1$ *to* $C_n$), e.g. low (<2 $mg.l^{-1}$), medium (2-6 $mg.l^{-1}$) and high (>6 $mg.l^{-1}$)<br>• Estuary is sub-divided into *n* zones ($Z_1$ *to* $Z_n$), e.g. lower surface, lower bottom, upper surface, upper bottom (assume zones are of equal volume, each <u>25% of total volume</u>)<br>• Estuary has *n* abiotic states ($S_1$ *to* $S_n$) each with a specific Oxygen condition ($C_1$ *to* $C_n$) occurring in a specific zone ($Z_1$ *to* $Z_n$) (see Table 3.2)<br>• For a particular flow scenario (e.g. Reference, Present, etc.) each abiotic state ($S_1$ *to* $S_n$) has a specific %occurrence *(*$\%S_1$ *to* $\%S_n$)<br>• For a specific flow scenario the fraction occurrence of *a specific Oxygen Condition (Ci) in a specific zone (Zi)* is determined by:<br><br>$Fraction_{Ci,Zi} = \%S_1Vol_{Zi} + \%S_2Vol_{Zi} + \ldots\ldots + \%S_nVol_{Zi}$ *(considering only* $S_1$ *to* $S_n$ *in which* $C_i$ *occurs* $Z_i$*)* |
| **Toxic substances** | Although there are large urban developments in close proximity of the estuary, agricultural activities in the catchment have probably contributed to pesticide/herbicide contamination in the estuary, considering the strong nutrient signal from this anthropogenic source. Assume similarity to Reference as 90% for Present and all Scenarios |

| **Scenario** | **1. Changes in longitudinal salinity gradient and vertical stratification** | | **2a. DIN/DIP in estuary** | | **2b. SS/Turbidity/ <u>Transparency</u> in estuary** | | **2c. DO in estuary** | | **2d. Toxic substances in estuary** | | **Overall score** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Score L/M/H** | **Summary of change** | **Score L/M/H** | **Summary of change** | **Score L/M/H** | **Summary of change** | **Score L/M/H** | **Summary of change** | **Score L/M/H** | **Summary of change** | |
| Present | 76<br>M/H | 20% ⇩stratified<br>4% ⇩Salinity | 74<br>M/H | ⇩ Summer (bottom)<br>⇧ Summer (surface)<br>⇧ Winter (overall) | 91<br>M/H | ⇩ Summer (surface and bottom, upper estuary) | 85<br>M/H | ⇩ Summer (bottom) | 90<br>L | ⇧Overall accumulation | 75 |

### 3.4.1.4 Physical habitat alteration

| **VARIABLE** | | **SCORE** | **MOTIVATION** | **CONFIDENCE** |
|---|---|---|---|---|
| 1. Resemblance of <u>intertidal sediment</u> structure and distribution to reference condition | | | | |
| 1 a | % Similarity in intertidal area exposed | 70 | Allow 20% change in the intertidal area due to changes in mouth regime (increase in State 2). In addition 10% is allocated for progressive infilling in the mouth and middle reaches due to a reduction in the frequency and magnitude of floods. | Low |
| 1 b | % Similarity in sand fraction relative to total sand and mud | 95 | Coarsening of sediment in estuary due to sediment “starvation” caused by dam trapping fluvial sediments and a related increase in marine sediment (5%). | Low |
| | | | | |

| VARIABLE | | SCORE | MOTIVATION | CONFIDENCE |
|---|---|---|---|---|
| 2 | Resemblance of subtidal estuary to reference condition: depth, bed or channel morphology | 70 | Subtidal: 50% decrease in the mouth area and middle reaches, ⇧1% deepening in upper estuary due to trapping of catchment sediment.<br>Allow 50% change in the subtidal area in the middle and lower reaches reduce flushing. | Low |
| **Anthropogenic influence:** | | | | |
| | Percentage of overall change in intertidal and supratidal habitat caused by **anthropogenic** activity as opposed to modifications to water flow into estuary | 10 | Retaining wall built on supratidal area of picnic area at the mouth | Low |
| | 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 | All flow related | Low |
| **Physical habitat score** | | **78** | | |

### *3.4.2 Biotic Component*

#### 3.4.2.1 Microalgae

| VARIABLE | SCORE | MOTIVATION | CONFIDENCE |
|---|---|---|---|
| Phytoplankton | | | |
| 1. Species richness | 100 (100%) | The estuary is likely to experience the full range of states that occurred in the reference condition. It is unlikely that there has been any loss of species. | L |
| 2a. Abundance | 92 | Biomass, measured using chl *a*, has increased because of elevated nutrients (🡅: 38% increase), but decreased due to more frequent mouth closures (🡇: 26% increase in States 1 and 2) and less pronounced stratification (🡇: 20% decrease in States 3 and 4).<br>An overall 8% decrease in biomass. | M |
| 2b. Community composition | 74 | A decrease in stratified conditions (States 3 and 4) to more closed conditions (States 1 and 2) is likely to support a shift from relatively large flagellates/dinoflagellates to one with a higher proportion of small flagellates and cyanophytes. Expect a 26% change. | M |
| Benthic microalgae | | | |
| 1. Species richness | 100 | The estuary is likely to experience the full range of states that occurred in the reference condition. It is unlikely that there has been any loss of species. | L |

| | | | |
|---|---|---|---|
| 2a. Abundance | 74 | Subtidal chl *a*: An increase in biomass in response to an increase in available habitat (increase in States 1 and 2) is likely to be negated by a decrease associated with reduced light availability and direct competition for resources with macroalgae.<br>Intertidal chl *a*: Reduced high flows (🡅 14%: 20.6 – 12.4 and 10.3 – 4.8) and elevated nutrients (🡅: 38% x 0.5) favour an increase in benthic chl-a. Loss of intertidal habitat (🡇 26% x 0.5) and a loss of water transparency during State 3 (🡇 12.3% x 0.5): Overall increase in benthic microalgal biomass of 26%.<br>*(note that vector arrow denotes chl-a response)* | M |
| 2b. Community composition | 74 | The increased flooding of the intertidal sediment during States 1 and 2 (26% change) is likely to see a shift in composition from more mobile species (e.g. pennate diatoms and euglenophytes) to attached taxa. | M |
| **Microalgae score** | **74** | | |

### 3.4.2.2 Macrophytes

| VARIABLE | SCORE | MOTIVATION | CONFIDENCE |
|---|---|---|---|
| 1. Species richness | 80 (90%) | Potential loss of salt tolerant salt marsh species due to a decrease in salinity. | L |
| 2a. Abundance/Biomass | 45 | *Macroalgae*: During the reference condition, the mouth was closed/semi-closed for 1.26 months and this has increased to 4.37 months at present.<br>*Macrophytes*: In contrast, the mouth was open for 10.7 months and has decreased to 7.6 months. Saltmarsh (~0.1 ha) is negatively affected by inundation so there has been a change from 1.07 ha-months to 0.76 ha-months in saltmarsh from reference to present. This represents a 55% change [100 – (1/ (5.13/2.33))] from the Reference Condition; 2.33 ha-months [1.26 + 1.07] at Reference to 5.13 ha-months [4.37 + 0.76] at present. | M |
| 2b. Community composition | 69 | Macroalgae would increase where there was open water and salt marsh dies back due to inundation during States 1 and 2. The ratio of macroalgae to macrophytes changed from 1.26:1.07 to 4.37:0.76 from Reference to Present representing a 69% change in community composition. | M |
| **Macrophytes score** | **45** | | |

### 3.4.2.3 Invertebrates

| VARIABLE | SCORE | MOTIVATION | CONFIDENCE |
|---|---|---|---|
| Zooplankton | | | |
| 1. Species richness | 100 | No change in species richness | M |
| 2a. Abundance | 90 | Marginal increase (10%) under present conditions because of less frequent flushing. | M |
| 2b. Community composition | 100 | No change in species composition | M |

| | | | |
|---|---|---|---|
| Macroinvertebrates (Benthos) | | | |
| 1. Species richness | 100 | No change in species richness | M |
| 2a. Abundance | 65 | The intertidal area in the lower estuary has increased by approximately 10% in the area covered under present conditions (magnitude and frequency of floods decreased), while sandy sediment has extended upstream, although the area affected relative to the estuary is low. Occasionally, the development of anoxic conditions would cause some mortality of benthic organisms that would not have occurred naturally. Because of the increase in macroalgal cover, a greater quantity of detritus becomes available to benthic consumers (40%). This greater amount would be offset by the greater amount of kelp material brought into the estuary under natural conditions. On balance, a 35% increase in benthic biomass predicted on average (Macrophyte coverage more permanent, sandy sediment extends further upstream and an increase in organic material available to detritivores. | L |
| 2b. Community composition | 65 | Because of the increase in the intertidal area and greater amount of detritus (increased submerged macrophyte cover), the relative importance of species in the community will change. | L |
| Macrocrustacea (Hyperbenthos) | | | |
| 1. Species richness | 100 | No change in species richness | M |
| 2a. Abundance | 100 | Not related to flow | M |
| 2b. Community composition | 100 | Not related to flow | M |
| **Invertebrates score** | **65** | | |

### 3.4.2.4 Fish

| VARIABLE | SCORE | MOTIVATION | CONFIDENCE |
|---|---|---|---|
| 1. Species richness | 80 (90%) | 3 Introduced freshwater species at the head of the estuary, but largely confined to the freshwater reaches. However, both *Micropterus* spp. can have devastating effects on glass eels and elvers recruiting through the estuary into the freshwater reaches. | M |

| | | | |
|---|---|---|---|
| 2a. Abundance | 95 | No real change in salinity, so unlikely to have been any change in numbers due to opportunistic species entering the estuary. Phytoplankton biomass decreases by 8% favouring selective over filter feeders, but a 26% increase in benthic microalgae will have favoured mullet species and provided an alternative food source to phytoplankton for *G. aestuaria* and *A. breviceps*. The latter two species and all juveniles <30 mm of all the species in the estuary would have benefited by a 10% increase in zooplankton. A 220% increase in occurrence of macroalgae, the preferred habitat for *S. temminckii* and *R. holubi* would have allowed these species to persist for longer periods in the estuary. However, the abundance of all species would depend on the relationship between algal biomass and oxygen levels. A 130% increase in macroinvertebrate biomass (*C. kraussi*) likely to favour species such as L. lithognathus and *R. globiceps* but the extent is likely to depend on the relationship between freshwater flow and prey availability. | M |
| 2b. Community composition | 90 | With the exception of the introduced freshwater species, community composition is unlikely to have changed much, and is still dominated by detrivorous Mugillidae and visual foraging *A. breviceps, P. knysnaensis* and *L. lithognathus*. | M |
| **Fish score** | **80** | | |

### 3.4.2.5 Birds

| VARIABLE | SCORE | MOTIVATION | CONFIDENCE |
|---|---|---|---|
| 1. Species richness | 100 (100%) | | |
| 2a. Abundance | 81 | There has been an increase in invertebrate abundance, but no significant change in fish. The 10% increase in intertidal habitat is not of much consequence. Gull populations may have increased as a result of general increases in population numbers, but in general, the estuary is less attractive to gulls, terns and waders because of the increase in closed/semi-closed conditions. There will also have been increases in human disturbance, especially in peak summer months. Overall numbers decrease by an estimated 19%.<br>• Invertebrate feeders 1%⇩<br>• Gulls and terns 21%⇩<br>• Other piscivores no change | L |
| 2b. Community composition | 100 | Numbers of different groups are small and likely to fluctuate greatly, making this kind of impact difficult to assess. In general, because the system is closed more often, one might expect shifts towards more wading birds under those conditions. However, even these would be incidental because of the low productivity of the system. Because of the dominance of gulls and terns (94% of birds) which are least impacted by flow-related changes, overall, impacts on community structure will be negligible. | L |
| **Bird score** | **81** | | |

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

| COMPONENT | % CHANGE CAUSED BY NON-FLOW RELATED ACTIVITIES | MOTIVATION | CONFIDENCE |
|---|---|---|---|
| Water Quality | 80 | Significant change as a result of anthropogenic inputs from agriculture (DIN and Toxic substances) | Medium |
| Microalgae | 20 | Elevated nutrients increase biomass slightly (10%) and the gauging weir above the estuary provides an area of higher residence time affecting biomass and community composition entering the estuary. | Medium |
| Macrophytes | 10 | Increase in nutrients would increase macroalgal abundance. However, only 10% change as nutrients mainly introduced during high flow, open mouth condition. | Medium |
| Invertebrates | 100 | Presence of the weir above the road bridge would terminate migration between the river and estuary, | Medium |
| Fish | 20 | Weir hinders the upstream migration of catadromous *A. mossambica* elvers and completely blocks the passage of *Monodactylus falciformis, Myxus capensis* and *Mugil cephalus* into the freshwater reaches. Abundance of exploited fish species also a function of their nationwide stock status | Medium |
| Birds | 50 | Some of the change in numbers is attributed to human disturbance and changes in regional bird populations. | Low |

### *3.4.3 Present Ecological Status (PES)*

The individual scores for each of the components (i.e. overall score listed) are incorporated into a Habitat health score and a Biological health score. This allows for the determination of the Estuarine Health Index (EHI) Score as illustrated in Table 3.11.

**Table 3.11 Estuarine Health Index (EHI) scores**

| Variable | Weight | Score | Weighted score |
|---|---|---|---|
| Hydrology | 25 | 67 | 17 |
| Hydrodynamics and mouth condition | 25 | 46 | 12 |
| Water quality | 25 | 74.8 | 19 |
| Physical habitat alteration | 25 | 78 | 19 |
| **Habitat Health Score** | | | **66** |
| Microalgae | 20 | 74 | 15 |
| Macrophytes | 20 | 45 | 9 |
| Invertebrates | 20 | 60 | 12 |
| Fish | 20 | 80 | 16 |
| Birds | 20 | 81 | 16 |
| **Biological Health Score** | | | **68** |
| **Estuarine Health Index Score** | | | **67** |

The Estuarine Health Index score for the Palmiet Estuary, based on its present state, is **67**, translating into a **Present Ecological Status** of a **C** (see Table 3.12). Major drivers of change in the system were a significant reduction in river inflow (floods and baseflows), increased mouth closure; reduced sediment scouring and an increased nutrient load from the catchment. Of special concern were the occurrence of macrophytes blooms in the estuary as a result of increase nutrients, reduced baseflow and closed (or semi-closed) mouth conditions. Die-off of these macrophyte blooms causes hypoxic or anoxic conditions in the estuary, which in turn puts the rest of the ecosystem under stress. An additional concern was the long periods of artificial droughts the estuary was currently experiencing, and the impact this would have on fish recruitment.

**Table 3.12 Guidelines for the Present Ecological Status**

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

# 4 RECOMMENDED ECOLOGICAL CATEGORY FOR THE PALMIET ESTUARY

The **Biodiversity Importance** score of the Palmiet Estuary on a national scale is calculated as **71** (Table 4.1; Turpie 2004).

**Table 4.1 Biodiversity Importance Scores**

| **Criterion** | **Weight** | **Score** |
|---|---|---|
| Plants | 30 | 80 |
| Invertebrates | 10 | 80 |
| Fish | 30 | 40 |
| Birds | 30 | 60 |
| **Weighted mean** | | 62 |
| **Maximum** | | **80** |
| **Score = (mean + max)/2** | | **71** |

The **Functional Importance** of the Palmiet Estuary on a regional scale is estimated to be **50,** since the estuary is an important movement corridor between the river and the sea for invertebrates and fish, especially eels (Table 4.2).

**Table 4.2 Functional Importance Scores**

| **Functional Importance** | **Score** |
|---|---|
| (a) Export of organic material generated in the estuary (regional scale) | 20 |
| (b) Nursery function for fish and crustaceans (marine/riverine) | 45 |
| **(c) Movement corridor for river invertebrates and fish breeding in sea** | **50** |
| (d) Roosting area for marine or coastal birds | 20 |
| (e) Catchment detritus, nutrients and sediments to sea | 20 |
| **Functional importance score** [Maximum score of (a) to (e)] | **50** |

The **Estuarine Importance Scores** (EIS) allocated to the Palmiet Estuary are given in Table 4.3 (Turpie and Clark 2007).

**Table 4.3 Estuarine Importance Scores**

| **Criterion** | **Weight** | **Score** | **Weighted score** |
|---|---|---|---|
| Size | 15 | 70 | 11 |
| Zonal Type Rarity | 10 | 20 | 2 |
| Habitat diversity | 25 | 60 | 15 |
| Biodiversity Importance | 25 | 71 | 18 |
| Functional Importance | 25 | 50 | 13 |
| **Estuarine Importance Score** (Score Rounded) | | | **58** |

The overall EIS for the Palmiet Estuary, based on its present state, is 58, signifying that the estuary is of **average importance** as in Table 4.4.

**Table 4.4 Estuarine Importance description**

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

The recommended Ecological Reserve Category (ERC) represents the proposed level of protection assigned to an estuary and is used to determine the recommended EWR for the estuary.

The relationship between EHI Score, PES and ERC is set out in Table 4.5.

**Table 4.5 Ecological Reserve Category**

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

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

The degree to which the Ecological Category needs to be elevated above the Present Ecological Status depends on the level of **importance** and the level of **protection** or **desired protection** of a particular estuary (see Table 4.6).

**Table 4.6 Guidelines for the Recommended Ecological Reserve Category**

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

* BAS = Best Attainable State

Note that the Palmiet Estuary abuts the Kogelberg Biosphere and as part of the development of a regional conservation plan for the cool and warm temperate estuaries, Turpie and Clarke (2007) recommended that the Palmiet Estuary be included in the core set of estuaries that need to be protected to meet biodiversity targets in South Africa. The conservation plan stipulates that 50% of the terrestrial marginal area be included as a no-development area, and that the Recommended Ecological Water Requirement Category be an A or B.

This study concluded that the **major pressures** currently contributing to the degraded health of the Palmiet Estuary are **poor water quality** and **reduction in river inflow in summer**. These impacts can be mitigated with very little effort. Therefore, based on the recommended health status for a protected area and the ease with which this can be achieve for the Palmiet Estuary, the **REC for the Palmiet Estuary is a Category B.**

# 5 QUANTIFICATION OF ECOLOGICAL RESERVE SCENARIOS

## 5.1 DESCRIPTION OF THE SCENARIOS

Aurecon Consulting Engineers provided simulated hydrological data for the Reference Conditions, Present State and Scenarios 1 to 4 (see Table 5.1). Scenario 5 represents similar flow conditions as the Present State, but with a 66% reduction in the nutrient input from the catchment. And was used to assess whether and to what extent the health of the Palmiet Estuary could be elevated through the management of water quality parameters. Scenario 6 was generated during the workshop to test the sensitivity of the Palmiet Estuary to increase base flows. It assumes that base flows cannot be suppressed for longer than three months at a time in summer as this will allow for excessive algae growth and associated anoxic or hypoxic conditions (low oxygen levels) to develop in the estuary.

**Table 5.1 Runoff scenarios evaluated as part of the Rapid Palmiet Estuary Flow requirement study**

| Scenario name | MAR (million $m^3$) | % Remaining | Scenario # | Description |
|---|---|---|---|---|
| Reference Condition | 256.3 | 100 | Natural | Natural |
| Present State | 163.7 | 63.9 | 1d4a | Present |
| Scenario 1 | 185.2 | 72.2 | 1d | Minimum Degradation - Campanula Dam (was the Present State 5 years ago) |
| Scenario 2 | 161.3 | 62.9 | 1d4as | Different pump rates |
| Scenario 3 | 148.7 | 58.0 | 0ifrs | No IFR releases and Lower Steenbras raised |
| Scenario 4 | 111.18 | 43.4 | 0sc | Lower Steenbras raised, Campanula Dam and no IFR releases |
| Scenario 5 | 163.7 | 63.9 | 1d4a | Similar to Present State, with a 66% reduction in nutrient input from the catchment |
| Scenario 6 | 161.3 | 62.9 | - | Similar to Scenario 2, but elevate base flows, with flows <1.0 $m^3s^{-1}$ occurring for 22 % of the time, i.e. flows not less than 1.0 $m^3s^{-1}$ for longer than 3 months in a year. |

Exceedance curves (Figure 5.1 and Figure 5.2) drawn with normal and logarithmic scales, based on simulated daily data for the Reference Condition, Present State and Scenarios 1 to 4, provide a clear indication of the reduction in daily inflows to the Palmiet Estuary. What is also clear from this analysis is that all flow ranges, from the high flows to the base flows, are systematically reduced under the various development options. Scenario 5 is similar in flow distribution to Present Sate. Simulated daily flow data were not available for Scenario 6 as it was generated at the workshop.

## 5.2 ABIOTIC COMPONENTS

### *5.2.1 Variability in river inflow*

The flow distributions (mean monthly flows in $m^3s^{-1}$) under the various Scenarios of the Palmiet Estuary, derived from a 77-year simulated data set, is provided in Table 5.2. The full 77-year series of simulated monthly runoff data for the Scenarios is provided in Table 5.5 to Table 5.9. A graphic representation of the percentage occurrence of the various Abiotic States is presented in Figure 5.3 to Figure 5.5 .

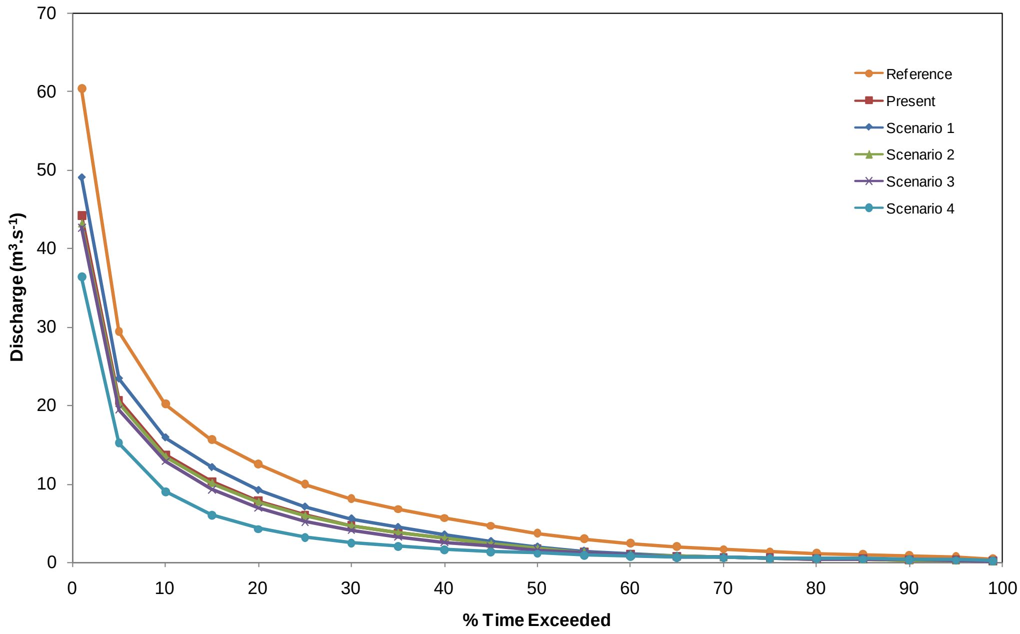



**Figure 5.1 Exceedance curve for the different scenarios indicating the decrease in daily flows under the various scenarios**

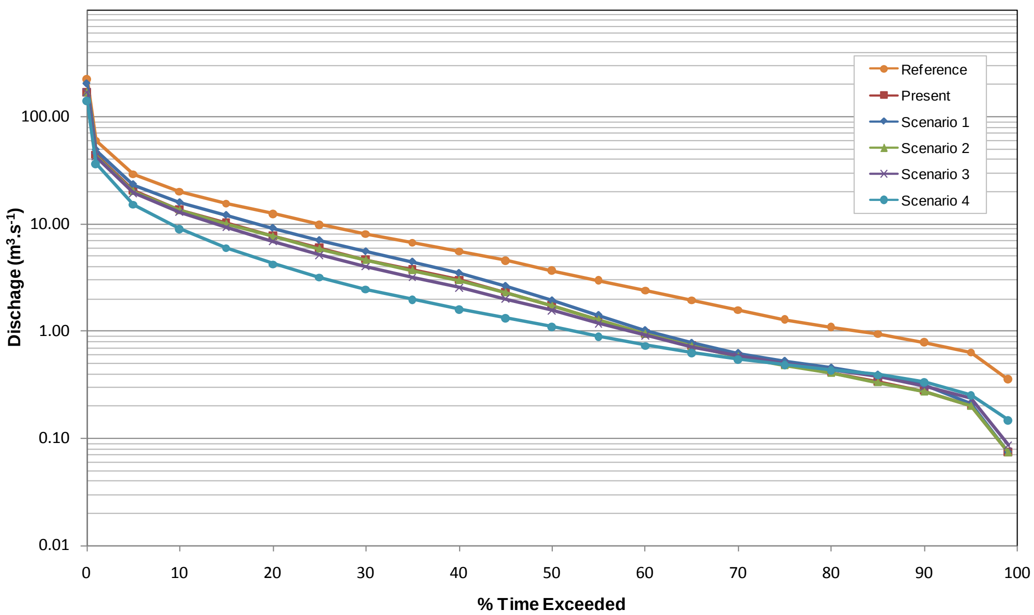



**Figure 5.2 Exceedance curve on a logarithmic scale for the different scenarios indicating the decrease in daily flows under the various scenarios**

**Table 5.2 A summary of the monthly flow ($m^3s^{-1}$) distribution under Scenario 1 to 6**

**Scenario 1**

| | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 99%ile | 20.44 | 9.04 | 3.58 | 2.93 | 2.85 | 2.46 | 6.88 | 18.42 | 28.08 | 43.56 | 38.17 | 27.72 |
| 90%ile | 12.99 | 3.90 | 1.51 | 0.82 | 0.83 | 1.14 | 3.53 | 10.38 | 22.36 | 24.41 | 26.32 | 18.69 |
| 80%ile | 9.12 | 2.59 | 0.86 | 0.57 | 0.68 | 0.82 | 2.12 | 6.31 | 17.26 | 20.44 | 21.00 | 15.39 |
| 70%ile | 7.65 | 2.28 | 0.76 | 0.54 | 0.56 | 0.62 | 1.54 | 5.00 | 12.38 | 17.02 | 18.06 | 12.92 |
| 60%ile | 5.56 | 1.95 | 0.68 | 0.52 | 0.52 | 0.52 | 1.28 | 4.06 | 9.92 | 14.34 | 16.30 | 12.20 |
| 50%ile | 4.57 | 1.63 | 0.65 | 0.52 | 0.52 | 0.52 | 1.07 | 3.28 | 7.59 | 12.87 | 14.86 | 10.84 |
| 40%ile | 4.13 | 1.46 | 0.57 | 0.52 | 0.52 | 0.43 | 0.83 | 2.75 | 6.31 | 9.95 | 13.22 | 9.02 |
| 30%ile | 3.22 | 1.27 | 0.54 | 0.52 | 0.48 | 0.33 | 0.61 | 2.32 | 4.66 | 8.59 | 10.93 | 7.87 |
| 20%ile | 2.79 | 1.02 | 0.54 | 0.52 | 0.33 | 0.27 | 0.52 | 1.87 | 4.14 | 7.17 | 9.22 | 6.69 |
| 10%ile | 2.20 | 0.90 | 0.52 | 0.41 | 0.27 | 0.25 | 0.33 | 1.44 | 2.82 | 5.61 | 8.15 | 5.43 |
| 1%ile | 1.22 | 0.61 | 0.33 | 0.10 | 0.08 | 0.12 | 0.25 | 1.14 | 1.32 | 3.23 | 5.70 | 4.44 |

**Scenarios 2 and 5**

| | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 99%ile | 20.44 | 8.79 | 3.58 | 2.81 | 2.35 | 2.44 | 6.71 | 12.85 | 25.23 | 43.50 | 36.36 | 27.49 |
| 90%ile | 10.43 | 3.90 | 1.43 | 0.82 | 0.83 | 1.05 | 3.53 | 7.91 | 19.45 | 22.70 | 26.15 | 17.93 |
| 80%ile | 6.61 | 2.52 | 0.86 | 0.57 | 0.68 | 0.81 | 2.06 | 5.38 | 12.39 | 17.16 | 19.62 | 13.37 |
| 70%ile | 5.89 | 1.98 | 0.74 | 0.52 | 0.54 | 0.56 | 1.50 | 4.34 | 9.39 | 13.35 | 16.73 | 11.27 |
| 60%ile | 4.52 | 1.66 | 0.66 | 0.52 | 0.52 | 0.51 | 1.19 | 3.78 | 8.25 | 11.40 | 15.80 | 9.75 |
| 50%ile | 3.66 | 1.47 | 0.60 | 0.52 | 0.49 | 0.44 | 0.97 | 3.12 | 7.03 | 9.91 | 13.54 | 7.91 |
| 40%ile | 3.17 | 1.36 | 0.56 | 0.45 | 0.34 | 0.33 | 0.74 | 2.56 | 5.46 | 8.88 | 11.20 | 6.58 |
| 30%ile | 2.81 | 1.20 | 0.54 | 0.35 | 0.32 | 0.30 | 0.57 | 2.13 | 4.14 | 6.64 | 9.94 | 6.05 |
| 20%ile | 2.40 | 1.00 | 0.51 | 0.32 | 0.29 | 0.27 | 0.48 | 1.60 | 3.57 | 5.43 | 8.43 | 5.67 |
| 10%ile | 1.76 | 0.89 | 0.44 | 0.28 | 0.26 | 0.25 | 0.33 | 1.30 | 2.56 | 4.63 | 7.01 | 5.05 |
| 1%ile | 1.22 | 0.61 | 0.33 | 0.10 | 0.08 | 0.12 | 0.25 | 0.70 | 1.27 | 3.00 | 5.02 | 3.95 |

**Scenario 3**

| | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 99%ile | 20.44 | 9.07 | 3.41 | 3.12 | 2.53 | 2.61 | 7.42 | 12.95 | 25.50 | 43.56 | 36.36 | 27.49 |
| 90%ile | 9.67 | 3.90 | 1.43 | 0.82 | 0.81 | 0.95 | 3.75 | 7.70 | 16.29 | 24.05 | 26.39 | 18.69 |
| 80%ile | 6.36 | 2.57 | 0.82 | 0.57 | 0.65 | 0.71 | 1.96 | 4.86 | 10.44 | 15.27 | 18.35 | 13.49 |
| 70%ile | 5.33 | 2.03 | 0.71 | 0.54 | 0.54 | 0.54 | 1.44 | 3.59 | 8.69 | 11.57 | 16.38 | 11.10 |
| 60%ile | 3.81 | 1.64 | 0.61 | 0.52 | 0.53 | 0.52 | 1.13 | 3.17 | 6.84 | 10.41 | 14.75 | 8.89 |
| 50%ile | 3.32 | 1.47 | 0.57 | 0.52 | 0.52 | 0.52 | 0.86 | 2.77 | 5.09 | 7.97 | 11.94 | 7.63 |
| 40%ile | 2.84 | 1.23 | 0.54 | 0.52 | 0.52 | 0.43 | 0.69 | 1.91 | 4.23 | 6.50 | 9.46 | 6.50 |
| 30%ile | 2.47 | 1.11 | 0.54 | 0.52 | 0.51 | 0.33 | 0.54 | 1.67 | 3.03 | 5.80 | 7.05 | 5.52 |
| 20%ile | 1.97 | 0.97 | 0.54 | 0.52 | 0.35 | 0.28 | 0.52 | 1.45 | 2.57 | 4.51 | 6.19 | 4.63 |
| 10%ile | 1.59 | 0.81 | 0.52 | 0.34 | 0.27 | 0.25 | 0.33 | 1.36 | 2.10 | 3.27 | 4.95 | 3.61 |
| 1%ile | 1.06 | 0.61 | 0.44 | 0.22 | 0.14 | 0.12 | 0.27 | 1.15 | 0.95 | 1.90 | 3.93 | 2.61 |

**Scenario 4**

| | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 99%ile | 20.53 | 6.90 | 3.28 | 1.91 | 1.80 | 2.03 | 6.52 | 10.55 | 23.93 | 43.83 | 34.63 | 27.63 |
| 90%ile | 8.10 | 2.74 | 1.13 | 0.65 | 0.64 | 0.73 | 2.61 | 5.19 | 11.37 | 22.28 | 22.34 | 18.77 |
| 80%ile | 4.00 | 2.29 | 0.64 | 0.54 | 0.55 | 0.55 | 1.41 | 3.08 | 6.35 | 10.73 | 16.68 | 12.77 |
| 70%ile | 2.54 | 1.49 | 0.56 | 0.54 | 0.54 | 0.54 | 1.07 | 2.58 | 4.93 | 6.28 | 14.79 | 7.23 |
| 60%ile | 2.04 | 1.26 | 0.54 | 0.52 | 0.54 | 0.54 | 0.80 | 2.25 | 4.07 | 4.71 | 11.42 | 4.79 |
| 50%ile | 1.81 | 1.01 | 0.54 | 0.52 | 0.52 | 0.52 | 0.65 | 1.86 | 3.40 | 4.04 | 5.73 | 3.74 |
| 40%ile | 1.66 | 0.90 | 0.54 | 0.52 | 0.52 | 0.52 | 0.54 | 1.43 | 2.60 | 3.69 | 4.59 | 3.20 |
| 30%ile | 1.48 | 0.84 | 0.54 | 0.52 | 0.52 | 0.52 | 0.54 | 1.39 | 2.01 | 3.03 | 3.97 | 2.75 |
| 20%ile | 1.32 | 0.71 | 0.54 | 0.52 | 0.52 | 0.52 | 0.52 | 1.37 | 1.70 | 2.49 | 3.04 | 2.34 |
| 10%ile | 1.12 | 0.63 | 0.52 | 0.52 | 0.52 | 0.52 | 0.52 | 1.36 | 1.40 | 2.05 | 2.49 | 1.79 |
| 1%ile | 0.78 | 0.54 | 0.36 | 0.27 | 0.23 | 0.21 | 0.24 | 1.15 | 0.68 | 1.26 | 1.85 | 1.42 |

**Scenario 5** Similar to Present State.

**Scenario 6**

| | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 99%ile | 20.44 | 8.79 | 3.58 | 2.81 | 2.35 | 2.44 | 6.71 | 12.85 | 25.23 | 43.50 | 36.36 | 27.49 |
| 90%ile | 10.43 | 3.90 | 1.43 | 0.82 | 0.83 | 1.05 | 3.53 | 7.91 | 19.45 | 22.70 | 26.15 | 17.93 |
| 80%ile | 6.61 | 2.52 | 1.00 | 0.57 | 0.68 | 0.81 | 2.06 | 5.38 | 12.39 | 17.16 | 19.62 | 13.37 |
| 70%ile | 5.89 | 1.98 | 1.00 | 0.52 | 0.54 | 0.56 | 1.50 | 4.34 | 9.39 | 13.35 | 16.73 | 11.27 |
| 60%ile | 4.52 | 1.66 | 1.00 | 0.52 | 0.52 | 0.51 | 1.19 | 3.78 | 8.25 | 11.40 | 15.80 | 9.75 |
| 50%ile | 3.66 | 1.47 | 1.00 | 0.52 | 0.49 | 0.44 | 1.00 | 3.12 | 7.03 | 9.91 | 13.54 | 7.91 |
| 40%ile | 3.17 | 1.36 | 1.00 | 0.45 | 0.34 | 0.33 | 1.00 | 2.56 | 5.46 | 8.88 | 11.20 | 6.58 |
| 30%ile | 2.81 | 1.20 | 1.00 | 0.35 | 0.32 | 0.30 | 1.00 | 2.13 | 4.14 | 6.64 | 9.94 | 6.05 |
| 20%ile | 2.40 | 1.00 | 1.00 | 0.32 | 0.29 | 0.27 | 1.00 | 1.60 | 3.57 | 5.43 | 8.43 | 5.67 |
| 10%ile | 1.76 | 1.00 | 1.00 | 0.28 | 0.26 | 0.25 | 1.00 | 1.30 | 2.56 | 4.63 | 7.01 | 5.05 |
| 1%ile | 1.22 | 1.00 | 1.00 | 0.10 | 0.08 | 0.12 | 1.00 | 1.00 | 1.27 | 3.00 | 5.02 | 3.95 |

### *5.2.2 Flood regime*

As the Palmiet Estuary is a relatively small estuary, the underlying assumption of the flood analyses was that relatively small floods would be able to reset its sediment processes, but that the frequency at which these events occur was of great importance as this drives the rate at which the deposition/erosion cycle in the system occurs.

To undertake a first assessment of the effects of the different scenarios on the occurrence of floods, the occurrences and magnitudes of the highest average monthly flows are listed in Table 5.3 for the period October 1928 to September 2005, for which data for all scenarios are available.

For each scenario, the occurrence of such high monthly flows and its significance is briefly discussed.

Simulated daily flow data for the period October 1963 until September 2005 were also analysed to estimate the effects of the different scenarios on the occurrence of floods, the occurrences and magnitudes. The results are summarised in Table 5.4. For each scenario, the occurrence of the higher daily flows and its significance is briefly discussed.

**Table 5.3 Palmiet highest monthly flows ($m^3s^{-1}$) simulated data for October 1928 to September 2005**

| Year | Month | SIMULATED HIGHEST AVERAGE MONTHLY FLOWS ($m^3\ s^{-1}$) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Reference | Present and Scenario 5 | Scenario 1 | Scenario 2 and 6 | Scenario 3 | Scenario 4 |
| **1974** | **Aug** | 50.11 | 37.30 | 44.83 | 37.30 | 37.30 | 18.61 |
| **1993** | **Jul** | 46.92 | 47.18 | 47.18 | 46.93 | 47.18 | 47.48 |
| **1944** | **Jun** | 42.29 | 21.41 | 27.68 | 21.41 | 20.73 | 13.43 |
| **1945** | **Jul** | 41.73 | 42.41 | 42.41 | 42.41 | 42.41 | 42.68 |
| **1994** | **Jun** | 39.07 | 20.07 | 26.07 | 20.07 | 20.66 | 10.17 |
| **1954** | **Jul** | 38.77 | 37.69 | 37.69 | 37.69 | 37.69 | 37.92 |
| **1992** | **Jun** | 38.39 | 24.39 | 27.64 | 23.93 | 24.29 | 19.76 |
| **1945** | **Jun** | 36.43 | 24.19 | 27.55 | 22.02 | 22.12 | 22.15 |
| **2001** | **Jul** | 36.38 | 22.35 | 27.54 | 19.94 | 20.01 | 8.12 |
| **1955** | **Aug** | 35.82 | 30.18 | 30.74 | 29.08 | 32.01 | 28.69 |
| **1986** | **Aug** | 35.67 | 32.25 | 33.86 | 32.25 | 33.85 | 34.13 |
| **1954** | **Aug** | 35.03 | 36.06 | 36.06 | 36.06 | 36.06 | 36.23 |
| **1959** | **May** | 34.08 | 18.42 | 24.66 | 18.42 | 18.66 | 14.22 |
| **1937** | **Jul** | 33.52 | 24.00 | 28.60 | 22.60 | 24.20 | 8.59 |
| **1977** | **Jun** | 33.23 | 29.35 | 29.35 | 29.35 | 29.35 | 29.55 |
| **1977** | **Jul** | 32.92 | 33.90 | 33.90 | 33.90 | 33.90 | 34.09 |
| **1957** | **Jun** | 32.01 | 20.46 | 24.65 | 20.45 | 19.30 | 18.07 |
| **1942** | **Jun** | 31.55 | 19.96 | 21.20 | 19.96 | 14.16 | 10.62 |
| **1951** | **Jun** | 31.37 | 19.41 | 21.67 | 19.41 | 15.75 | 12.10 |
| **1977** | **Aug** | 30.99 | 31.90 | 31.90 | 31.90 | 31.90 | 32.06 |
| **1963** | **Aug** | 30.57 | 25.08 | 26.36 | 25.08 | 20.36 | 15.87 |
| **1976** | **Jun** | 30.12 | 11.60 | 17.34 | 11.60 | 11.60 | 6.98 |
| **Average of 22 events** | | 36.23 | 27.71 | 30.40 | 27.35 | 26.98 | 22.80 |
| **% Remaining** | | | 76 | 84 | 76 | 74 | 63 |

**Table 5.4 Palmiet highest daily flows ($m^3s^{-1}$) simulated data for October 1963 to September 2005**

| Flow ($m^3s^{-1}$) | Natural | Present and Scenario 5 | Scenario 1 | Scenario 2 and 6 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|---|---|
| **Average** | **8.147** | **5.184** | **5.917** | **5.095** | **4.764** | **3.551** |
| **Occurrence of floods exceeding:** | | | | | | |
| >150 | 3 | 1 | 2 | 1 | 1 | 0 |
| >100 | 31 | 8 | 11 | 8 | 8 | 7 |
| >75 | 82 | 25 | 20 | 24 | 23 | 15 |
| >50 | 137 | 81 | 115 | 76 | 72 | 46 |
| **Total** | **253** | **115** | **148** | **109** | **104** | **68** |
| **% Occurrence in relation to Reference Condition** | | | | | | |
| >150 | 100 | 33 | 67 | 33 | 33 | 0 |
| >100 | 100 | 26 | 35 | 26 | 26 | 23 |
| >75 | 100 | 30 | 24 | 29 | 28 | 18 |
| >50 | 100 | 59 | 84 | 55 | 53 | 34 |
| **Total** | **100** | **45** | **58** | **43** | **41** | **27** |

| | |
|---|---|
| **Scenario 1** | The simulated monthly runoff data shows that for the conditions of this scenario the highest monthly flow was 47.2 $m^3s^{-1}$ in July 1993. Average monthly flow higher than 30 $m^3s^{-1}$ was exceeded 9 times during the 77-year period. These exceedances occurred 4 times in July and 5 times in August. These results are similar to those under present conditions.<br><br>An analysis of the simulated daily flow data indicates that the occurrence of daily flows higher than 75 $m^3\ s^{-1}$ have been reduced between 33 to 76 %, depending on the size class. As the Palmiet Estuary is a relative small system, smaller events (flows higher than 50 $m^3\ s^{-1}$) may also assist in maintaining the sediment equilibrium, i.e. removing sediment from the mouth region and basin. Flows higher than 50 $m^3s^{-1}$ have been reduced by 16 %. The total reduction in the occurrence for daily flows higher than 50 $m^3s^{-1}$ is 42 %. |
| **Scenario 2** | The simulated monthly runoff data shows that for the conditions of this scenario the highest monthly flow was also 46.93 $m^3s^{-1}$ in July 1993. Average monthly flow higher than 30 $m^3s^{-1}$ was exceeded 8 times during the 77-year period. These exceedances occurred 4 times in July and 4 times in August. These results are also similar to those under present conditions.<br><br>An analysis of the simulated daily flow data indicates that the occurrence of daily flows higher than 75 $m^3\ s^{-1}$ have been reduced between 67 to 74 %, depending on the size class. As the Palmiet Estuary is a relative small system, smaller events (flows higher than 50 $m^3\ s^{-1}$) may also assist in maintaining the sediment equilibrium, i.e. removing sediment from the mouth region and basin. Flows higher than 50 $m^3s^{-1}$ have been reduced by 45 %. The total reduction in the occurrence for daily flows higher than 50 $m^3s^{-1}$ is 57 %. |
| **Scenario 3** | The simulated monthly runoff data shows that for the conditions of this scenario the highest monthly flow was also 47.2 $m^3s^{-1}$ in July 1993. Average monthly flow higher than 30 $m^3s^{-1}$ was exceeded 9 times during the 77-year period. These exceedances occurred 4 times in July and 5 times in August. These results are also similar to those under present conditions.<br><br>An analysis of the simulated daily flow data indicate that the occurrence of daily flows higher than 75 $m^3\ s^{-1}$ have been reduced between 67 to 74%, depending on the size class. As the Palmiet Estuary is a relative small system, smaller events (flows higher than 50 $m^3\ s^{-1}$) may also assist in maintaining the sediment equilibrium, i.e. removing sediment from the mouth region and basin. Flows higher than 50 $m^3s^{-1}$ have been reduced by 47 %. The total reduction in the occurrence for daily flows higher than 50 $m^3s^{-1}$ is 59 %. |
| **Scenario 4** | The simulated monthly runoff data shows that for the conditions of this scenario the highest monthly flow was also 47.2 $m^3s^{-1}$ in July 1993. Average monthly flow higher than 30 $m^3s^{-1}$ was exceeded 7 times during the 77-year period. These exceedances occurred 4 times in July and 3 times in August. These results indicate a slightly lower occurrence of large floods for this Scenario 4 compared to Present day conditions and also compared to those under Scenarios 1 to 3.<br><br>An analysis of the simulated daily flow data indicate that the occurrence of daily flows higher than 75 $m^3\ s^{-1}$ have been reduced between 82 to 100%, depending on the size class. As the Palmiet Estuary is a relative small system smaller events, (flows higher than 50 $m^3s^{-1}$) may also assist in maintaining the sediment equilibrium, i.e. removing sediment from the mouth region and basin. Flows higher than 50 $m^3s^{-1}$ have been reduced by 66 %. The total reduction in the occurrence for daily flows higher than 50 $m^3s^{-1}$ is 73 %. |
| **Scenario 5** | Similar to Present State. |
| **Scenario 6** | Similar to Scenario 2. |

### *5.2.3 Droughts*

Hydrological drought conditions in the Palmiet Estuary are defined as years in which the annual inflow (million $m^3$) falls below the Reference Condition 10 %ile, i.e. 175 million $m^3$.

| | |
|---|---|
| **Scenario 1** | Annual flows are less than 175 million $m^3$ for 53 % of the time. An analysis of the 77-year period also highlights the occurrence of extended drought periods varying between 2 to 5 years in a row (see Figure 5.5). |
| **Scenario 2** | Annual flows are less than 175 million $m^3$ for 66 % of the time. An analysis of the 77-year period also highlights the occurrence of extended drought periods varying between 2 to 10 years in a row (see Figure 5.5). |
| **Scenario 3** | Annual flows are less than 175 million $m^3$ for 68 % of the time. An analysis of the 77-year period also highlights the occurrence of extended drought periods varying between 2 to 12 years in a row (see Figure 5.5). |
| **Scenario 4** | Annual flows are less than 175 million $m^3$ for 83 % of the time. An analysis of the 77-year period also highlights the occurrence of extended drought periods varying between 2 to 19 years in a row (see Figure 5.5). |
| **Scenario 5** | Similar to Present State. |
| **Scenario 6** | Similar to Scenario 2. |

### *5.2.4 Sediment processes*

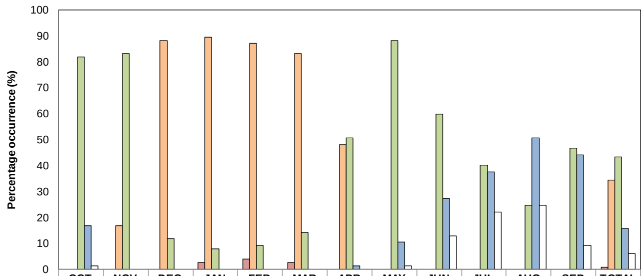
This section describes the changes in sediment processes under the Scenarios compared with Reference Condition.

| | |
|---|---|
| **Scenario 1** | Major floods play an important role in the long-term equilibrium of sedimentation/erosion in the estuary. As stated previously, the frequency at which small events occur drives the rate at which the deposition/erosion cycles occur. If the period between flood events increases, marine sand will deposit in lower regions through wave action. The net result is reduction of inter- and sub-tidal habitat in the lower reaches between floods.<br><br>While Palmiet Estuary was a relatively sediment starved system from a catchment perspective, the large dams in the system are now trapping what little sediment would have came down, which in turn is preventing the infilling of some of the rocky areas in the upper reaches. The net result is a very rocky substrate in the upper reaches.<br><br>The flood analysis indicates that there is about a 40 % reduction in the occurrence of large and intermediate floods to the Palmiet Estuary from Reference Condition. This represents a slight increase in high flow events in relation to the Present State. Therefore, the long-term equilibrium in sediment dynamics in the system is judged to be very similar to present. |
| **Scenario 2** | There is about a 57 % reduction in the occurrence of large and intermediate floods to the Palmiet Estuary from Reference Condition. This represents a slight decrease in high flow events in relation to the Present Sate. Therefore, the long-term equilibrium in sediment dynamics in the system is judged to be very similar to present. |
| **Scenario 3** | There is about a 59 % reduction in the occurrence of large and intermediate floods to the Palmiet Estuary from Reference Condition. This represents a slight decrease in high flow events in relation to the Present Sate. Therefore, the long-term equilibrium in sediment dynamics in the system is judged to be very similar to present. |
| **Scenario 4** | There is about a 73% reduction in the occurrence of large and intermediate floods to the Palmiet Estuary from Reference Condition. This represents a decrease in high flow events in relation to the Present Sate. Therefore, the long-term equilibrium in sediment dynamics in the system is judged to somewhat more disturbed under the Scenario 4 compared to present day conditions and that infilling would occur even more frequently in the lower reaches. |
| **Scenario 5** | Similar to Present State. |
| **Scenario 6** | Similar to Scenario 2. |

### *5.2.5 Occurrence and duration of different Abiotic states*

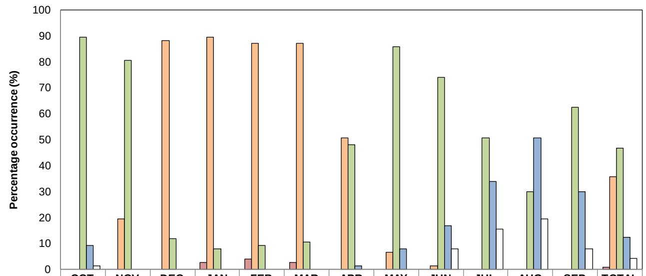
Figure 5.3 provides an estimation of the occurrence and duration of different abiotic states for each of the Scenarios.

**Scenario 1**



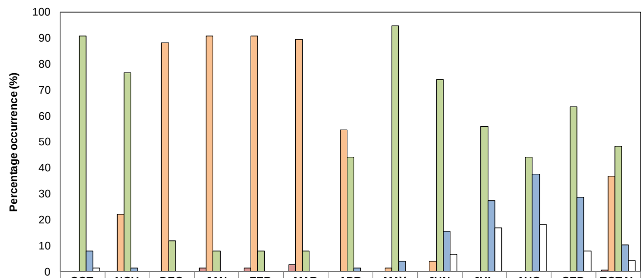

| | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| State 1 | 0.0 | 0.0 | 0.0 | 2.6 | 3.9 | 2.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 |
| State 2 | 0.0 | 16.9 | 88.3 | 89.6 | 87.0 | 83.1 | 48.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 34.4 |
| State 3 | 81.8 | 83.1 | 11.7 | 7.8 | 9.1 | 14.3 | 50.6 | 88.3 | 59.7 | 40.3 | 24.7 | 46.8 | 43.2 |
| State 4 | 16.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.3 | 10.4 | 27.3 | 37.7 | 50.6 | 44.2 | 15.7 |
| State 5 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.3 | 13.0 | 22.1 | 24.7 | 9.1 | 6.0 |

**Scenario 2**



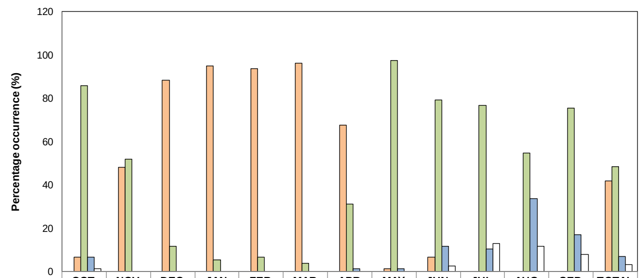

| | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| State 1 | 0.0 | 0.0 | 0.0 | 2.6 | 3.9 | 2.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 |
| State 2 | 0.0 | 19.5 | 88.3 | 89.6 | 87.0 | 87.0 | 50.6 | 6.5 | 1.3 | 0.0 | 0.0 | 0.0 | 35.8 |
| State 3 | 89.6 | 80.5 | 11.7 | 7.8 | 9.1 | 10.4 | 48.1 | 85.7 | 74.0 | 50.6 | 29.9 | 62.3 | 46.6 |
| State 4 | 9.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.3 | 7.8 | 16.9 | 33.8 | 50.6 | 29.9 | 12.4 |
| State 5 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 7.8 | 15.6 | 19.5 | 7.8 | 4.3 |

**Scenario 3**



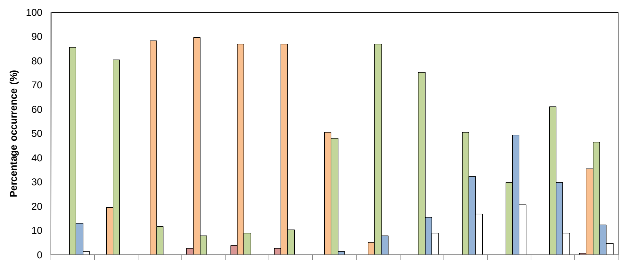

| | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| State 1 | 0.0 | 0.0 | 0.0 | 1.3 | 1.3 | 2.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 |
| State 2 | 0.0 | 22.1 | 88.3 | 90.9 | 90.9 | 89.6 | 54.5 | 1.3 | 3.9 | 0.0 | 0.0 | 0.0 | 36.8 |
| State 3 | 90.9 | 76.6 | 11.7 | 7.8 | 7.8 | 7.8 | 44.2 | 94.8 | 74.0 | 55.8 | 44.2 | 63.6 | 48.3 |
| State 4 | 7.8 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 1.3 | 3.9 | 15.6 | 27.3 | 37.7 | 28.6 | 10.3 |
| State 5 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 6.5 | 16.9 | 18.2 | 7.8 | 4.2 |

**Scenario 4**



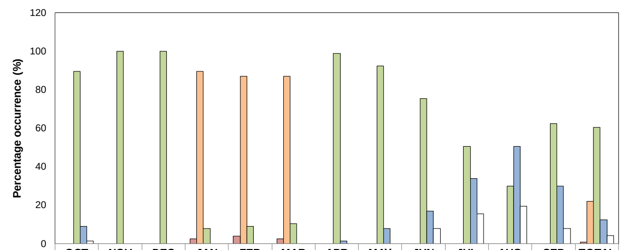

| | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| State 1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| State 2 | 6.5 | 48.1 | 88.3 | 94.8 | 93.5 | 96.1 | 67.5 | 1.3 | 6.5 | 0.0 | 0.0 | 0.0 | 41.9 |
| State 3 | 85.7 | 51.9 | 11.7 | 5.2 | 6.5 | 3.9 | 31.2 | 97.4 | 79.2 | 76.6 | 54.5 | 75.3 | 48.3 |
| State 4 | 6.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.3 | 1.3 | 11.7 | 10.4 | 33.8 | 16.9 | 6.8 |
| State 5 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.6 | 13.0 | 11.7 | 7.8 | 3.0 |

**Scenario 5**




| | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| State 1 | 0.0 | 0.0 | 0.0 | 2.6 | 3.9 | 2.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 |
| State 2 | 0.0 | 19.5 | 88.3 | 89.6 | 87.0 | 87.0 | 50.6 | 5.2 | 0.0 | 0.0 | 0.0 | 0.0 | 35.6 |
| State 3 | 85.7 | 80.5 | 11.7 | 7.8 | 9.1 | 10.4 | 48.1 | 87.0 | 75.3 | 50.6 | 29.9 | 61.0 | 46.4 |
| State 4 | 13.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.3 | 7.8 | 15.6 | 32.5 | 49.4 | 29.9 | 12.4 |
| State 5 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 9.1 | 16.9 | 20.8 | 9.1 | 4.8 |

**Scenario 6**




| | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| State 1 | 0.0 | 0.0 | 0.0 | 2.6 | 3.9 | 2.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 |
| State 2 | 0.0 | 0.0 | 0.0 | 89.6 | 87.0 | 87.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 22.0 |
| State 3 | 89.6 | 100.0 | 100.0 | 7.8 | 9.1 | 10.4 | 98.7 | 92.2 | 75.3 | 50.6 | 29.9 | 62.3 | 60.5 |
| State 4 | 9.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.3 | 7.8 | 16.9 | 33.8 | 50.6 | 29.9 | 12.4 |
| State 5 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 7.8 | 15.6 | 19.5 | 7.8 | 4.3 |

**Figure 5.3 Graphic summary of the occurrence of the various abiotic states under Scenarios 1 to 6**

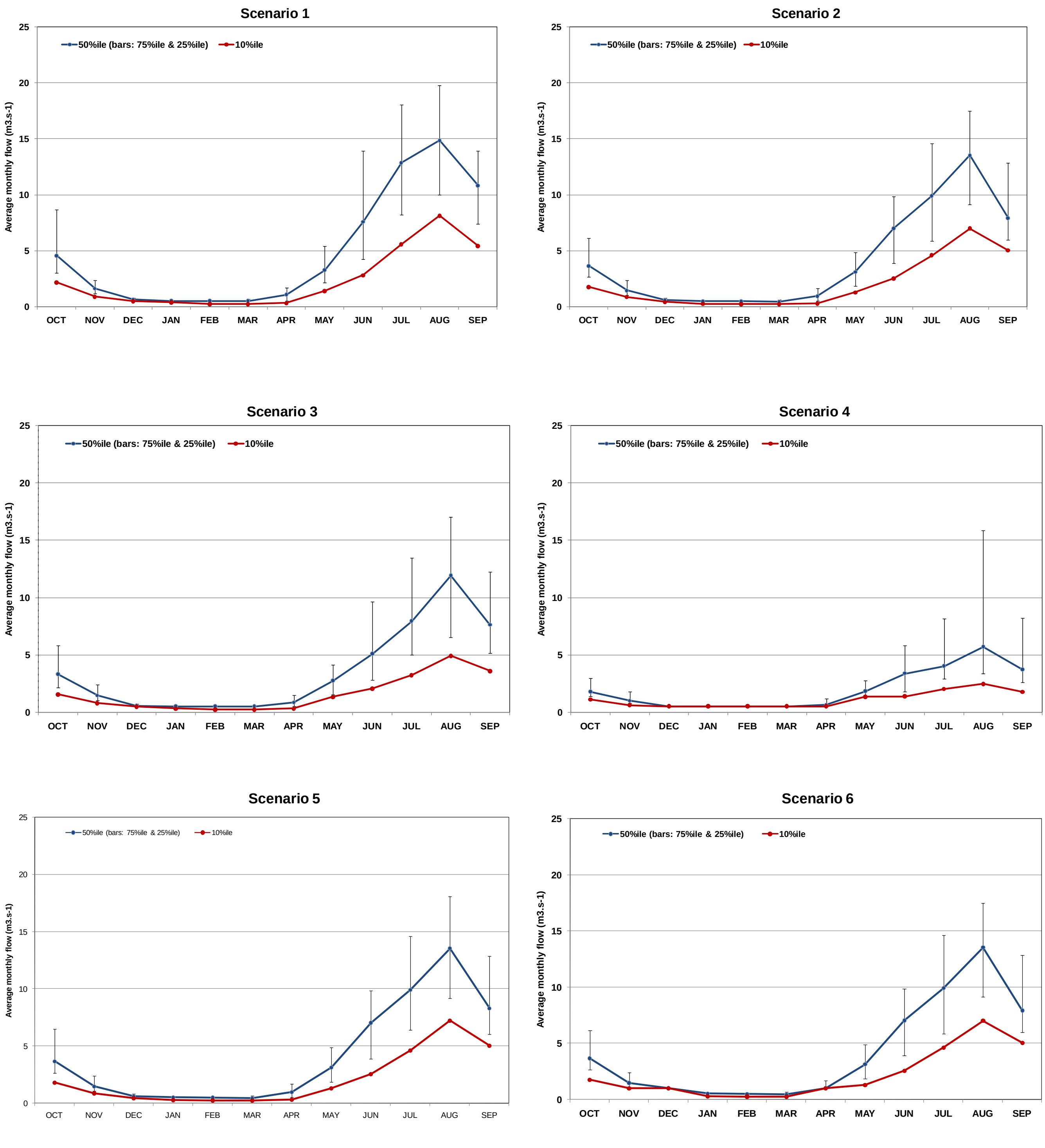



**Figure 5.4 Graphic illustrations of the reduction in median (50 %ile) and drought (10 %ile) flows. The 75 %ile and 25 %ile values are indicative of the variability in flow for individual months EHI Scoring of abiotic components**

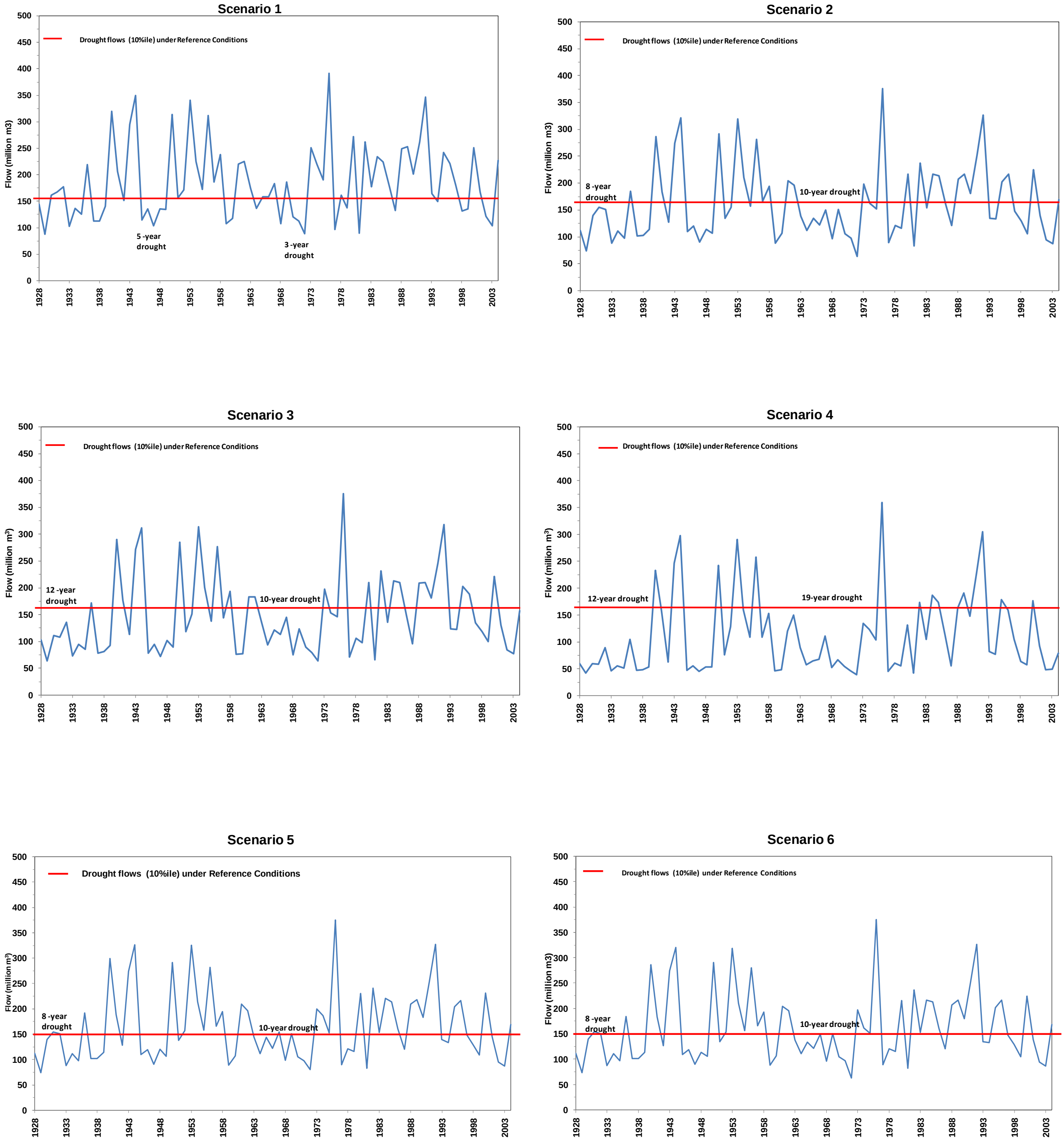



**Figure 5.5 Graphic illustrations of the number of times the annual inflow to the Palmiet Estuary falls below the Reference Condition drought conditions under Scenarios 1 to 6**

## Table 5.5 Simulated monthly flows to the Palmiet Estuary for Scenario 1 ($m^3s^{-1}$)

| YEAR | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1928 | 3.14 | 1.00 | 0.70 | 0.52 | 0.52 | 0.26 | 1.52 | 2.72 | 3.39 | 14.65 | 18.06 | 7.74 |
| 1929 | 1.37 | 0.78 | 0.54 | 0.52 | 0.54 | 0.54 | 0.89 | 1.18 | 1.36 | 3.27 | 5.79 | 16.54 |
| 1930 | 9.12 | 2.16 | 0.79 | 0.52 | 0.52 | 0.28 | 2.67 | 3.36 | 3.05 | 7.43 | 15.72 | 15.18 |
| 1931 | 11.83 | 2.33 | 0.70 | 0.54 | 0.86 | 0.83 | 0.52 | 3.18 | 8.95 | 9.88 | 8.39 | 15.44 |
| 1932 | 6.17 | 1.13 | 0.55 | 0.52 | 0.52 | 0.29 | 0.32 | 1.72 | 11.54 | 16.30 | 19.78 | 7.99 |
| 1933 | 3.58 | 1.01 | 0.52 | 0.52 | 0.35 | 0.32 | 0.30 | 2.08 | 2.25 | 5.64 | 10.70 | 11.44 |
| 1934 | 9.01 | 2.16 | 0.54 | 0.52 | 0.27 | 0.48 | 1.32 | 4.95 | 8.45 | 9.85 | 7.19 | 6.67 |
| 1935 | 2.49 | 2.08 | 0.74 | 0.99 | 0.74 | 0.62 | 0.55 | 4.09 | 5.84 | 8.60 | 11.02 | 9.51 |
| 1936 | 3.93 | 2.28 | 1.53 | 0.71 | 0.52 | 0.52 | 1.07 | 2.82 | 17.24 | 28.60 | 15.07 | 8.52 |
| 1937 | 4.23 | 1.21 | 0.54 | 0.52 | 0.52 | 0.48 | 1.68 | 4.10 | 3.21 | 5.77 | 7.88 | 12.28 |
| 1938 | 5.84 | 1.53 | 0.57 | 0.52 | 0.80 | 0.65 | 1.27 | 3.28 | 2.75 | 5.59 | 13.74 | 6.03 |
| 1939 | 1.94 | 1.38 | 0.65 | 0.52 | 1.20 | 1.14 | 3.15 | 5.69 | 12.18 | 10.79 | 6.49 | 8.32 |
| 1940 | 2.39 | 2.71 | 0.87 | 0.61 | 0.54 | 0.52 | 5.16 | 16.45 | 24.25 | 20.49 | 16.95 | 30.52 |
| 1941 | 12.95 | 2.33 | 0.80 | 0.57 | 0.52 | 0.52 | 0.57 | 4.01 | 21.20 | 13.46 | 13.54 | 7.58 |
| 1942 | 1.72 | 0.64 | 0.54 | 2.54 | 1.64 | 0.62 | 1.45 | 2.47 | 4.53 | 9.77 | 18.38 | 13.03 |
| 1943 | 4.29 | 1.62 | 0.58 | 0.52 | 0.54 | 0.28 | 0.49 | 4.21 | 27.68 | 23.41 | 25.72 | 22.43 |
| 1944 | 9.08 | 1.63 | 0.85 | 0.52 | 0.32 | 0.24 | 0.70 | 10.37 | 27.55 | 42.41 | 29.31 | 8.73 |
| 1945 | 7.47 | 2.29 | 0.60 | 0.52 | 0.52 | 0.97 | 1.39 | 1.81 | 2.87 | 4.66 | 8.32 | 12.08 |
| 1946 | 2.99 | 1.02 | 0.52 | 0.39 | 0.26 | 0.92 | 0.96 | 2.65 | 4.05 | 18.08 | 12.32 | 6.95 |
| 1947 | 2.14 | 1.54 | 0.54 | 0.42 | 0.30 | 0.48 | 0.64 | 1.92 | 4.27 | 9.01 | 7.35 | 10.59 |
| 1948 | 13.22 | 2.53 | 0.54 | 0.52 | 0.52 | 0.25 | 1.40 | 2.43 | 4.25 | 5.62 | 11.44 | 8.28 |
| 1949 | 4.01 | 2.07 | 0.73 | 0.52 | 0.52 | 0.24 | 2.66 | 2.31 | 1.73 | 14.47 | 8.62 | 12.85 |
| 1950 | 8.97 | 8.74 | 2.38 | 0.73 | 0.52 | 0.52 | 3.76 | 5.00 | 21.67 | 24.58 | 15.76 | 26.53 |
| 1951 | 10.50 | 2.76 | 0.79 | 0.52 | 0.50 | 0.43 | 0.53 | 2.16 | 2.34 | 7.93 | 17.94 | 12.60 |
| 1952 | 6.87 | 1.82 | 0.83 | 0.35 | 0.29 | 0.27 | 3.38 | 7.98 | 7.35 | 14.05 | 15.16 | 6.12 |
| 1953 | 2.78 | 1.98 | 0.65 | 0.52 | 0.31 | 0.33 | 1.13 | 13.05 | 19.10 | 37.69 | 36.06 | 14.98 |
| 1954 | 3.95 | 1.67 | 0.58 | 0.52 | 4.50 | 2.31 | 1.39 | 1.32 | 5.34 | 17.35 | 30.74 | 15.51 |
| 1955 | 12.22 | 2.99 | 0.87 | 0.52 | 0.54 | 0.41 | 0.56 | 4.84 | 10.29 | 12.07 | 13.80 | 5.94 |
| 1956 | 4.57 | 1.24 | 0.54 | 0.52 | 0.69 | 0.80 | 1.19 | 13.00 | 24.65 | 30.08 | 26.88 | 13.83 |
| 1957 | 19.73 | 3.77 | 0.56 | 0.52 | 0.80 | 1.12 | 0.86 | 5.51 | 7.44 | 4.23 | 14.86 | 10.84 |
| 1958 | 3.47 | 1.34 | 0.57 | 0.34 | 0.33 | 0.36 | 5.45 | 24.66 | 13.94 | 7.38 | 21.00 | 11.14 |
| 1959 | 5.57 | 1.44 | 0.54 | 0.52 | 0.29 | 0.34 | 0.48 | 2.79 | 9.37 | 8.32 | 5.62 | 5.56 |
| 1960 | 2.24 | 0.73 | 0.66 | 1.28 | 0.81 | 0.52 | 0.52 | 1.55 | 4.70 | 5.70 | 13.79 | 11.96 |
| 1961 | 5.36 | 1.07 | 0.52 | 0.52 | 0.49 | 0.52 | 1.91 | 1.53 | 17.41 | 14.67 | 26.29 | 12.90 |
| 1962 | 16.13 | 4.17 | 0.70 | 0.54 | 0.52 | 0.52 | 0.54 | 1.36 | 4.13 | 17.92 | 26.36 | 12.04 |
| 1963 | 2.48 | 1.27 | 0.70 | 0.52 | 0.56 | 0.59 | 0.73 | 1.78 | 7.87 | 14.15 | 22.41 | 12.63 |
| 1964 | 8.40 | 4.10 | 0.97 | 0.52 | 0.57 | 1.15 | 1.67 | 4.89 | 5.23 | 8.25 | 11.18 | 4.46 |
| 1965 | 4.46 | 1.48 | 0.92 | 0.54 | 0.52 | 1.13 | 1.23 | 2.32 | 4.19 | 12.87 | 17.50 | 12.78 |
| 1966 | 2.75 | 0.80 | 0.52 | 0.52 | 0.27 | 0.33 | 4.81 | 6.09 | 13.17 | 13.33 | 9.97 | 7.19 |
| 1967 | 6.58 | 1.72 | 0.66 | 0.54 | 0.56 | 0.54 | 0.83 | 5.45 | 13.53 | 13.95 | 17.04 | 7.81 |
| 1968 | 8.38 | 1.70 | 0.55 | 0.57 | 0.58 | 0.74 | 1.19 | 1.34 | 4.29 | 5.43 | 8.40 | 7.40 |
| 1969 | 8.69 | 2.14 | 0.58 | 0.52 | 0.52 | 0.30 | 0.27 | 2.53 | 7.59 | 13.16 | 20.26 | 13.92 |
| 1970 | 5.08 | 1.60 | 0.94 | 0.54 | 0.52 | 0.52 | 0.52 | 1.40 | 2.76 | 8.91 | 14.67 | 7.89 |
| 1971 | 2.53 | 0.96 | 0.55 | 0.52 | 0.56 | 0.54 | 2.13 | 5.00 | 5.88 | 7.12 | 9.80 | 6.77 |
| 1972 | 1.83 | 0.80 | 0.54 | 0.52 | 0.29 | 0.25 | 0.32 | 1.13 | 1.18 | 8.40 | 9.18 | 8.83 |
| 1973 | 3.97 | 0.95 | 0.54 | 0.52 | 0.50 | 0.27 | 0.26 | 2.93 | 6.23 | 6.96 | 44.83 | 26.83 |
| 1974 | 14.12 | 2.61 | 0.58 | 0.52 | 0.52 | 0.27 | 0.68 | 4.25 | 7.54 | 18.45 | 24.37 | 8.76 |
| 1975 | 5.25 | 1.44 | 0.54 | 0.52 | 0.33 | 0.39 | 0.75 | 1.87 | 17.34 | 20.26 | 11.75 | 11.73 |
| 1976 | 4.46 | 9.99 | 3.80 | 0.86 | 0.66 | 0.82 | 2.37 | 15.22 | 29.35 | 33.90 | 31.90 | 14.78 |
| 1977 | 3.23 | 1.00 | 0.68 | 0.52 | 0.49 | 0.45 | 0.84 | 1.46 | 1.52 | 4.17 | 10.98 | 11.08 |
| 1978 | 7.22 | 1.90 | 0.55 | 0.54 | 1.90 | 1.17 | 0.52 | 5.19 | 11.99 | 10.86 | 9.36 | 9.86 |
| 1979 | 16.48 | 3.06 | 0.54 | 0.52 | 0.56 | 0.54 | 1.29 | 3.56 | 8.33 | 6.24 | 5.73 | 5.18 |
| 1980 | 4.06 | 8.15 | 3.51 | 4.17 | 1.73 | 0.81 | 3.17 | 3.07 | 3.73 | 21.10 | 24.27 | 25.28 |
| 1981 | 5.15 | 1.26 | 0.65 | 0.52 | 0.52 | 0.27 | 1.70 | 1.59 | 4.22 | 5.05 | 7.82 | 5.17 |
| 1982 | 2.50 | 0.95 | 0.95 | 0.57 | 2.33 | 1.70 | 0.62 | 8.69 | 23.41 | 24.30 | 15.01 | 18.37 |
| 1983 | 5.69 | 0.89 | 0.52 | 0.52 | 0.33 | 0.44 | 0.84 | 10.40 | 10.29 | 11.94 | 8.66 | 16.61 |
| 1984 | 13.07 | 2.45 | 2.79 | 1.19 | 1.57 | 2.94 | 4.35 | 3.44 | 7.05 | 19.26 | 21.00 | 9.29 |
| 1985 | 5.41 | 1.62 | 0.54 | 0.52 | 0.57 | 1.26 | 1.90 | 2.29 | 6.71 | 13.53 | 33.86 | 16.27 |
| 1986 | 3.05 | 1.25 | 0.58 | 0.52 | 0.54 | 0.52 | 1.38 | 5.34 | 11.00 | 11.50 | 18.18 | 13.04 |
| 1987 | 3.15 | 1.99 | 0.95 | 0.30 | 0.09 | 0.29 | 1.13 | 2.53 | 6.72 | 11.51 | 8.84 | 12.73 |
| 1988 | 4.23 | 1.41 | 0.22 | 0.08 | 0.18 | 1.98 | 4.61 | 7.73 | 14.34 | 15.99 | 20.69 | 22.90 |
| 1989 | 10.74 | 2.81 | 0.81 | 0.52 | 0.72 | 0.88 | 3.17 | 10.39 | 16.86 | 23.95 | 18.07 | 6.47 |
| 1990 | 2.81 | 1.02 | 0.52 | 0.16 | 0.18 | 0.03 | 0.33 | 3.56 | 11.75 | 22.87 | 16.29 | 16.37 |
| 1991 | 8.41 | 2.50 | 0.68 | 0.52 | 0.37 | 0.33 | 2.07 | 7.72 | 27.64 | 21.29 | 14.83 | 12.88 |
| 1992 | 17.14 | 3.42 | 0.66 | 0.52 | 0.74 | 0.28 | 11.40 | 8.45 | 19.42 | 47.18 | 16.40 | 5.25 |
| 1993 | 1.22 | 0.53 | 0.83 | 0.10 | 0.06 | 0.19 | 0.33 | 1.37 | 26.07 | 17.07 | 10.03 | 4.57 |
| 1994 | 2.83 | 0.73 | 0.37 | 0.22 | 0.17 | 0.14 | 0.48 | 2.92 | 8.07 | 17.00 | 17.03 | 6.14 |
| 1995 | 12.94 | 2.39 | 3.29 | 1.17 | 0.54 | 0.52 | 0.52 | 2.23 | 12.11 | 22.33 | 14.16 | 19.16 |
| 1996 | 22.68 | 8.72 | 2.63 | 0.80 | 0.52 | 0.63 | 0.94 | 3.25 | 17.27 | 8.99 | 12.32 | 4.89 |
| 1997 | 1.21 | 5.36 | 1.50 | 0.57 | 0.52 | 0.25 | 1.08 | 14.35 | 13.29 | 15.30 | 10.22 | 4.35 |
| 1998 | 1.54 | 5.40 | 2.06 | 0.76 | 0.52 | 0.52 | 0.71 | 2.60 | 6.43 | 8.51 | 10.71 | 9.93 |
| 1999 | 4.28 | 1.63 | 0.39 | 0.47 | 0.09 | 0.71 | 0.40 | 1.88 | 5.22 | 10.05 | 9.01 | 17.14 |
| 2000 | 3.19 | 0.91 | 0.54 | 0.52 | 0.39 | 0.16 | 0.29 | 6.36 | 5.62 | 27.54 | 26.07 | 23.23 |
| 2001 | 4.34 | 1.38 | 0.65 | 1.82 | 0.79 | 0.52 | 1.63 | 3.70 | 9.26 | 16.55 | 16.31 | 6.32 |
| 2002 | 4.82 | 1.59 | 0.54 | 0.52 | 0.40 | 1.30 | 1.03 | 3.75 | 3.55 | 3.08 | 14.96 | 10.32 |
| 2003 | 5.54 | 1.38 | 0.76 | 0.54 | 0.44 | 0.27 | 0.22 | 1.14 | 4.33 | 6.47 | 13.00 | 4.95 |
| 2004 | 9.73 | 1.80 | 0.54 | 0.52 | 0.52 | 0.16 | 5.04 | 7.37 | 19.95 | 9.60 | 21.12 | 9.51 |

| State 1 | <0.15 | State 2 | **0.15-1** | State 3 | 1.0-10 | State 4 | 10 - 20 | State 5 | > 20 |
|---|---|---|---|---|---|---|---|---|---|

## Table 5.6 Simulated monthly flows to the Palmiet Estuary for Scenario 2 ($m^3s^{-1}$)

| YEAR | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1928 | 2.41 | 0.96 | 0.70 | 0.52 | 0.52 | 0.26 | 1.52 | 2.72 | 3.39 | 10.94 | 12.33 | 6.11 |
| 1929 | 1.24 | 0.73 | 0.52 | 0.39 | 0.47 | 0.50 | 0.48 | 0.53 | 1.36 | 2.73 | 5.79 | 13.43 |
| 1930 | 6.50 | 1.81 | 0.78 | 0.31 | 0.34 | 0.28 | 2.67 | 3.36 | 2.00 | 5.84 | 15.72 | 13.32 |
| 1931 | 11.21 | 2.07 | 0.70 | 0.46 | 0.86 | 0.55 | 0.33 | 3.18 | 7.72 | 9.88 | 8.39 | 13.22 |
| 1932 | 5.90 | 1.07 | 0.51 | 0.33 | 0.31 | 0.29 | 0.32 | 1.43 | 10.09 | 12.23 | 18.19 | 6.36 |
| 1933 | 2.84 | 0.97 | 0.39 | 0.26 | 0.33 | 0.32 | 0.30 | 1.57 | 2.13 | 4.44 | 10.70 | 8.98 |
| 1934 | 8.51 | 1.99 | 0.52 | 0.27 | 0.27 | 0.48 | 1.32 | 4.35 | 5.92 | 6.76 | 5.60 | 6.03 |
| 1935 | 2.42 | 1.64 | 0.74 | 0.99 | 0.74 | 0.58 | 0.53 | 2.91 | 3.65 | 5.44 | 10.54 | 6.76 |
| 1936 | 2.89 | 1.85 | 1.38 | 0.71 | 0.34 | 0.38 | 0.97 | 2.82 | 16.62 | 22.60 | 13.65 | 5.66 |
| 1937 | 2.79 | 1.07 | 0.54 | 0.52 | 0.49 | 0.37 | 1.62 | 4.10 | 2.87 | 4.18 | 7.88 | 12.28 |
| 1938 | 4.95 | 1.37 | 0.57 | 0.31 | 0.80 | 0.65 | 1.15 | 3.28 | 2.09 | 5.23 | 12.15 | 6.03 |
| 1939 | 1.62 | 1.23 | 0.65 | 0.34 | 1.15 | 0.84 | 2.94 | 4.28 | 9.00 | 7.08 | 5.82 | 8.32 |
| 1940 | 2.39 | 2.52 | 0.87 | 0.61 | 0.51 | 0.30 | 4.27 | 11.09 | 18.35 | 20.38 | 16.95 | 30.52 |
| 1941 | 11.89 | 2.33 | 0.80 | 0.57 | 0.52 | 0.52 | 0.57 | 3.95 | 19.96 | 9.12 | 13.54 | 5.83 |
| 1942 | 1.54 | 0.64 | 0.54 | 2.38 | 1.61 | 0.62 | 1.45 | 1.95 | 4.53 | 8.92 | 16.38 | 7.67 |
| 1943 | 3.98 | 1.45 | 0.58 | 0.33 | 0.32 | 0.28 | 0.49 | 4.18 | 21.41 | 22.70 | 25.72 | 22.43 |
| 1944 | 6.63 | 1.49 | 0.85 | 0.52 | 0.27 | 0.24 | 0.70 | 10.37 | 22.02 | 42.41 | 29.31 | 5.97 |
| 1945 | 6.17 | 1.98 | 0.60 | 0.52 | 0.30 | 0.97 | 1.37 | 1.66 | 2.87 | 4.66 | 8.32 | 12.08 |
| 1946 | 2.99 | 0.90 | 0.37 | 0.26 | 0.26 | 0.92 | 0.96 | 1.98 | 3.81 | 18.08 | 9.14 | 5.42 |
| 1947 | 1.86 | 1.01 | 0.44 | 0.28 | 0.30 | 0.48 | 0.64 | 1.36 | 4.03 | 9.01 | 7.35 | 7.46 |
| 1948 | 8.23 | 2.53 | 0.54 | 0.52 | 0.52 | 0.25 | 1.40 | 2.43 | 3.93 | 5.62 | 10.08 | 7.13 |
| 1949 | 2.79 | 1.64 | 0.73 | 0.33 | 0.28 | 0.24 | 2.37 | 2.31 | 1.73 | 13.83 | 6.94 | 7.09 |
| 1950 | 5.83 | 7.89 | 2.38 | 0.73 | 0.52 | 0.52 | 3.76 | 4.34 | 19.41 | 22.99 | 15.76 | 26.53 |
| 1951 | 7.01 | 2.76 | 0.79 | 0.52 | 0.50 | 0.43 | 0.53 | 2.16 | 2.34 | 6.61 | 16.59 | 10.67 |
| 1952 | 5.97 | 1.82 | 0.83 | 0.35 | 0.29 | 0.27 | 3.38 | 7.87 | 5.80 | 12.46 | 15.16 | 4.00 |
| 1953 | 1.99 | 1.98 | 0.65 | 0.52 | 0.31 | 0.33 | 1.07 | 10.81 | 15.18 | 37.69 | 36.06 | 13.39 |
| 1954 | 3.24 | 1.67 | 0.58 | 0.37 | 4.20 | 2.28 | 1.39 | 1.32 | 3.03 | 17.12 | 29.08 | 15.51 |
| 1955 | 9.91 | 2.99 | 0.87 | 0.52 | 0.54 | 0.41 | 0.56 | 4.84 | 9.39 | 11.09 | 12.21 | 5.94 |
| 1956 | 3.24 | 1.24 | 0.54 | 0.52 | 0.69 | 0.80 | 1.19 | 7.96 | 20.45 | 30.08 | 26.88 | 12.50 |
| 1957 | 19.73 | 3.77 | 0.56 | 0.52 | 0.80 | 1.12 | 0.86 | 5.51 | 7.44 | 3.19 | 9.48 | 9.82 |
| 1958 | 3.47 | 1.31 | 0.48 | 0.34 | 0.33 | 0.36 | 5.23 | 18.42 | 9.67 | 4.78 | 20.30 | 8.40 |
| 1959 | 4.03 | 1.44 | 0.54 | 0.52 | 0.29 | 0.34 | 0.48 | 2.79 | 8.95 | 5.32 | 5.07 | 3.79 |
| 1960 | 1.89 | 0.73 | 0.61 | 1.28 | 0.81 | 0.30 | 0.33 | 1.09 | 4.06 | 5.25 | 13.11 | 11.06 |
| 1961 | 3.66 | 1.07 | 0.39 | 0.28 | 0.36 | 0.51 | 1.49 | 1.28 | 17.04 | 14.67 | 26.29 | 10.28 |
| 1962 | 16.13 | 4.17 | 0.70 | 0.54 | 0.52 | 0.52 | 0.54 | 1.36 | 3.91 | 13.24 | 25.08 | 7.22 |
| 1963 | 1.96 | 1.26 | 0.60 | 0.34 | 0.56 | 0.46 | 0.62 | 0.95 | 7.03 | 8.57 | 20.64 | 9.30 |
| 1964 | 4.55 | 4.10 | 0.97 | 0.52 | 0.57 | 1.15 | 1.67 | 3.83 | 4.70 | 6.40 | 9.60 | 4.18 |
| 1965 | 3.20 | 1.30 | 0.92 | 0.53 | 0.34 | 0.93 | 1.01 | 2.32 | 3.00 | 11.28 | 17.50 | 8.33 |
| 1966 | 2.18 | 0.79 | 0.52 | 0.52 | 0.27 | 0.33 | 4.78 | 4.08 | 9.41 | 9.06 | 8.94 | 5.40 |
| 1967 | 5.61 | 1.49 | 0.57 | 0.49 | 0.55 | 0.33 | 0.78 | 5.39 | 9.38 | 10.07 | 16.96 | 5.03 |
| 1968 | 6.11 | 1.70 | 0.55 | 0.57 | 0.58 | 0.74 | 1.19 | 1.34 | 4.29 | 5.43 | 7.69 | 6.37 |
| 1969 | 5.88 | 1.86 | 0.51 | 0.28 | 0.35 | 0.30 | 0.27 | 1.88 | 7.15 | 9.89 | 19.79 | 8.78 |
| 1970 | 3.77 | 1.40 | 0.94 | 0.54 | 0.33 | 0.29 | 0.31 | 1.05 | 2.70 | 8.86 | 13.23 | 6.42 |
| 1971 | 2.13 | 0.96 | 0.44 | 0.36 | 0.55 | 0.48 | 2.01 | 4.79 | 5.24 | 4.58 | 8.95 | 6.32 |
| 1972 | 1.38 | 0.65 | 0.47 | 0.34 | 0.29 | 0.25 | 0.32 | 0.78 | 0.99 | 5.87 | 6.19 | 6.52 |
| 1973 | 2.81 | 0.89 | 0.44 | 0.32 | 0.29 | 0.27 | 0.26 | 2.93 | 4.33 | 3.93 | 37.30 | 20.83 |
| 1974 | 8.91 | 2.61 | 0.58 | 0.52 | 0.52 | 0.27 | 0.68 | 4.25 | 6.41 | 13.81 | 16.78 | 5.72 |
| 1975 | 3.55 | 1.38 | 0.54 | 0.52 | 0.32 | 0.39 | 0.75 | 1.87 | 11.60 | 14.62 | 11.75 | 10.11 |
| 1976 | 4.46 | 8.99 | 3.80 | 0.86 | 0.66 | 0.82 | 2.37 | 10.13 | 29.35 | 33.90 | 31.90 | 14.78 |
| 1977 | 3.23 | 1.00 | 0.68 | 0.35 | 0.35 | 0.45 | 0.72 | 0.97 | 1.52 | 4.17 | 10.81 | 9.65 |
| 1978 | 5.37 | 1.40 | 0.55 | 0.44 | 1.77 | 1.00 | 0.33 | 5.16 | 7.94 | 7.60 | 7.65 | 6.65 |
| 1979 | 11.68 | 2.64 | 0.54 | 0.35 | 0.49 | 0.32 | 1.01 | 3.56 | 8.33 | 5.01 | 4.85 | 5.06 |
| 1980 | 2.94 | 6.52 | 3.51 | 4.17 | 1.73 | 0.81 | 3.17 | 1.85 | 2.78 | 14.30 | 22.50 | 17.63 |
| 1981 | 3.84 | 1.23 | 0.65 | 0.52 | 0.52 | 0.27 | 1.70 | 1.59 | 4.16 | 4.67 | 7.06 | 5.17 |
| 1982 | 2.27 | 0.95 | 0.88 | 0.57 | 1.49 | 1.30 | 0.62 | 6.27 | 19.51 | 22.71 | 14.89 | 18.37 |
| 1983 | 3.67 | 0.89 | 0.52 | 0.52 | 0.30 | 0.44 | 0.84 | 10.40 | 8.17 | 9.91 | 5.88 | 16.61 |
| 1984 | 12.21 | 2.45 | 2.79 | 1.19 | 1.57 | 2.94 | 4.35 | 2.42 | 5.79 | 17.17 | 21.00 | 7.91 |
| 1985 | 4.48 | 1.62 | 0.54 | 0.52 | 0.57 | 1.26 | 1.90 | 2.29 | 6.71 | 12.25 | 32.25 | 16.27 |
| 1986 | 2.65 | 1.23 | 0.58 | 0.52 | 0.54 | 0.52 | 1.38 | 5.34 | 7.89 | 10.58 | 16.59 | 13.04 |
| 1987 | 3.15 | 1.53 | 0.95 | 0.30 | 0.09 | 0.29 | 1.13 | 2.53 | 6.72 | 10.37 | 7.80 | 10.88 |
| 1988 | 2.66 | 1.41 | 0.22 | 0.08 | 0.18 | 1.98 | 4.61 | 4.89 | 9.39 | 11.49 | 18.92 | 22.90 |
| 1989 | 6.32 | 2.81 | 0.81 | 0.52 | 0.72 | 0.88 | 3.17 | 7.67 | 10.79 | 23.95 | 18.07 | 6.06 |
| 1990 | 1.23 | 1.02 | 0.52 | 0.16 | 0.18 | 0.03 | 0.33 | 3.56 | 9.85 | 18.61 | 16.29 | 16.37 |
| 1991 | 8.41 | 2.50 | 0.68 | 0.52 | 0.37 | 0.33 | 2.07 | 7.72 | 23.93 | 21.29 | 14.83 | 12.88 |
| 1992 | 17.14 | 3.42 | 0.66 | 0.52 | 0.74 | 0.28 | 11.40 | 7.68 | 12.59 | 46.93 | 16.40 | 5.25 |
| 1993 | 1.22 | 0.53 | 0.83 | 0.10 | 0.06 | 0.19 | 0.33 | 1.37 | 20.07 | 11.87 | 10.03 | 4.57 |
| 1994 | 2.83 | 0.73 | 0.37 | 0.22 | 0.17 | 0.14 | 0.48 | 2.92 | 8.07 | 12.63 | 16.33 | 5.29 |
| 1995 | 8.52 | 2.39 | 3.29 | 1.17 | 0.54 | 0.52 | 0.52 | 2.23 | 9.02 | 15.00 | 14.16 | 19.16 |
| 1996 | 22.68 | 8.72 | 2.63 | 0.80 | 0.52 | 0.63 | 0.94 | 3.12 | 15.65 | 8.99 | 12.32 | 4.89 |
| 1997 | 1.21 | 5.36 | 1.50 | 0.57 | 0.52 | 0.25 | 1.08 | 8.77 | 9.08 | 12.96 | 10.22 | 4.35 |
| 1998 | 1.54 | 5.40 | 2.06 | 0.76 | 0.52 | 0.52 | 0.71 | 2.60 | 6.40 | 8.51 | 10.14 | 9.93 |
| 1999 | 3.64 | 1.07 | 0.39 | 0.47 | 0.09 | 0.71 | 0.40 | 1.77 | 5.22 | 6.65 | 8.57 | 10.92 |
| 2000 | 2.71 | 0.91 | 0.37 | 0.26 | 0.39 | 0.16 | 0.29 | 5.71 | 4.75 | 19.94 | 26.07 | 23.23 |
| 2001 | 2.88 | 1.35 | 0.65 | 1.82 | 0.79 | 0.52 | 1.63 | 3.70 | 8.30 | 10.17 | 15.82 | 5.15 |
| 2002 | 4.74 | 1.47 | 0.44 | 0.32 | 0.29 | 1.12 | 0.78 | 3.14 | 3.55 | 3.08 | 10.83 | 6.02 |
| 2003 | 4.71 | 1.11 | 0.60 | 0.48 | 0.24 | 0.27 | 0.22 | 0.75 | 3.81 | 6.47 | 9.41 | 4.80 |
| 2004 | 6.26 | 1.63 | 0.49 | 0.35 | 0.27 | 0.16 | 4.87 | 5.31 | 13.81 | 7.91 | 16.72 | 6.33 |

| State 1 | <0.15 | State 2 | 0.15-1 | State 3 | 1-10 | State 4 | 10 - 20 | State 5 | > 20 |
|---|---|---|---|---|---|---|---|---|---|

## Table 5.7 Simulated monthly flows to the Palmiet Estuary for Scenario 3 ($m^3s^{-1}$)

| YEAR | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1928 | 2.41 | 0.96 | 0.60 | 0.52 | 0.52 | 0.26 | 1.44 | 1.66 | 2.23 | 10.42 | 12.58 | 5.24 |
| 1929 | 1.18 | 0.72 | 0.54 | 0.52 | 0.54 | 0.54 | 0.54 | 1.32 | 0.94 | 1.65 | 4.29 | 11.60 |
| 1930 | 6.50 | 1.81 | 0.73 | 0.52 | 0.52 | 0.28 | 2.72 | 2.81 | 1.92 | 3.36 | 9.80 | 10.88 |
| 1931 | 7.50 | 2.33 | 0.70 | 0.54 | 0.86 | 0.55 | 0.52 | 2.26 | 4.16 | 5.48 | 5.55 | 10.40 |
| 1932 | 4.39 | 1.11 | 0.54 | 0.52 | 0.52 | 0.29 | 0.32 | 1.45 | 7.72 | 10.37 | 17.94 | 6.13 |
| 1933 | 2.37 | 1.01 | 0.52 | 0.52 | 0.35 | 0.32 | 0.30 | 1.57 | 2.25 | 2.89 | 6.57 | 8.98 |
| 1934 | 6.36 | 1.75 | 0.53 | 0.27 | 0.27 | 0.48 | 1.32 | 4.20 | 4.86 | 6.46 | 4.85 | 4.46 |
| 1935 | 1.78 | 1.64 | 0.74 | 0.99 | 0.74 | 0.57 | 0.54 | 2.91 | 3.40 | 4.91 | 7.33 | 6.76 |
| 1936 | 2.89 | 1.85 | 1.38 | 0.71 | 0.48 | 0.38 | 0.89 | 1.75 | 9.68 | 24.20 | 15.07 | 5.32 |
| 1937 | 2.79 | 1.20 | 0.54 | 0.52 | 0.52 | 0.48 | 1.68 | 3.28 | 2.61 | 2.46 | 5.11 | 8.39 |
| 1938 | 4.95 | 1.34 | 0.57 | 0.31 | 0.80 | 0.65 | 1.22 | 2.12 | 2.09 | 3.16 | 7.98 | 5.48 |
| 1939 | 1.62 | 1.07 | 0.65 | 0.34 | 1.15 | 0.84 | 3.12 | 3.31 | 7.20 | 7.12 | 3.96 | 4.69 |
| 1940 | 2.06 | 2.49 | 0.87 | 0.61 | 0.54 | 0.52 | 5.55 | 11.14 | 18.57 | 20.49 | 16.95 | 30.52 |
| 1941 | 11.54 | 1.97 | 0.77 | 0.57 | 0.52 | 0.52 | 0.57 | 3.51 | 14.16 | 13.46 | 13.54 | 5.53 |
| 1942 | 1.39 | 0.64 | 0.54 | 2.50 | 1.64 | 0.62 | 1.45 | 1.56 | 2.17 | 6.47 | 13.01 | 10.98 |
| 1943 | 2.94 | 1.61 | 0.58 | 0.52 | 0.54 | 0.28 | 0.49 | 3.58 | 20.73 | 23.41 | 25.72 | 22.43 |
| 1944 | 5.50 | 1.63 | 0.63 | 0.52 | 0.52 | 0.24 | 0.70 | 7.75 | 22.12 | 42.41 | 29.31 | 5.97 |
| 1945 | 5.48 | 2.29 | 0.60 | 0.52 | 0.52 | 0.97 | 1.04 | 1.36 | 1.75 | 2.78 | 4.64 | 7.63 |
| 1946 | 2.99 | 0.88 | 0.42 | 0.26 | 0.26 | 0.92 | 0.96 | 1.87 | 2.58 | 10.94 | 9.44 | 4.18 |
| 1947 | 1.56 | 0.97 | 0.54 | 0.52 | 0.39 | 0.48 | 0.68 | 1.45 | 2.84 | 5.01 | 5.25 | 7.46 |
| 1948 | 11.64 | 2.53 | 0.54 | 0.52 | 0.52 | 0.25 | 1.40 | 1.94 | 2.54 | 3.53 | 6.51 | 6.57 |
| 1949 | 2.79 | 1.56 | 0.73 | 0.52 | 0.28 | 0.24 | 2.37 | 1.78 | 0.95 | 8.46 | 6.94 | 7.09 |
| 1950 | 5.83 | 8.70 | 2.10 | 0.73 | 0.52 | 0.52 | 4.04 | 3.06 | 15.75 | 24.58 | 15.76 | 26.53 |
| 1951 | 7.01 | 2.76 | 0.74 | 0.52 | 0.54 | 0.43 | 0.54 | 1.67 | 2.11 | 4.44 | 10.27 | 13.58 |
| 1952 | 5.29 | 2.58 | 0.79 | 0.52 | 0.52 | 0.27 | 3.56 | 5.36 | 4.86 | 14.04 | 15.16 | 3.94 |
| 1953 | 1.90 | 1.48 | 0.65 | 0.52 | 0.52 | 0.38 | 1.13 | 8.64 | 16.07 | 37.69 | 36.06 | 13.10 |
| 1954 | 2.76 | 1.22 | 0.58 | 0.52 | 4.95 | 2.31 | 1.39 | 1.32 | 3.03 | 10.39 | 32.01 | 15.51 |
| 1955 | 9.56 | 2.99 | 0.71 | 0.52 | 0.54 | 0.54 | 0.54 | 3.39 | 6.78 | 7.81 | 11.22 | 7.37 |
| 1956 | 3.24 | 1.13 | 0.54 | 0.52 | 0.69 | 0.80 | 0.86 | 8.36 | 19.30 | 30.08 | 26.88 | 12.22 |
| 1957 | 19.73 | 3.77 | 0.54 | 0.52 | 0.80 | 0.79 | 0.83 | 3.21 | 4.80 | 3.19 | 9.48 | 6.48 |
| 1958 | 2.81 | 1.14 | 0.54 | 0.52 | 0.52 | 0.36 | 6.09 | 18.66 | 9.67 | 4.49 | 20.06 | 8.12 |
| 1959 | 4.03 | 1.23 | 0.54 | 0.52 | 0.46 | 0.34 | 0.48 | 2.05 | 6.27 | 5.32 | 3.81 | 3.79 |
| 1960 | 1.61 | 0.73 | 0.61 | 1.28 | 0.81 | 0.30 | 0.33 | 1.36 | 2.56 | 3.83 | 7.78 | 7.84 |
| 1961 | 3.66 | 1.07 | 0.52 | 0.28 | 0.36 | 0.51 | 1.49 | 1.37 | 10.51 | 10.16 | 27.20 | 12.04 |
| 1962 | 16.13 | 4.17 | 0.70 | 0.54 | 0.52 | 0.52 | 0.52 | 1.36 | 3.37 | 10.77 | 20.36 | 10.17 |
| 1963 | 1.78 | 1.17 | 0.60 | 0.52 | 0.56 | 0.54 | 0.65 | 1.36 | 5.95 | 8.57 | 20.62 | 9.02 |
| 1964 | 4.55 | 4.10 | 0.97 | 0.52 | 0.57 | 0.78 | 1.51 | 3.20 | 3.03 | 5.52 | 6.28 | 4.18 |
| 1965 | 3.20 | 1.47 | 0.92 | 0.54 | 0.52 | 0.93 | 1.03 | 1.64 | 2.56 | 6.35 | 12.38 | 14.24 |
| 1966 | 2.18 | 0.79 | 0.52 | 0.52 | 0.27 | 0.33 | 4.78 | 4.08 | 8.60 | 9.10 | 6.91 | 4.62 |
| 1967 | 3.72 | 1.72 | 0.57 | 0.54 | 0.56 | 0.52 | 0.83 | 4.44 | 8.33 | 11.50 | 17.04 | 5.03 |
| 1968 | 5.76 | 1.70 | 0.54 | 0.57 | 0.58 | 0.54 | 0.89 | 1.34 | 3.00 | 3.34 | 4.70 | 5.57 |
| 1969 | 5.88 | 1.86 | 0.54 | 0.28 | 0.35 | 0.30 | 0.27 | 1.88 | 5.32 | 7.92 | 13.26 | 8.76 |
| 1970 | 3.77 | 1.58 | 0.94 | 0.54 | 0.52 | 0.52 | 0.52 | 1.36 | 2.70 | 6.09 | 9.76 | 5.63 |
| 1971 | 2.05 | 0.87 | 0.54 | 0.36 | 0.55 | 0.48 | 2.01 | 3.65 | 3.49 | 4.58 | 6.54 | 4.76 |
| 1972 | 1.38 | 0.65 | 0.47 | 0.34 | 0.29 | 0.25 | 0.32 | 0.78 | 0.99 | 5.87 | 6.19 | 6.52 |
| 1973 | 2.81 | 0.89 | 0.44 | 0.32 | 0.29 | 0.27 | 0.26 | 2.93 | 4.33 | 3.93 | 37.30 | 20.83 |
| 1974 | 8.91 | 2.61 | 0.58 | 0.52 | 0.52 | 0.27 | 0.57 | 3.67 | 4.37 | 11.39 | 18.37 | 5.72 |
| 1975 | 3.48 | 1.44 | 0.54 | 0.52 | 0.33 | 0.39 | 0.75 | 1.56 | 11.60 | 14.77 | 10.14 | 9.83 |
| 1976 | 3.32 | 10.18 | 3.80 | 0.86 | 0.66 | 0.69 | 2.51 | 10.13 | 29.35 | 33.90 | 31.90 | 14.78 |
| 1977 | 1.95 | 1.10 | 0.57 | 0.52 | 0.52 | 0.54 | 0.76 | 1.34 | 1.03 | 3.32 | 7.08 | 8.04 |
| 1978 | 3.96 | 1.15 | 0.55 | 0.44 | 1.77 | 1.00 | 0.50 | 4.62 | 6.87 | 6.77 | 5.70 | 6.65 |
| 1979 | 9.84 | 3.06 | 0.54 | 0.52 | 0.56 | 0.52 | 1.07 | 2.82 | 5.71 | 4.94 | 4.25 | 3.19 |
| 1980 | 2.62 | 6.88 | 2.60 | 5.08 | 1.73 | 0.81 | 3.17 | 1.85 | 1.97 | 15.10 | 18.27 | 19.28 |
| 1981 | 3.84 | 1.23 | 0.54 | 0.52 | 0.52 | 0.27 | 1.75 | 1.50 | 3.06 | 3.09 | 4.62 | 3.82 |
| 1982 | 1.96 | 0.90 | 0.88 | 0.57 | 1.57 | 1.21 | 0.62 | 6.01 | 16.62 | 24.30 | 14.61 | 18.37 |
| 1983 | 3.54 | 0.89 | 0.52 | 0.52 | 0.30 | 0.44 | 0.84 | 8.08 | 8.17 | 6.49 | 5.01 | 16.61 |
| 1984 | 11.86 | 2.45 | 2.25 | 1.19 | 0.67 | 3.54 | 5.13 | 2.42 | 3.58 | 18.51 | 21.00 | 7.63 |
| 1985 | 4.48 | 1.57 | 0.54 | 0.52 | 0.57 | 1.26 | 1.46 | 1.36 | 4.48 | 12.93 | 33.85 | 16.27 |
| 1986 | 2.65 | 1.23 | 0.54 | 0.52 | 0.54 | 0.52 | 1.15 | 4.16 | 6.98 | 7.97 | 17.05 | 13.04 |
| 1987 | 2.48 | 0.68 | 0.95 | 0.52 | 0.27 | 0.29 | 1.13 | 2.50 | 5.54 | 8.50 | 5.32 | 7.88 |
| 1988 | 2.32 | 1.27 | 0.52 | 0.08 | 0.18 | 1.98 | 5.38 | 4.96 | 9.43 | 10.56 | 19.58 | 22.90 |
| 1989 | 6.32 | 2.81 | 0.77 | 0.52 | 0.72 | 0.60 | 3.17 | 7.67 | 11.12 | 23.95 | 18.07 | 3.33 |
| 1990 | 1.07 | 0.99 | 0.54 | 0.52 | 0.18 | 0.03 | 0.33 | 3.56 | 9.73 | 18.98 | 16.29 | 16.37 |
| 1991 | 8.41 | 2.50 | 0.57 | 0.52 | 0.49 | 0.33 | 1.80 | 5.18 | 24.29 | 21.29 | 14.83 | 12.88 |
| 1992 | 17.14 | 3.42 | 0.66 | 0.52 | 0.52 | 0.28 | 11.61 | 5.31 | 13.98 | 47.18 | 16.40 | 2.66 |
| 1993 | 1.11 | 0.54 | 0.83 | 0.50 | 0.06 | 0.19 | 0.33 | 1.37 | 20.66 | 11.87 | 6.19 | 3.32 |
| 1994 | 2.00 | 0.73 | 0.52 | 0.52 | 0.17 | 0.14 | 0.48 | 2.92 | 5.67 | 12.63 | 16.38 | 3.88 |
| 1995 | 9.29 | 2.39 | 3.29 | 1.09 | 0.54 | 0.52 | 0.52 | 1.36 | 9.02 | 15.31 | 14.16 | 19.16 |
| 1996 | 22.68 | 8.72 | 2.63 | 0.80 | 0.52 | 0.52 | 0.52 | 3.12 | 10.15 | 6.52 | 11.94 | 3.08 |
| 1997 | 1.05 | 6.25 | 1.50 | 0.57 | 0.52 | 0.52 | 1.15 | 9.09 | 9.08 | 10.47 | 8.01 | 2.92 |
| 1998 | 1.26 | 6.98 | 2.06 | 0.76 | 0.52 | 0.52 | 0.54 | 1.82 | 4.57 | 7.37 | 8.30 | 10.08 |
| 1999 | 3.16 | 1.02 | 0.52 | 0.54 | 0.37 | 0.71 | 0.45 | 1.88 | 5.09 | 6.65 | 5.32 | 12.27 |
| 2000 | 1.95 | 0.82 | 0.52 | 0.52 | 0.40 | 0.16 | 0.29 | 5.78 | 3.61 | 20.01 | 26.07 | 23.23 |
| 2001 | 2.88 | 1.35 | 0.54 | 1.82 | 0.79 | 0.52 | 0.68 | 2.77 | 7.28 | 10.85 | 16.31 | 3.31 |
| 2002 | 3.60 | 1.44 | 0.54 | 0.52 | 0.52 | 1.30 | 0.78 | 2.40 | 2.37 | 1.98 | 10.62 | 5.96 |
| 2003 | 3.72 | 1.09 | 0.60 | 0.54 | 0.54 | 0.40 | 0.28 | 1.27 | 2.98 | 5.94 | 9.08 | 2.45 |
| 2004 | 6.26 | 1.62 | 0.54 | 0.35 | 0.27 | 0.16 | 4.87 | 4.91 | 13.97 | 6.33 | 15.12 | 5.19 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| State 1 | <0.15 | State 2 | **0.15-1** | State 3 | 1-10 | State 4 | 10 - 20 | State 5 | > 20 |

## Table 5.8 Simulated monthly flows to the Palmiet Estuary for Scenario 4 ($m^3s^{-1}$)

| YEAR | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1928 | 1.78 | 0.69 | 0.54 | 0.52 | 0.52 | 0.52 | 1.07 | 1.39 | 1.47 | 5.69 | 5.73 | 2.60 |
| 1929 | 0.92 | 0.56 | 0.54 | 0.52 | 0.54 | 0.54 | 0.54 | 1.32 | 0.69 | 1.17 | 2.82 | 5.92 |
| 1930 | 3.31 | 1.31 | 0.58 | 0.52 | 0.52 | 0.52 | 2.11 | 1.86 | 1.27 | 2.07 | 4.50 | 3.93 |
| 1931 | 3.32 | 1.65 | 0.55 | 0.54 | 0.68 | 0.54 | 0.52 | 1.68 | 2.76 | 3.40 | 2.60 | 3.81 |
| 1932 | 2.41 | 0.85 | 0.54 | 0.52 | 0.52 | 0.52 | 0.52 | 1.39 | 5.16 | 5.15 | 11.43 | 4.86 |
| 1933 | 1.42 | 0.76 | 0.52 | 0.52 | 0.52 | 0.52 | 0.52 | 1.39 | 1.58 | 1.90 | 3.72 | 4.19 |
| 1934 | 2.99 | 1.38 | 0.54 | 0.52 | 0.52 | 0.54 | 1.05 | 3.04 | 3.19 | 3.00 | 2.27 | 2.08 |
| 1935 | 1.31 | 1.13 | 0.58 | 0.79 | 0.59 | 0.54 | 0.54 | 2.12 | 2.24 | 3.04 | 3.41 | 3.14 |
| 1936 | 1.79 | 1.28 | 1.09 | 0.56 | 0.52 | 0.52 | 0.67 | 1.39 | 5.97 | 8.59 | 13.41 | 3.86 |
| 1937 | 1.64 | 0.85 | 0.54 | 0.52 | 0.52 | 0.52 | 1.25 | 2.26 | 1.72 | 1.62 | 2.37 | 3.87 |
| 1938 | 2.50 | 1.05 | 0.54 | 0.52 | 0.63 | 0.55 | 0.91 | 1.53 | 1.38 | 2.07 | 3.89 | 2.61 |
| 1939 | 1.14 | 0.83 | 0.55 | 0.27 | 0.91 | 0.67 | 2.31 | 2.18 | 3.99 | 3.29 | 1.86 | 2.06 |
| 1940 | 1.42 | 1.31 | 0.69 | 0.54 | 0.54 | 0.52 | 3.22 | 5.86 | 6.13 | 20.42 | 17.03 | 30.70 |
| 1941 | 10.42 | 1.79 | 0.61 | 0.54 | 0.52 | 0.52 | 0.54 | 2.49 | 10.62 | 13.12 | 13.65 | 4.70 |
| 1942 | 1.05 | 0.54 | 0.54 | 1.79 | 1.20 | 0.54 | 0.76 | 1.37 | 1.41 | 3.25 | 5.37 | 5.76 |
| 1943 | 1.63 | 1.05 | 0.54 | 0.52 | 0.54 | 0.52 | 0.54 | 2.57 | 13.43 | 23.50 | 25.88 | 22.52 |
| 1944 | 4.69 | 1.47 | 0.54 | 0.52 | 0.52 | 0.52 | 0.56 | 5.28 | 22.15 | 42.68 | 29.44 | 3.66 |
| 1945 | 2.43 | 1.51 | 0.54 | 0.52 | 0.52 | 0.67 | 0.80 | 1.36 | 1.21 | 1.83 | 2.86 | 3.43 |
| 1946 | 1.90 | 0.69 | 0.52 | 0.52 | 0.52 | 0.73 | 0.76 | 1.46 | 1.70 | 5.94 | 4.26 | 1.87 |
| 1947 | 1.13 | 0.69 | 0.54 | 0.52 | 0.54 | 0.54 | 0.54 | 1.37 | 1.92 | 3.29 | 2.48 | 3.34 |
| 1948 | 3.70 | 1.72 | 0.54 | 0.52 | 0.52 | 0.52 | 1.07 | 1.41 | 1.67 | 2.32 | 3.08 | 3.05 |
| 1949 | 1.76 | 1.11 | 0.58 | 0.52 | 0.52 | 0.52 | 1.87 | 1.39 | 0.63 | 4.78 | 3.24 | 3.18 |
| 1950 | 2.69 | 2.73 | 1.47 | 0.58 | 0.52 | 0.52 | 2.18 | 2.01 | 12.10 | 24.74 | 15.82 | 26.66 |
| 1951 | 4.99 | 2.63 | 0.58 | 0.52 | 0.54 | 0.54 | 0.54 | 1.39 | 1.45 | 2.91 | 5.06 | 7.60 |
| 1952 | 5.20 | 2.44 | 0.62 | 0.52 | 0.52 | 0.52 | 2.61 | 3.52 | 2.50 | 12.17 | 15.25 | 2.25 |
| 1953 | 1.10 | 0.94 | 0.55 | 0.52 | 0.52 | 0.52 | 0.85 | 5.82 | 12.32 | 37.92 | 36.23 | 12.23 |
| 1954 | 1.61 | 0.84 | 0.54 | 0.52 | 3.05 | 1.57 | 0.58 | 1.32 | 1.81 | 4.55 | 28.69 | 15.53 |
| 1955 | 8.51 | 2.85 | 0.56 | 0.52 | 0.54 | 0.54 | 0.54 | 2.43 | 4.45 | 3.69 | 10.58 | 5.93 |
| 1956 | 1.51 | 0.85 | 0.54 | 0.52 | 0.54 | 0.62 | 0.65 | 5.39 | 18.07 | 30.27 | 27.03 | 11.36 |
| 1957 | 19.85 | 3.57 | 0.54 | 0.52 | 0.64 | 0.63 | 0.62 | 2.28 | 3.16 | 1.86 | 4.33 | 3.03 |
| 1958 | 1.44 | 0.90 | 0.54 | 0.52 | 0.52 | 0.52 | 3.89 | 14.22 | 7.97 | 1.96 | 18.23 | 7.22 |
| 1959 | 1.80 | 0.94 | 0.54 | 0.52 | 0.54 | 0.52 | 0.54 | 1.56 | 4.14 | 2.93 | 1.80 | 1.77 |
| 1960 | 1.19 | 0.58 | 0.54 | 1.01 | 0.64 | 0.52 | 0.52 | 1.36 | 1.82 | 2.52 | 4.13 | 3.56 |
| 1961 | 1.92 | 0.85 | 0.52 | 0.52 | 0.52 | 0.54 | 1.18 | 1.37 | 6.29 | 4.70 | 15.94 | 11.14 |
| 1962 | 16.19 | 4.01 | 0.55 | 0.54 | 0.52 | 0.52 | 0.52 | 1.36 | 2.35 | 6.00 | 15.87 | 8.22 |
| 1963 | 1.20 | 0.80 | 0.54 | 0.52 | 0.56 | 0.54 | 0.54 | 1.36 | 4.01 | 4.57 | 11.18 | 8.14 |
| 1964 | 2.44 | 4.01 | 0.77 | 0.52 | 0.54 | 0.62 | 1.17 | 2.19 | 1.98 | 2.69 | 2.90 | 1.96 |
| 1965 | 1.51 | 1.00 | 0.73 | 0.54 | 0.52 | 0.74 | 0.77 | 1.39 | 1.70 | 3.72 | 5.22 | 6.70 |
| 1966 | 1.61 | 0.62 | 0.52 | 0.52 | 0.52 | 0.52 | 3.37 | 2.67 | 4.10 | 4.54 | 3.99 | 2.63 |
| 1967 | 1.71 | 1.23 | 0.54 | 0.54 | 0.56 | 0.52 | 0.62 | 3.08 | 4.88 | 8.19 | 16.73 | 2.93 |
| 1968 | 4.70 | 1.49 | 0.54 | 0.54 | 0.54 | 0.54 | 0.67 | 1.34 | 2.07 | 2.20 | 2.63 | 2.60 |
| 1969 | 2.74 | 1.47 | 0.54 | 0.52 | 0.52 | 0.52 | 0.52 | 1.48 | 3.56 | 4.38 | 5.26 | 3.56 |
| 1970 | 1.86 | 1.06 | 0.75 | 0.54 | 0.52 | 0.52 | 0.52 | 1.36 | 1.91 | 4.00 | 4.71 | 2.67 |
| 1971 | 1.21 | 0.69 | 0.35 | 0.28 | 0.44 | 0.38 | 1.58 | 2.46 | 2.30 | 2.30 | 3.03 | 2.24 |
| 1972 | 1.06 | 0.54 | 0.37 | 0.27 | 0.23 | 0.20 | 0.25 | 0.62 | 0.78 | 3.90 | 3.40 | 3.03 |
| 1973 | 1.81 | 0.70 | 0.37 | 0.25 | 0.23 | 0.21 | 0.21 | 2.28 | 2.87 | 2.48 | 18.61 | 20.87 |
| 1974 | 8.15 | 2.43 | 0.54 | 0.52 | 0.52 | 0.52 | 0.54 | 2.61 | 2.88 | 6.20 | 18.46 | 2.75 |
| 1975 | 1.57 | 1.00 | 0.54 | 0.52 | 0.54 | 0.52 | 0.60 | 1.39 | 6.98 | 10.22 | 8.04 | 7.24 |
| 1976 | 1.87 | 6.36 | 3.64 | 0.67 | 0.54 | 0.55 | 2.44 | 9.39 | 29.55 | 34.09 | 32.06 | 14.82 |
| 1977 | 1.43 | 0.76 | 0.54 | 0.52 | 0.52 | 0.54 | 0.57 | 1.34 | 0.77 | 2.19 | 4.01 | 3.74 |
| 1978 | 2.09 | 0.91 | 0.54 | 0.54 | 1.40 | 0.79 | 0.52 | 3.23 | 4.18 | 3.14 | 2.65 | 2.99 |
| 1979 | 4.07 | 2.05 | 0.54 | 0.52 | 0.56 | 0.52 | 0.80 | 2.01 | 3.76 | 2.43 | 1.98 | 1.53 |
| 1980 | 1.28 | 2.45 | 1.62 | 2.32 | 1.33 | 0.55 | 1.27 | 1.36 | 0.90 | 4.71 | 12.64 | 19.35 |
| 1981 | 2.30 | 0.85 | 0.54 | 0.52 | 0.52 | 0.52 | 1.34 | 1.37 | 2.01 | 2.03 | 2.22 | 1.81 |
| 1982 | 1.19 | 0.72 | 0.69 | 0.54 | 1.18 | 0.94 | 0.54 | 4.09 | 7.33 | 16.44 | 13.82 | 18.45 |
| 1983 | 2.16 | 0.70 | 0.52 | 0.52 | 0.54 | 0.54 | 0.67 | 5.47 | 4.16 | 3.00 | 4.79 | 16.68 |
| 1984 | 10.80 | 2.24 | 2.13 | 0.96 | 0.54 | 3.46 | 5.16 | 1.39 | 1.63 | 14.20 | 21.10 | 6.77 |
| 1985 | 1.96 | 1.08 | 0.54 | 0.52 | 0.54 | 0.90 | 1.09 | 1.36 | 2.93 | 4.04 | 34.13 | 16.26 |
| 1986 | 1.47 | 0.85 | 0.54 | 0.52 | 0.54 | 0.52 | 0.86 | 2.88 | 4.23 | 3.69 | 13.54 | 13.10 |
| 1987 | 1.75 | 0.56 | 0.75 | 0.52 | 0.52 | 0.52 | 0.90 | 1.79 | 3.64 | 4.06 | 2.49 | 3.58 |
| 1988 | 1.49 | 1.01 | 0.52 | 0.50 | 0.52 | 1.57 | 3.34 | 2.78 | 4.02 | 6.66 | 16.76 | 22.64 |
| 1989 | 4.77 | 2.63 | 0.61 | 0.52 | 0.58 | 0.54 | 2.61 | 5.13 | 10.88 | 24.15 | 18.09 | 1.46 |
| 1990 | 0.79 | 0.69 | 0.54 | 0.52 | 0.52 | 0.50 | 0.52 | 2.69 | 5.83 | 10.76 | 16.32 | 16.48 |
| 1991 | 8.06 | 2.30 | 0.54 | 0.52 | 0.54 | 0.52 | 1.43 | 3.49 | 19.76 | 21.47 | 14.90 | 12.90 |
| 1992 | 17.23 | 3.25 | 0.55 | 0.52 | 0.52 | 0.52 | 10.79 | 2.95 | 13.11 | 47.48 | 16.47 | 1.42 |
| 1993 | 0.87 | 0.54 | 0.65 | 0.50 | 0.50 | 0.52 | 0.52 | 1.37 | 10.17 | 6.60 | 6.33 | 2.33 |
| 1994 | 1.35 | 0.58 | 0.52 | 0.52 | 0.52 | 0.52 | 0.54 | 2.24 | 3.72 | 6.06 | 10.55 | 1.75 |
| 1995 | 7.60 | 2.24 | 3.16 | 0.87 | 0.54 | 0.52 | 0.52 | 1.36 | 5.37 | 11.91 | 14.26 | 19.26 |
| 1996 | 22.69 | 8.63 | 2.44 | 0.63 | 0.52 | 0.52 | 0.52 | 2.26 | 5.74 | 3.05 | 11.41 | 1.58 |
| 1997 | 0.77 | 2.51 | 1.19 | 0.54 | 0.52 | 0.52 | 0.86 | 5.89 | 7.37 | 10.63 | 7.19 | 1.42 |
| 1998 | 0.99 | 2.74 | 1.40 | 0.60 | 0.52 | 0.52 | 0.54 | 1.41 | 3.05 | 3.94 | 3.86 | 4.63 |
| 1999 | 2.17 | 0.79 | 0.52 | 0.54 | 0.52 | 0.56 | 0.52 | 1.41 | 3.40 | 3.84 | 2.50 | 4.94 |
| 2000 | 1.44 | 0.63 | 0.52 | 0.52 | 0.52 | 0.52 | 0.52 | 4.18 | 2.38 | 8.12 | 24.20 | 23.34 |
| 2001 | 1.70 | 1.00 | 0.54 | 1.44 | 0.62 | 0.52 | 0.54 | 2.01 | 4.67 | 4.70 | 14.76 | 2.39 |
| 2002 | 1.95 | 1.00 | 0.54 | 0.52 | 0.52 | 0.89 | 0.62 | 1.72 | 1.57 | 1.29 | 4.87 | 2.74 |
| 2003 | 1.85 | 0.86 | 0.54 | 0.54 | 0.54 | 0.52 | 0.52 | 1.34 | 2.12 | 3.90 | 4.33 | 1.42 |
| 2004 | 2.91 | 1.28 | 0.54 | 0.52 | 0.52 | 0.22 | 3.64 | 3.23 | 6.36 | 2.95 | 4.50 | 3.23 |

| State 1 | <0.15 | State 2 | 0.15-1 | State 3 | 1-10 | State 4 | 10 - 20 | State 5 | > 20 |
|---|---|---|---|---|---|---|---|---|---|

## Table 5.9 Simulated monthly flows to the Palmiet Estuary for Scenario 6 ($m^3s^{-1}$)

| YEAR | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1928 | 2.41 | 1.00 | 1.00 | 0.52 | 0.52 | 0.26 | 1.52 | 2.72 | 3.39 | 10.94 | 12.33 | 6.11 |
| 1929 | 1.24 | 1.00 | 1.00 | 0.39 | 0.47 | 0.50 | 1.00 | 1.00 | 1.36 | 2.73 | 5.79 | 13.43 |
| 1930 | 6.50 | 1.81 | 1.00 | 0.31 | 0.34 | 0.28 | 2.67 | 3.36 | 2.00 | 5.84 | 15.72 | 13.32 |
| 1931 | 11.21 | 2.07 | 1.00 | 0.46 | 0.86 | 0.55 | 1.00 | 3.18 | 7.72 | 9.88 | 8.39 | 13.22 |
| 1932 | 5.90 | 1.07 | 1.00 | 0.33 | 0.31 | 0.29 | 1.00 | 1.43 | 10.09 | 12.23 | 18.19 | 6.36 |
| 1933 | 2.84 | 1.00 | 1.00 | 0.26 | 0.33 | 0.32 | 1.00 | 1.57 | 2.13 | 4.44 | 10.70 | 8.98 |
| 1934 | 8.51 | 1.99 | 1.00 | 0.27 | 0.27 | 0.48 | 1.32 | 4.35 | 5.92 | 6.76 | 5.60 | 6.03 |
| 1935 | 2.42 | 1.64 | 1.00 | 0.99 | 0.74 | 0.58 | 1.00 | 2.91 | 3.65 | 5.44 | 10.54 | 6.76 |
| 1936 | 2.89 | 1.85 | 1.38 | 0.71 | 0.34 | 0.38 | 1.00 | 2.82 | 16.62 | 22.60 | 13.65 | 5.66 |
| 1937 | 2.79 | 1.07 | 1.00 | 0.52 | 0.49 | 0.37 | 1.62 | 4.10 | 2.87 | 4.18 | 7.88 | 12.28 |
| 1938 | 4.95 | 1.37 | 1.00 | 0.31 | 0.80 | 0.65 | 1.15 | 3.28 | 2.09 | 5.23 | 12.15 | 6.03 |
| 1939 | 1.62 | 1.23 | 1.00 | 0.34 | 1.15 | 0.84 | 2.94 | 4.28 | 9.00 | 7.08 | 5.82 | 8.32 |
| 1940 | 2.39 | 2.52 | 1.00 | 0.61 | 0.51 | 0.30 | 4.27 | 11.09 | 18.35 | 20.38 | 16.95 | 30.52 |
| 1941 | 11.89 | 2.33 | 1.00 | 0.57 | 0.52 | 0.52 | 1.00 | 3.95 | 19.96 | 9.12 | 13.54 | 5.83 |
| 1942 | 1.54 | 1.00 | 1.00 | 2.38 | 1.61 | 0.62 | 1.45 | 1.95 | 4.53 | 8.92 | 16.38 | 7.67 |
| 1943 | 3.98 | 1.45 | 1.00 | 0.33 | 0.32 | 0.28 | 1.00 | 4.18 | 21.41 | 22.70 | 25.72 | 22.43 |
| 1944 | 6.63 | 1.49 | 1.00 | 0.52 | 0.27 | 0.24 | 1.00 | 10.37 | 22.02 | 42.41 | 29.31 | 5.97 |
| 1945 | 6.17 | 1.98 | 1.00 | 0.52 | 0.30 | 0.97 | 1.37 | 1.66 | 2.87 | 4.66 | 8.32 | 12.08 |
| 1946 | 2.99 | 1.00 | 1.00 | 0.26 | 0.26 | 0.92 | 1.00 | 1.98 | 3.81 | 18.08 | 9.14 | 5.42 |
| 1947 | 1.86 | 1.01 | 1.00 | 0.28 | 0.30 | 0.48 | 1.00 | 1.36 | 4.03 | 9.01 | 7.35 | 7.46 |
| 1948 | 8.23 | 2.53 | 1.00 | 0.52 | 0.52 | 0.25 | 1.40 | 2.43 | 3.93 | 5.62 | 10.08 | 7.13 |
| 1949 | 2.79 | 1.64 | 1.00 | 0.33 | 0.28 | 0.24 | 2.37 | 2.31 | 1.73 | 13.83 | 6.94 | 7.09 |
| 1950 | 5.83 | 7.89 | 2.38 | 0.73 | 0.52 | 0.52 | 3.76 | 4.34 | 19.41 | 22.99 | 15.76 | 26.53 |
| 1951 | 7.01 | 2.76 | 1.00 | 0.52 | 0.50 | 0.43 | 1.00 | 2.16 | 2.34 | 6.61 | 16.59 | 10.67 |
| 1952 | 5.97 | 1.82 | 1.00 | 0.35 | 0.29 | 0.27 | 3.38 | 7.87 | 5.80 | 12.46 | 15.16 | 4.00 |
| 1953 | 1.99 | 1.98 | 1.00 | 0.52 | 0.31 | 0.33 | 1.07 | 10.81 | 15.18 | 37.69 | 36.06 | 13.39 |
| 1954 | 3.24 | 1.67 | 1.00 | 0.37 | 4.20 | 2.28 | 1.39 | 1.32 | 3.03 | 17.12 | 29.08 | 15.51 |
| 1955 | 9.91 | 2.99 | 1.00 | 0.52 | 0.54 | 0.41 | 1.00 | 4.84 | 9.39 | 11.09 | 12.21 | 5.94 |
| 1956 | 3.24 | 1.24 | 1.00 | 0.52 | 0.69 | 0.80 | 1.19 | 7.96 | 20.45 | 30.08 | 26.88 | 12.50 |
| 1957 | 19.73 | 3.77 | 1.00 | 0.52 | 0.80 | 1.12 | 1.00 | 5.51 | 7.44 | 3.19 | 9.48 | 9.82 |
| 1958 | 3.47 | 1.31 | 1.00 | 0.34 | 0.33 | 0.36 | 5.23 | 18.42 | 9.67 | 4.78 | 20.30 | 8.40 |
| 1959 | 4.03 | 1.44 | 1.00 | 0.52 | 0.29 | 0.34 | 1.00 | 2.79 | 8.95 | 5.32 | 5.07 | 3.79 |
| 1960 | 1.89 | 1.00 | 1.00 | 1.28 | 0.81 | 0.30 | 1.00 | 1.09 | 4.06 | 5.25 | 13.11 | 11.06 |
| 1961 | 3.66 | 1.07 | 1.00 | 0.28 | 0.36 | 0.51 | 1.49 | 1.28 | 17.04 | 14.67 | 26.29 | 10.28 |
| 1962 | 16.13 | 4.17 | 1.00 | 0.54 | 0.52 | 0.52 | 1.00 | 1.36 | 3.91 | 13.24 | 25.08 | 7.22 |
| 1963 | 1.96 | 1.26 | 1.00 | 0.34 | 0.56 | 0.46 | 1.00 | 1.00 | 7.03 | 8.57 | 20.64 | 9.30 |
| 1964 | 4.55 | 4.10 | 1.00 | 0.52 | 0.57 | 1.15 | 1.67 | 3.83 | 4.70 | 6.40 | 9.60 | 4.18 |
| 1965 | 3.20 | 1.30 | 1.00 | 0.53 | 0.34 | 0.93 | 1.01 | 2.32 | 3.00 | 11.28 | 17.50 | 8.33 |
| 1966 | 2.18 | 1.00 | 1.00 | 0.52 | 0.27 | 0.33 | 4.78 | 4.08 | 9.41 | 9.06 | 8.94 | 5.40 |
| 1967 | 5.61 | 1.49 | 1.00 | 0.49 | 0.55 | 0.33 | 1.00 | 5.39 | 9.38 | 10.07 | 16.96 | 5.03 |
| 1968 | 6.11 | 1.70 | 1.00 | 0.57 | 0.58 | 0.74 | 1.19 | 1.34 | 4.29 | 5.43 | 7.69 | 6.37 |
| 1969 | 5.88 | 1.86 | 1.00 | 0.28 | 0.35 | 0.30 | 1.00 | 1.88 | 7.15 | 9.89 | 19.79 | 8.78 |
| 1970 | 3.77 | 1.40 | 1.00 | 0.54 | 0.33 | 0.29 | 1.00 | 1.05 | 2.70 | 8.86 | 13.23 | 6.42 |
| 1971 | 2.13 | 1.00 | 1.00 | 0.36 | 0.55 | 0.48 | 2.01 | 4.79 | 5.24 | 4.58 | 8.95 | 6.32 |
| 1972 | 1.38 | 1.00 | 1.00 | 0.34 | 0.29 | 0.25 | 1.00 | 1.00 | 1.00 | 5.87 | 6.19 | 6.52 |
| 1973 | 2.81 | 1.00 | 1.00 | 0.32 | 0.29 | 0.27 | 1.00 | 2.93 | 4.33 | 3.93 | 37.30 | 20.83 |
| 1974 | 8.91 | 2.61 | 1.00 | 0.52 | 0.52 | 0.27 | 1.00 | 4.25 | 6.41 | 13.81 | 16.78 | 5.72 |
| 1975 | 3.55 | 1.38 | 1.00 | 0.52 | 0.32 | 0.39 | 1.00 | 1.87 | 11.60 | 14.62 | 11.75 | 10.11 |
| 1976 | 4.46 | 8.99 | 3.80 | 0.86 | 0.66 | 0.82 | 2.37 | 10.13 | 29.35 | 33.90 | 31.90 | 14.78 |
| 1977 | 3.23 | 1.00 | 1.00 | 0.35 | 0.35 | 0.45 | 1.00 | 1.00 | 1.52 | 4.17 | 10.81 | 9.65 |
| 1978 | 5.37 | 1.40 | 1.00 | 0.44 | 1.77 | 1.00 | 1.00 | 5.16 | 7.94 | 7.60 | 7.65 | 6.65 |
| 1979 | 11.68 | 2.64 | 1.00 | 0.35 | 0.49 | 0.32 | 1.01 | 3.56 | 8.33 | 5.01 | 4.85 | 5.06 |
| 1980 | 2.94 | 6.52 | 3.51 | 4.17 | 1.73 | 0.81 | 3.17 | 1.85 | 2.78 | 14.30 | 22.50 | 17.63 |
| 1981 | 3.84 | 1.23 | 1.00 | 0.52 | 0.52 | 0.27 | 1.70 | 1.59 | 4.16 | 4.67 | 7.06 | 5.17 |
| 1982 | 2.27 | 1.00 | 1.00 | 0.57 | 1.49 | 1.30 | 1.00 | 6.27 | 19.51 | 22.71 | 14.89 | 18.37 |
| 1983 | 3.67 | 1.00 | 1.00 | 0.52 | 0.30 | 0.44 | 1.00 | 10.40 | 8.17 | 9.91 | 5.88 | 16.61 |
| 1984 | 12.21 | 2.45 | 2.79 | 1.19 | 1.57 | 2.94 | 4.35 | 2.42 | 5.79 | 17.17 | 21.00 | 7.91 |
| 1985 | 4.48 | 1.62 | 1.00 | 0.52 | 0.57 | 1.26 | 1.90 | 2.29 | 6.71 | 12.25 | 32.25 | 16.27 |
| 1986 | 2.65 | 1.23 | 1.00 | 0.52 | 0.54 | 0.52 | 1.38 | 5.34 | 7.89 | 10.58 | 16.59 | 13.04 |
| 1987 | 3.15 | 1.53 | 1.00 | 0.30 | 0.09 | 0.29 | 1.13 | 2.53 | 6.72 | 10.37 | 7.80 | 10.88 |
| 1988 | 2.66 | 1.41 | 1.00 | 0.08 | 0.18 | 1.98 | 4.61 | 4.89 | 9.39 | 11.49 | 18.92 | 22.90 |
| 1989 | 6.32 | 2.81 | 1.00 | 0.52 | 0.72 | 0.88 | 3.17 | 7.67 | 10.79 | 23.95 | 18.07 | 6.06 |
| 1990 | 1.23 | 1.02 | 1.00 | 0.16 | 0.18 | 0.03 | 1.00 | 3.56 | 9.85 | 18.61 | 16.29 | 16.37 |
| 1991 | 8.41 | 2.50 | 1.00 | 0.52 | 0.37 | 0.33 | 2.07 | 7.72 | 23.93 | 21.29 | 14.83 | 12.88 |
| 1992 | 17.14 | 3.42 | 1.00 | 0.52 | 0.74 | 0.28 | 11.40 | 7.68 | 12.59 | 46.93 | 16.40 | 5.25 |
| 1993 | 1.22 | 1.00 | 1.00 | 0.10 | 0.06 | 0.19 | 1.00 | 1.37 | 20.07 | 11.87 | 10.03 | 4.57 |
| 1994 | 2.83 | 1.00 | 1.00 | 0.22 | 0.17 | 0.14 | 1.00 | 2.92 | 8.07 | 12.63 | 16.33 | 5.29 |
| 1995 | 8.52 | 2.39 | 3.29 | 1.17 | 0.54 | 0.52 | 1.00 | 2.23 | 9.02 | 15.00 | 14.16 | 19.16 |
| 1996 | 22.68 | 8.72 | 2.63 | 0.80 | 0.52 | 0.63 | 1.00 | 3.12 | 15.65 | 8.99 | 12.32 | 4.89 |
| 1997 | 1.21 | 5.36 | 1.50 | 0.57 | 0.52 | 0.25 | 1.08 | 8.77 | 9.08 | 12.96 | 10.22 | 4.35 |
| 1998 | 1.54 | 5.40 | 2.06 | 0.76 | 0.52 | 0.52 | 1.00 | 2.60 | 6.40 | 8.51 | 10.14 | 9.93 |
| 1999 | 3.64 | 1.07 | 1.00 | 0.47 | 0.09 | 0.71 | 1.00 | 1.77 | 5.22 | 6.65 | 8.57 | 10.92 |
| 2000 | 2.71 | 1.00 | 1.00 | 0.26 | 0.39 | 0.16 | 1.00 | 5.71 | 4.75 | 19.94 | 26.07 | 23.23 |
| 2001 | 2.88 | 1.35 | 1.00 | 1.82 | 0.79 | 0.52 | 1.63 | 3.70 | 8.30 | 10.17 | 15.82 | 5.15 |
| 2002 | 4.74 | 1.47 | 1.00 | 0.32 | 0.29 | 1.12 | 1.00 | 3.14 | 3.55 | 3.08 | 10.83 | 6.02 |
| 2003 | 4.71 | 1.11 | 1.00 | 0.48 | 0.24 | 0.27 | 1.00 | 1.00 | 3.81 | 6.47 | 9.41 | 4.80 |
| 2004 | 6.26 | 1.63 | 1.00 | 0.35 | 0.27 | 0.16 | 4.87 | 5.31 | 13.81 | 7.91 | 16.72 | 6.33 |

| State 1 | <0.15 | State 2 | 0.15-1.0 | State 3 | 1.0-10 | State 4 | 10 - 20 | State 5 | > 20 |
|---|---|---|---|---|---|---|---|---|---|

### *5.2.6 Hydrology*

This section describes the changes in the hydrology for the scenarios.

#### 5.2.6.1 Low flows

| | |
|---|---|
| **Scenario 1** | MAR 185.2 million $m^3$, a reduction of 27.8 % compared to Reference Condition.<br><br>For the Palmiet Estuary, low flows are defined as months in which river inflow to the estuary is less than 1.0 $m^3s^{-1}$ i.e. flows representative of State 1 (closed mouth) and State 2 (semi-closed). Months with flows of less than 1.0 $m^3/s$ occurred under the Reference Condition for 10.5 % (~1 month) of the year. Under the Scenario 1 low flows occur for 35.2 % (~4 months) of the year. Occurrence of large flows based on daily flow analyses: 58 % similar. Reduction in magnitude based on average monthly flows: 84 % similar. |
| **Scenario 2** | MAR 161.3 million $m^3$, a reduction of 37.1 % compared to Reference. Low flows occur for 36.6 % (~4.5 months) of the year. Occurrence of large flows based on daily flow analyses: 43 % similar. Reduction in magnitude based on average monthly flows: 76 % similar. |
| **Scenario 3** | MAR 148.7 million $m^3$, a reduction of 42.0 % compared to Reference. Low flows occur for 37.2 % (~4.5 months) of the year. Occurrence of large flows based on daily flow analyses: 41 % similar. Reduction in magnitude based on average monthly flows: 74 % similar. |
| **Scenario 4** | MAR 111.18 million $m^3$, a reduction of 56.6 % compared to Reference. Low flows occur for 41.9 % (~5 months) of the year. Occurrence of large flows based on daily flow analyses: 27 % similar. Reduction in magnitude based on average monthly flows: 63 % similar. |
| **Scenario 5** | Similar to Present State |
| **Scenario 6** | MAR 161.9 million $m^3$, a reduction of 36.8 % compared to Reference. Low flows occur for 22.8 % (~2.5 months) of the year. Occurrence of large flows based on daily flow analyses: 43 % similar. Reduction in magnitude based on average monthly flows: 76 % similar.<br>*Note: Scenario 6 was generated at the workshop (i.e. manipulation of the baseflows in a spread sheet model), in reality if more baseflows were to be released to the Palmiet Estuary there would be a small reduction in floods to the system as some of the dams will be less full. As the Palmiet Estuary is a small system and scours relatively easily this effect was seen as negligible for evaluation purposes.* |

*Lowflow Scoring Formula: 100 – (% Reference -% Present) DWAF (2004)*
*Floods Scoring Formula: % Change in occurrence (2/3) +% Change in magnitude (1/3)*

#### 5.2.6.2 Floods

| **Scenario** | **a.% similarity in period of low flows OR MAR as a % of MAR in the Reference Condition** | | | **b.% similarity in mean annual frequency and magnitude of floods** | | | **Overall score** |
|---|---|---|---|---|---|---|---|
| | **Score** | **L/M/H** | **Summary of change** | **Score** | **L/M/H** | **Summary of change** | |
| Present | 74 | H | ⇧ 25.9 % in low flow conditions | 56 | L | Frequency: ⇩55 Magnitude: ⇩24 | 67 |
| 1 | 75 | H | ⇧ 24.7 % in low flow conditions | 67 | L | Frequency: ⇩42 Magnitude: ⇩16 | 72 |
| 2 | 74 | H | ⇧ 26.1 % in low flow conditions | 54 | L | Frequency: ⇩57 Magnitude: ⇩24 | 66 |
| 3 | 73 | H | ⇧ 26.7 % in low flow conditions | 52 | L | Frequency: ⇩59 Magnitude: ⇩26 | 65 |
| 4 | 69 | H | ⇧ 31.4 % in low flow conditions | 40 | L | Frequency: ⇩73 Magnitude: ⇩37 | 57 |
| 5 | 74 | H | ⇧ 25.9 % in low flow conditions | 56 | L | Frequency: ⇩55 Magnitude: ⇩24 | 67 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 6 | 88 | H | ⇧ 12.2 % in low flow conditions | 54 | L | Frequency: ⇩57 Magnitude: ⇩24 | 74 |

### *5.2.7 Hydrodynamics and mouth condition*

This section describes the changes in the mouth conditions for the different run-off scenarios.

| | |
|---|---|
| **Scenario 1** | Extended periods of mouth closure (State 1) only occurred for very short periods of the time (0.1 %) under the Reference Condition and increased slightly to 0.8 % of the time under Scenario 1. While State 2 (semi-closed) increased by 24.0 % from the Reference Condition to Scenario 1. The mouth is closed or semi-closed for 35.2 % (~5 months) of the time. |
| **Scenario 2** | Extended periods of mouth closure (State 1) only occurred for very short periods of the time (0.1 %) under the Reference Condition and increased slightly to 0.8 % of the time under Scenario 2. While State 2 (semi-closed) increased by 25.4 % from the Reference Condition to Scenario 2. The mouth is closed or semi-closed for 36.6 % (~5 months) of the time. |
| **Scenario 3** | Extended periods of mouth closure (State 1) only occurred for very short periods of the time (0.1 %) under the Reference Condition and increased slightly to 0.4 % of the time under Scenario 3. While State 2 (semi-closed) increased by 26.4 % from the Reference Condition to Scenario 3. The mouth is closed or semi-closed for 37.2 % (~5 months) of the time. |
| **Scenario 4** | Extended periods of mouth closure (State 1) will not occur. While State 2 (semi-closed) increased by 31.5 % from the Reference Condition to Scenario 4. The mouth is closed or semi-closed for 41.9 % (~6 months) of the time. |
| **Scenario 5** | Similar to Present State. |
| **Scenario 6** | Extended periods of mouth closure (State 1) only occurred for very short periods of the time (0.1 %) under the Reference Condition and increased slightly to 0.8 % of the time under Scenario 2. While State 2 (semi-closed) increased by 11.6 % from the Reference Condition to Scenario 2. The mouth is closed or semi-closed for 22.7 % (~2.5 months) of the time. |

*Note: method scores mouth closure conservatively following the guidelines provided in DWAF (2004)*

| **Scenario** | **Change in mean duration of closure over 77-year period in relation to the Reference Conditions** | | | **Overall score** |
|---|---|---|---|---|
| | **Score** | **L/M/H** | **Summary of change** | |
| Present | 46 | M | **State 1: ⇧ 0.7 % and State 2:⇧ 25.2 %** | 46 |
| 1 | 47 | M | **State 1: ⇧ 0.7 % and State 2:⇧ 24.0 %** | 47 |
| 2 | 43 | M | **State 1: ⇧ 0.7 % and State 2:⇧ 25.4 %** | 43 |
| 3 | 43 | M | **State 1: ⇧ 0.3 % and State 2:⇧ 26.4 %** | 43 |
| 4 | 36 | M | **State 1: ⇩ 0.1 % and State 2:⇧ 31.5 %** | 36 |
| 5 | 46 | M | **State 1: ⇧ 0.7 % and State 2:⇧ 25.2 %** | 46 |
| 6 | 77 | M | **State 1: ⇧ 0.7 % and State 2:⇧ 11.6 %** | 77 |

### *5.2.8 Water quality*

#### 5.2.8.1 Salinity

The change in salinity was calculated based on two conditions, change in the average salinity and change in the structure of the Palmiet Estuary. Change in the average salinity was calculated as the average salinity per state for a zone (lower surface, upper surface, lower bottom and upper bottom) multiplied by the % occurrence of the state. Change in structure was calculated on the loss of State 3 and 4, which represents the highly stratified states.

**Scenario 1**

| St | Average salinity (ppt) | | | | | |
|---|---|---|---|---|---|---|
| | Reference | | | Scenario 1 | | |
| | % | L | U | % | L | U |
| 1 | 0.1 | **15** | 15 | 0.8 | 5 | 5 |
| | | 30 | 30 | | 5 | 15 |
| 2 | 10.4 | **15** | 15 | **34.4** | 5 | 5 |
| | | 20 | 25 | | 15 | 10 |
| 3 | 58.7 | **20** | 15 | **43.2** | 20 | 15 |
| | | 35 | 30 | | 35 | 30 |
| 4 | 20.6 | **0** | 0 | **15.7** | 0 | 0 |
| | | 25 | 10 | | 25 | 10 |
| 5 | 10.3 | **0** | 0 | **6.0** | 0 | 0 |
| | | 0 | 0 | | 0 | 0 |

Reference:

| | |
|---|---|
| 13 | 10 |
| 28 | 22 |

Scenario 1

| | |
|---|---|
| 10 | 8 |
| 21 | 18 |

There was an average change in salinity of about 4 %.

State 3 and 4 decreased from 79 % under the Reference Condition to 59 % under the Scenario 1, i.e. 20 % change.

**Scenario 2**

| St | Average salinity (ppt) | | | | | |
|---|---|---|---|---|---|---|
| | Reference | | | Scenario 2 | | |
| | % | L | U | % | L | U |
| 1 | 0.1 | **15** | 15 | 0.8 | 5 | 5 |
| | | 30 | 30 | | 5 | 15 |
| 2 | 10.4 | **15** | 15 | **35.8** | 5 | 5 |
| | | 20 | 25 | | 15 | 10 |
| 3 | 58.7 | **20** | 15 | **46.6** | 20 | 15 |
| | | 35 | 30 | | 35 | 30 |
| 4 | 20.6 | **0** | 0 | **12.4** | 0 | 0 |
| | | 25 | 10 | | 25 | 10 |
| 5 | 10.3 | **0** | 0 | **4.3** | 0 | 0 |
| | | 0 | 0 | | 0 | 0 |

Reference:

| | |
|---|---|
| 13 | 10 |
| 28 | 22 |

Scenario 2

| | |
|---|---|
| 11 | 9 |
| 21 | 19 |

There was an average change in salinity of about 3.4 %.

State 3 and 4 decreased from 79 % under the Reference Condition to 59 % under the Scenario 2, i.e. 20 % change.

**Scenario 3**

State 3 and 4 decreased from 79 % under the Reference Condition to 59 % under the Scenario 3, i.e. 20 % change.

| St | Average salinity (ppt) | | | | | |
|---|---|---|---|---|---|---|
| | Reference | | | Scenario 3 | | |
| | % | L | U | % | L | U |
| 1 | 0.1 | **15** | 15 | **0.4** | 5 | 5 |
| | | 30 | 30 | | 5 | 15 |
| 2 | 10.4 | **15** | 15 | **36.8** | 5 | 5 |
| | | 20 | 25 | | 15 | 10 |
| 3 | 58.7 | **20** | 15 | **48.3** | 20 | 15 |
| | | 35 | 30 | | 35 | 30 |
| 4 | 20.6 | **0** | 0 | **10.3** | 0 | 0 |
| | | 25 | 10 | | 25 | 10 |
| 5 | 10.3 | **0** | 0 | **4.2** | 0 | 0 |
| | | 0 | 0 | | 0 | 0 |

Reference:

| | |
|---|---|
| 13 | 10 |
| 28 | 22 |

Scenario 3

| | |
|---|---|
| 12 | 9 |
| 21 | 19 |

There was an average change in salinity of about 3.1 %.

**Scenario 4**

State 3 and 4 decreased from 79 % under the Reference Condition to 55 % under the Scenario 4, i.e. 24 % change.

| St | Average salinity (ppt) | | | | | |
|---|---|---|---|---|---|---|
| | Reference | | | Scenario 4 | | |
| | % | L | U | % | L | U |
| 1 | 0.1 | **15** | 15 | **0.0** | 5 | 5 |
| | | 30 | 30 | | 5 | 15 |
| 2 | 10.4 | **15** | 15 | **41.9** | 5 | 5 |
| | | 20 | 25 | | 15 | 10 |
| 3 | 58.7 | **20** | 15 | **48.3** | 20 | 15 |
| | | 35 | 30 | | 35 | 30 |
| 4 | 20.6 | **0** | 0 | **6.8** | 0 | 0 |
| | | 25 | 10 | | 25 | 10 |
| 5 | 10.3 | **0** | 0 | **3.0** | 0 | 0 |
| | | 0 | 0 | | 0 | 0 |

Reference:

| | |
|---|---|
| 13 | 10 |
| 28 | 22 |

Scenario 4

| | |
|---|---|
| 12 | 9 |
| 21 | 19 |

There was an average change in salinity of about 3.2 %.

**Scenario 5**

Similar to Present

**Scenario 6**

State 3 and 4 decreased from 79 % under the Reference Condition to 73 % under the Scenario 6, i.e. 6 % change.

| St | Average salinity (ppt) | | | | | |
|---|---|---|---|---|---|---|
| | Reference | | | Scenario 4 | | |
| | % | L | U | % | L | U |
| 1 | 0.1 | **15** | 15 | **0.8** | 5 | 5 |
| | | 30 | 30 | | 5 | 15 |
| 2 | 10.4 | **15** | 15 | **22.0** | 5 | 5 |
| | | 20 | 25 | | 15 | 10 |
| 3 | 58.7 | **20** | 15 | **60.5** | 20 | 15 |
| | | 35 | 30 | | 35 | 30 |
| 4 | 20.6 | **0** | 0 | **12.4** | 0 | 0 |
| | | 25 | 10 | | 25 | 10 |
| 5 | 10.3 | **0** | 0 | **3.0** | 0 | 0 |
| | | 0 | 0 | | 0 | 0 |

Reference:

| | |
|---|---|
| 13 | 10 |
| 28 | 22 |

Scenario 6

| | |
|---|---|
| 13 | 10 |
| 25 | 22 |

There was an average change in salinity of about 0.8 %.

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

Scoring of scenarios followed a similar approach as described in Chapter 3.4.1.3 for the Present State

| Scenario | 1. Changes in longitudinal salinity gradient and vertical stratification | | 2a. DIN/DIP in estuary | | 2b. SS/Turbidity/ Transparency in estuary | | 2c. DO in estuary | | 2d. Toxic substances in estuary | | Overall score |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Score | Summary of change | Score | Summary of change | Score | Summary of change | Score | Summary of change | Score | Summary of change | |
| Present | 76 M/H | 20 % ⇩stratified 4 % ⇩Salinity | 74 M/H | ⇩ Summer (bottom) ⇧ Summer (surface) ⇧ Winter (overall) | 91 M/H | ⇩ Summer (surface and bottom, upper estuary) | 85 M/H | ⇩ Summer (bottom) | 90 L | ⇧Overall accumulation | **74.8** |
| 1 | 76 | 20 % ⇩stratified 4 % ⇩Salinity | 72 M/H | ⇩ Summer (bottom) ⇧ Summer (surface) ⇧ Winter (overall) | 88 M/H | ⇩ Summer (surface and bottom, upper estuary) | 85 M/H | ⇩ Summer (bottom) | 90 L | ⇧Overall accumulation | **73.6** |
| 2 | 76 | 20 % ⇩stratified 4 % ⇩Salinity | 75 M/H | ⇩ Summer (bottom) ⇧ Summer (surface) ⇧ Winter (overall) | 91 M/H | ⇩ Summer (surface and bottom, upper estuary) | 84 M/H | ⇩ Summer (bottom) | 90 L | ⇧Overall accumulation | **75.4** |
| 3 | 76 | 20 % ⇩stratified 4 % ⇩Salinity | 76 M/H | ⇩ Summer (bottom) ⇧ Summer (surface) ⇧ Winter (overall) | 92 M/H | ⇩ Summer (surface and bottom, upper estuary) | 84 M/H | ⇩ Summer (bottom) | 90 L | ⇧Overall accumulation | **76** |
| 4 | 73 | 24 % ⇩stratified 3 % ⇩Salinity | 78 M/H | ⇩ Summer (bottom) ⇧ Summer (surface) ⇧ Winter (overall) | 92 M/H | ⇩ Summer (surface and bottom, upper estuary) | 82 M/H | ⇩ Summer (bottom) | 90 L | ⇧Overall accumulation | **76** |
| 5 | 76 | 20 % ⇩stratified 4 % ⇩Salinity | 85 M/H | ⇩ Summer (bottom) ⇧ Summer (surface) ⇧ Winter (overall) | 91 M/H | ⇩ Summer (surface and bottom, upper estuary) | 85 M/H | ⇩ Summer (bottom) | 90 L | ⇧Overall accumulation | **81.4** |
| 6 | 79 | 6 % ⇩stratified 0.8 % ⇩Salinity | 72 M/H | ⇩ Summer (bottom) ⇧ Summer (surface) ⇧ Winter (overall) | 99 M/H | ⇩ Summer (surface and bottom, upper estuary) | 91 M/H | ⇩ Summer (bottom) | 90 L | ⇧Overall accumulation | **74.8** |

### *5.2.9 Physical habitat alteration*

This section describes the changes in the hydrology for the scenarios

| | |
|---|---|
| **Scenario 1** | Intertidal area: 10% loss due to infilling in mouth region and a 20 % loss due to increased semi-closed mouth conditions.<br>Sand/mud fraction: The system is becoming slightly more coarse grain due to an increase in marine sediment.<br>Subtidal: 30 % decrease mostly in the mouth area and middle reaches, ⇧1 % deepening in upper estuary due to trapping of catchment sediment. |
| **Scenario 2** | Intertidal area: 10 % loss due to infilling in mouth region and a 20 % loss due to increased semi-closed mouth conditions.<br>Sand/mud fraction: The system is becoming slightly more coarse grain due to an increase in marine sediment.<br>Subtidal: 30 % decrease mostly in the mouth area and middle reaches, ⇧1 % deepening in upper estuary due to trapping of catchment sediment. |
| **Scenario 3** | Intertidal area: 10 % loss due to infilling in mouth region and a 20 % loss due to increased semi-closed mouth conditions.<br>Sand/mud fraction: The system is becoming slightly more coarse grain due to an increase in marine sediment.<br>Subtidal: 30 % decrease mostly in the mouth area and middle reaches, ⇧1 % deepening in upper estuary due to trapping of catchment sediment. |
| **Scenario 4** | Intertidal area: 15 % loss due to infilling in mouth region and a 30 % loss due to increased semi-closed mouth conditions.<br>Sand/mud fraction: The system is becoming slightly more coarse grain due to an increase in marine sediment.<br>Subtidal: 40 % decrease mostly the mouth area and middle reaches, ⇧1 % deepening in upper estuary due to trapping of catchment sediment. |
| **Scenario 5** | Similar to Present State |
| **Scenario 6** | Similar to Scenario 2 |

| **Scenario** | **1. Resemblance of intertidal sediment structure and distribution to reference condition** | | | | | | **2. Resemblance of submerged estuary to Reference Condition: depth, bed or channel morphology (i.e. based on subtidal habitat, channel morphology, and taking degree of sedimentation, and obstruction or constriction into account)** | | | **Overall score** |
|---|---|---|---|---|---|---|---|---|---|---|
| | **a. % similarity in intertidal area exposed % similarity in intertidal area exposed** | | | **% similarity in sand fraction relative to total sand and mud** | | | | | | |
| | **Score** | **L/M/H** | **Summary of change** | **Score** | **L/M/H** | **Summary of change** | **Score** | **L/M/H** | **Summary of change** | |
| Present | **70** | **L** | ⇩ 30 % | **100** | **M** | No change | **70** | **L** | ⇩29 % lower reaches<br>⇧1 % deepening in upper estuary | 77.5 |
| 1 | **70** | **L** | ⇩ 30 % | **100** | **M** | No change | **70** | **L** | ⇩29 % lower reaches<br>⇧1 % deepening in upper estuary | 77.5 |
| 2 | **70** | **L** | ⇩ 30 % | **100** | **M** | No change | **70** | **L** | ⇩29 % lower reaches<br>⇧1 % deepening in upper estuary | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 3 | **70** | **L** | ⇩ 30 % | **100** | **M** | No change | **70** | **L** | ⇩29 % lower reaches<br>⇧1 % deepening in upper estuary | 77.5 |
| 4 | **55** | **L** | ⇩ 45 % | **100** | **M** | No change | **60** | **L** | ⇩39 %<br>⇧1 % deepening in upper estuary | 68.75 |
| 5 | **70** | **L** | ⇩ 30 % | **100** | **M** | No change | **70** | **L** | ⇩29 % lower reaches<br>⇧1 % deepening in upper estuary | 77.5 |
| 6 | **70** | **L** | ⇩ 30 % | **100** | **M** | No change | **70** | **L** | ⇩29 % lower reaches<br>⇧1 % deepening in upper estuary | 77.5 |

## 5.3 BIOTIC COMPONENTS

Predict the change in biotic characteristics of the Scenarios compared with the Reference Condition, list the <u>causes</u> of these changes and provide the confidence (H/M/L) in the predictions. Apply the guidelines for the EHI scoring:

### *5.3.1 Microalgae*

This section describes the changes in microalgae for the different run-off scenarios

| | |
|---|---|
| **Scenario 1 - 6** | The major factors affecting phytoplankton biomass and composition are the increase in nutrients (⬆ in chl-a), an increase in the frequency/duration of mouth closures (⬇ in chl-a and shift in community composition) and the reduction in the frequency/duration of stratified conditions (⬇ in chl-a); nutrients, mouth closure and stratification.<br>The major factors affecting benthic microalgal biomass and composition are the reduction in high flows (States 1 and 2; ⬆ in chl-a), an increase in nutrients (⬆ in chl-a), a loss of intertidal habitat (⬇ in chl-a and shift in community composition) and a loss of water transparency in State 3 (⬇ in chl-a); high flows, nutrients, intertidal habitat and transparency. |

#### 5.3.1.1 Phytoplankton

| Scenario | 1. Species richness (% similarity in brackets) | | 2a. Abundance | | 2b.Community composition | |
|---|---|---|---|---|---|---|
| | Score | Summary of change | Score | Summary of change | Score | Summary of change |
| Present | 100 (100 %) L | Unlikely to lose species. | 92 M | Nutrients (⇧: 38 % increase), mouth closure (⇩: 26 % increase in States 1 and 2) and stratification (⇩: 20 % decrease in States 3 and 4). 8 % ⇩ in biomass. | 74 M | Mouth closure (⇩: 26 % increase in States 1 and 2): Dinoflagellates ➔ cyanophytes. 26 % change in community composition. |
| 1 | 100 (100 %) L | Unlikely to lose species. | 100 M | Nutrients (⇧: 45 % increase), mouth closure (⇩: 24.7 % increase in States 1 and 2) and stratification (⇩: 20 % decrease in States 3 and 4). No change in biomass. | 75 M | Mouth closure (⇩: 25 % increase in States 1 and 2): Dinoflagellates ➔ cyanophytes. 25 % change in community composition. |
| 2 | 100 (100 %) L | Unlikely to lose species. | 91 M | Nutrients (⇧: 37 % increase), mouth closure (⇩: 26.1 % increase in States 1 and 2) and stratification (⇩: 20 % decrease in States 3 and 4). 9 % ⇩ in biomass. | 74 M | Mouth closure (⇩: 26 % increase in States 1 and 2): Dinoflagellates ➔ cyanophytes. 26 % change in community composition. |
| 3 | 100 (100 %) L | Unlikely to lose species. | 89 M | Nutrients (⇧: 36 % increase), mouth closure (⇩: 26.7 % increase in States 1 and 2) and stratification (⇩: 20 % decrease in States 3 and 4). 11 % ⇩ in biomass. | 73 M | Mouth closure (⇩: 27 % increase in States 1 and 2): Dinoflagellates ➔ cyanophytes. 27 % change in community composition. |
| 4 | 100 (100 %) L | Unlikely to lose species. | 79 M | Nutrients (⇧: 34 % increase), mouth closure (⇩: 31.4 % increase in States 1 and 2) and stratification (⇩: 24 % decrease in States 3 and 4). 21 % ⇩ in biomass. | 69 M | Mouth closure (⇩: 31 % increase in States 1 and 2): Dinoflagellates ➔ cyanophytes. 31 % change in community composition. |
| 5 | 100 (100 %) L | Unlikely to lose species. | 73 M | Nutrients (⇧: 19 % increase), mouth closure (⇩: 26 % increase in States 1 and 2) and stratification (⇩: 20 % decrease in States 3 and 4). 27 % ⇩ in biomass. | 74 M | Mouth closure (⇩: 26 % increase in States 1 and 2): Dinoflagellates ➔ cyanophytes. 26 % change in community composition. |
| 6 | 100 (100 %) L | Unlikely to lose species. | 94 | Nutrients (⇧: 38 % increase), mouth closure (⇩: 12.3 % increase in States 1 and 2) and stratification (⇩: 20 % increase in States 3 and 4). 6 % ⇧ in biomass. | 88 | Mouth closure (⇩: 12.3 % increase in States 1 and 2): Dinoflagellates ➔ cyanophytes. 12 % change in community composition. |

### 5.3.1.2 Benthic microalgae

| Scenario | 1. Species richness (% similarity in brackets) | | 2a. Abundance | | 2b.Community composition | |
|---|---|---|---|---|---|---|
| | Score | Summary of change | Score | Summary of change | Score | Summary of change |
| Present | 100 (100 %) L | Unlikely to lose species. | 86 % M | Reduced high flows (⇧ 14 %: 20.6 – 12.4 and 10.3 – 4.8), elevated nutrients (⇧: 38 % x 0.5), loss of intertidal habitat (⇩ 26 % x 0.5) and loss of water transparency during State 3 (⇩ 12.3 % x 0.5): 14 % ⇧ in biomass. *(Note that vector arrows denote chl-a response)* | 74 % M | States 1 and 2 (26 % change): mobile species (e.g. pennate diatoms and euglenophytes) ➔ attached taxa. |
| 1 | 100 (100 %) L | Unlikely to lose species. | 89 % M | Reduced high flows (⇧ 9 %: 20.6 – 15.7 and 10.3 – 6.0), elevated nutrients (⇧: 45 % x 0.5), loss of intertidal habitat (⇩ 24.7 % x 0.5) and loss of water transparency during State 3 (⇩ 15.5 % x 0.5): 11 % ⇧ in biomass. | 75 % M | States 1 and 2 (24.7 % change) |
| 2 | 100 (100 %) L | Unlikely to lose species. | 86 % M | Reduced high flows (⇧ 14 %: 20.6 – 12.4 and 10.3 – 4.3), elevated nutrients (⇧: 37 % x 0.5), loss of intertidal habitat (⇩ 26.1 % x 0.5) and loss of water transparency during State 3 (⇩ 12.1 % x 0.5): 14 % ⇧ in biomass. | 74 % M | States 1 and 2 (26.1 % change) |
| 3 | 100 (100 %) L | Unlikely to lose species. | 85 % M | Reduced high flows (⇧ 16 %: 20.6 – 10.3 and 10.3 – 4.2), elevated nutrients (⇧: 36 % x 0.5), loss of intertidal habitat (⇩ 26.7 % x 0.5) and loss of water transparency during State 3 (⇩ 10.4 % x 0.5): 15 % ⇧ in biomass. | 73 % M | States 1 and 2 (26.7 % change) |
| 4 | 100 (100 %) L | Unlikely to lose species. | 82 % M | Reduced high flows (⇧ 21 %: 20.6 – 6.8 and 10.3 – 3.0), elevated nutrients (⇧: 36 % x 0.5), loss of intertidal habitat (⇩ 31.4 % x 0.5) and loss of water transparency during State 3 (⇩ 10.4 % x 0.5): 18 % ⇧ in biomass. | 69 % M | States 1 and 2 (31.4 % change) |
| 5 | 100 (100 %) L | Unlikely to lose species. | 96 % M | Reduced high flows (⇧ 14 %: 20.6 – 12.4 and 10.3 – 4.8), elevated nutrients (⇧: 19 % x 0.5), loss of intertidal habitat (⇩ 26 % x 0.5) and loss of water transparency during State 3 (⇩ 12.3 % x 0.5): 4 % ⇧ in biomass. *(Note that vector arrows denote chl-a response)* | 74 % M | States 1 and 2 (26 % change): mobile species (e.g. pennate diatoms and euglenophytes) ➔ attached taxa. |

| Scenario | 1. Species richness (% similarity in brackets) | | 2a. Abundance | | 2b.Community composition | |
|---|---|---|---|---|---|---|
| | Score | Summary of change | Score | Summary of change | Score | Summary of change |
| 6 | 100<br>(100 %)<br>L | Unlikely to lose species. | 72 %<br>M | Reduced high flows (⇧ 14.2 %: 20.6 – 12.4 and 10.3 – 4.3), elevated nutrients (⇧: 38 % x 0.5), loss of intertidal habitat (⇩ 12.3 % x 0.5) and increase in water transparency during State 3 (⇧: 1.8 % x 0.5): 14 % ⇧ in biomass.<br>*(Note that vector arrows denote chl-a response)* | 88 %<br>M | States 1 and 2 (12.3 % change): mobile species (e.g. pennate diatoms and euglenophytes) ➔ attached taxa. |

| Scenario | Minimum score species richness | Minimum score abundance | Minimum score community composition | Overall score |
|---|---|---|---|---|
| Present | 100 | 86 | 74 | 74 |
| 1 | 100 | 89 | 75 | 75 |
| 2 | 100 | 86 | 74 | 74 |
| 3 | 100 | 85 | 73 | 73 |
| 4 | 100 | 79 | 69 | 69 |
| 5 | 100 | 73 | 74 | 73 |
| 6 | 100 | 72 | 88 | 72 |

This section provides a summary of the parameters used as a proxy for change  for microalgae (based on parameter determining final score only).

| Parameters | Present | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Scenario 5 | Scenario 6 |
|---|---|---|---|---|---|---|---|
| States 1and2 / intertidal | ⇧ 26 % | ⇧ 25 % | ⇧ 26 % | ⇧ 27 % | ⇧ 31 % | ⇧ 26 % | ⇧ 12.3 % |
| Nutrients | ⇧ 38 % | ⇧ 45 % | ⇧ 37 % | ⇧ 36 % | ⇧ 34 % | ⇧ 19 % | ⇧ 38 % |
| Transparency | ⇩ 12.3 % | ⇩ 15.5 % | ⇩ 12.1 % | ⇩ 10.4 % | ⇩ 10.4 % | ⇩ 12.3 % | ⇩ 1.8 % |
| Stratification | ⇩ 20 % | ⇩ 20 % | ⇩ 20 % | ⇩ 20 % | ⇩ 24 % | ⇩ 20 % | ⇩ 20 % |

### 5.3.2 Macrophytes

This section describes the changes in macrophytes for the different run-off scenarios

| | |
|---|---|
| **Scenario 1** | *Macroalgae*: 1 ha stand will persist for 35.2 % of the year (4.22 ha-months). *Macrophytes*: 0.1 ha stand inundated with water for 35.2 % of the year (0.78 ha-months). Macroalgae + macrophytes ha-months ⬆ 47 % similar to Reference Condition. |
| **Scenario 2** | *Macroalgae*: 1 ha stand will persist for 36.6 % of the year (4.39 ha-months). *Macrophytes*: 0.1 ha stand inundated with water for 36.6 % of the year (0.76 ha-months). Macroalgae + macrophytes ha-months ⬆ 45 % similar to Reference Condition. |
| **Scenario 3** | *Macroalgae*: 1 ha stand will persist for 37.2 % of the year (4.46 ha-months). *Macrophytes*: 0.1 ha stand inundated with water for 37.2 % of the year (0.75 ha-months). Macroalgae + macrophytes ha-months ⬆ 45 % similar to Reference Condition. |
| **Scenario 4** | *Macroalgae*: 1 ha stand will persist for 41.9 % of the year (5.03 ha-months). *Macrophytes*: 0.1 ha stand inundated with water for 41.9 % of the year (0.70 ha-months). Macroalgae + macrophytes ha-months ⬆ 41 % similar to Reference Condition. |
| **Scenario 5** | *Macroalgae*: 1 ha stand will persist for 36.4 % of the year (4.37 ha-months). *Macrophytes*: 0.1 ha stand inundated with water for 41.9 % of the year (0.76 ha-months). Macroalgae + macrophytes ha-months ⬆ 45 % similar to Reference Condition. |
| **Scenario 6** | *Macroalgae*: 1 ha stand will persist for 22.8 % of the year (2.74 ha-months). *Macrophytes*: 0.1 ha stand inundated with water for 22.8 % of the year (0.93 ha-months). Macroalgae + macrophytes ha-months ⬆ 64 % similar to Reference Condition. |

| **Scenario** | **1. Species richness (% similarity in brackets)** | | **2a. Abundance** | | **2b.Community composition** | | **Overall score** |
|---|---|---|---|---|---|---|---|
| | **Score** | **Summary of change** | **Score** | **Summary of change** | **Score** | **Summary of change** | |
| Present | 80<br>(90 %)<br>L | ⬆ salinity ➔ loss of salt tolerant salt marsh spp. | 45<br>M | Macroalgae: 4.37 ha-months<br>Salt marsh: 0.76 ha-months | 69<br>M | Macroalgae:macrophyte (85:15) | 45 |
| 1 | 80<br>(90 %)<br>L | “ | 47<br>M | Macroalgae: 4.22 ha-months<br>Salt marsh: 0.78 ha-months | 70<br>M | Macroalgae:macrophyte (84:16) | 47 |
| 2 | 80<br>(90 %)<br>L | “ | 45<br>M | Macroalgae: 4.39 ha-months<br>Salt marsh: 0.76 ha-months | 69<br>M | Macroalgae:macrophyte (85:15) | 45 |

| Scenario | 1. Species richness (% similarity in brackets) | | 2a. Abundance | | 2b.Community composition | | Overall score |
|---|---|---|---|---|---|---|---|
| | Score | Summary of change | Score | Summary of change | Score | Summary of change | |
| 3 | 80<br>(90 %)<br>L | “ | 45<br>M | Macroalgae: 4.46 ha-months<br>Salt marsh: 0.75 ha-months | 68<br>M | Macroalgae:macrophyte (86:14) | 45 |
| 4 | 80<br>(90 %)<br>L | “ | 41<br>M | Macroalgae: 5.03 ha-months<br>Salt marsh: 0.70 ha-months | 66<br>M | Macroalgae:macrophyte (88:12) | 41 |
| 5 | 80<br>(90 %)<br>L | “ | 45<br>M | Macroalgae: 4.37 ha-months<br>Salt marsh: 0.76 ha-months | 100<br>M | Macroalgae:macrophyte (85:15) | 45 |
| 6 | 80<br>(90 %)<br>L | “ | 64<br>M | Macroalgae: 2.74 ha-months<br>Salt marsh: 0.93 ha-months | 90<br>M | Macroalgae:macrophyte (75:25) | 64 |

This section provides a summary of the parameters used as a proxy for change for macrophytes

| Parameters | Present | Future Scenario 1 | Future Scenario 2 | Future Scenario 3 | Future Scenario 4 | Future Scenario 5 | Future Scenario 6 |
|---|---|---|---|---|---|---|---|
| States 1and2 (-10.5 % ref) | ⇧ 26 % | ⇧ 25 % | ⇧ 26 % | ⇧ 27 % | ⇧ 31 % | ⇧ 26 % | ⇧ 12.3 % |
| Droughts* | | 2-5 years | 2-10 years | 2-12 years | 2-19 years | 2-5 years | (?) |
| Nutrients* | ⇧ 38 % | ⇧ 45 % | ⇧ 37 % | ⇧ 36 % | ⇧ 34 % | ⇧ 19 % | ⇧ 38 % |
| Salinity* | ⇩ 4 % | ⇩ 4 % | ⇩ 4 % | ⇩ 4 % | ⇩ 3 % | ⇩ 4 % | ⇩ 4 % (?) |
| Loss of intertidal zone* | ⇩ 20 % | ⇩ 20 % | ⇩ 20 % | ⇩ 20 % | ⇩ 30 % | ⇩ 20 % | ⇩ 20 % |

*Significant but not included in the scoring

### *5.3.3 Invertebrates*

This section describes the changes in invertebrates for the different run-off scenarios

| | |
|---|---|
| **Scenario 1** | The following discussion refers to the benthos only – zooplankton biomass in the estuary is naturally extremely low. Hyperbenthos also predicted to be low<br><br>The occurrence of floods that would scour sediment (particularly the sandbank in the mouth area) from the estuary (flows >50 $m^3 sec^{-1}$) reduced by 42 %. The sandbank at the mouth is more stable, supporting a relatively high biomass of the sandprawn *Callianassa kraussi*. Subtidally, there is a greater persistence of macrophytes and detrital material. This condition would persist under the present scenario. The increase in State 1 and 2 by approximately 35.2 % (State 2 approximately 34 % of this value) leads to less water exchange across the mouth, and reduced salinity values (to about 10 ppt) in the lower estuary because of dilution effects and limited marine inflow. There will be no recruitment from the *Callianassa kraussi* intertidal population during these months as 10 ppt is well below the threshold required for breeding. Recruitment will still be possible from subtidal populations, but this will be offset by increased macrophyte coverage (Sandprawns prefer unvegitated areas for colonization). Anoxic conditions will be similar to Present. Overall, biomass likely to reduce by about 5 % compared to Present, and therefore moves along a trajectory towards more natural conditions. This reduction likely to be a result of reduced recruitment success, aggravated by the salinity values that now hover around the salinity threshold required for breeding. |
| **Scenario 2** | Very similar to above Scenario, and the slight decrease in States 1 and 2 (by approximately 1 %) compared to Scenario 1, will increase anoxic conditions as described above by a very small margin. The frequency and amplitude of floods will decrease further (by 15 and 10 respectively) compared to the previous scenario, and the intertidal sandbank will be less frequently removed (more stable as a habitat for burrowing invertebrates). Persistent stratification will exacerbate oxygen exchange with bottom waters. |
| **Scenario 3** | Very similar to Scenario 2, and the slight increase in States 1 and 2 (by approximately 1 %) compared to Scenario 2, will exacerbate anoxic conditions as described above by a very small margin. This is offset by the increase in State 3 compared to Scenario 2 (by approximately 2 %), and this will reduce the occurrence of anoxic conditions. Biomass of the subtidal benthos will therefore be less prone to mortality events – overall, biomass will be more stable and, on average remain at higher levels compared to the previous scenario. |
| **Scenario 4** | Very similar to Scenario 3, and the increase in States 1 and 2 (by approximately 4.5 %) compared to Scenario 3, will exacerbate anoxic conditions as described above. This is offset by a similar increase in State 3 compared to Scenario 3 (approx. 2 %), leading to an increase in stagnation and anoxia overall, compared to the previous scenario. The most significant change under this scenario is the frequency and amplitude of larger floods - by approx 14 % and 11 % respectively compared to Scenario 3. Biomass of the subtidal benthos will therefore be less prone to mortality events and the sandbank is more stable – overall, invertebrate biomass will also be more stable and, on average remain at higher levels compared to the previous scenario and much higher compared to natural. |
| **Scenario 5** | Since zooplankton biomass is typically low in blackwater systems, removal of nutrients is unlikely to impact this component to any degree (minimal impact), so that the only component of the invertebrates to be influenced would be the benthos. Since the nutrient levels are reduced considerably, phytoplankton and macrophyte biomass would also reduce and so lead to less food availability. Consequently, invertebrate biomass would also reduce to more natural levels. |
| **Scenario 6** | Because of improved flow conditions, this scenario would lead to improved oxygen levels, However, low salinity levels that would move closer to the threshold required for *Callianassa kraussi* breeding purposes and therefore recruitment to the benthic population would decline. This moves biomass of the key benthic species closer to natural conditions. |

### 5.3.3.1 Zooplankton

| Scenario | 1. Species richness ( % similarity in brackets) | | 2a. Abundance | | 2b.Community composition | |
|---|---|---|---|---|---|---|
| | Score L/M/H | Summary of change | Score L/M/H | Summary of change | Score L/M/H | Summary of change |
| Present | 100<br>L | No change | 90<br>L | 10 % increase above natural, less frequent scouring of estuary. Abundance also very low, even under natural conditions | 100<br>L | No change |
| 1 | 100<br>L | No change | 90<br>L | 10 % increase above natural, less frequent scouring of estuary. Abundance also very low, even under natural conditions | 100<br>L | No change |
| 2 | 100<br>L | No change | 90<br>L | 10 % increase above natural, less frequent scouring of estuary. Abundance also very low, even under natural conditions | 100<br>L | No change |
| 3 | 100<br>L | No change | 90<br>L | 10 % increase above natural, less frequent scouring of estuary. Abundance also very low, even under natural conditions | 100<br>L | No change |
| 4 | 100<br>L | No change | 90<br>L | 10 % increase above natural, less frequent scouring of estuary. Abundance also very low, even under natural conditions | 100<br>L | No change |
| 5 | 100<br>L | No change | 90<br>L | 10 % increase above natural, less frequent scouring of estuary. Abundance also very low, even under natural conditions | 100<br>L | No change |
| 6 | 100<br>L | No change | 90<br>L | 10 % increase above natural, less frequent scouring of estuary. Abundance also very low, even under natural conditions | 100<br>L | No change |

### 5.3.3.2 Benthic invertebrates

| Scenario | Species richness ( % similarity in brackets) | | 2a. Abundance | | 2b.Community composition | |
|---|---|---|---|---|---|---|
| | Score L/M/H | Summary of change | Score L/M/H | Summary of change | Score L/M/H | Summary of change |
| Present | 100<br>L | No change | 65<br>L | There is an increase in intertidal area by about 10 % (lower sandbank) and increased food availability in form of detritus and greater persistence of the macrophytes on average. Overall, biomass about 135 % of natural. | 65<br>L | Because of the increased intertidal area compared to natural (30 %) and increased detrital material (increased macrophyte coverage), the relative importance of individual species will also shift in the community. |
| 1 | 100<br>L | No change | 70<br>L | There is an increase in intertidal area by about 10 % (lower sandbank) and increased food availability in form of detritus (10 %). However, there is likely to be a reduction in recruitment success to the estuarine population because salinity values now hover around the breeding threshold – moving along a trajectory towards the natural state. Biomass will be more variable and hence more similar to the natural state. | 70<br>L | Because of the increased intertidal area compared to natural (30 %) and increased detrital material (increased macrophyte coverage), the relative importance of individual species will also shift in the community. Recruitment however, will be more variable under this scenario, moving along a trajectory that approached the natural condition. |
| 2 | 100<br>L | No change | 65<br>L | There is an increase in intertidal area by about 10 % (lower sandbank) and increased food availability in form of detritus (10 %). However, there is likely to be a reduction in recruitment success to the estuarine population because salinity values now hover around the breeding threshold – moving along a trajectory towards the natural state.<br>The marginal increase in State 2, compared to Scenario 1 (by 1 %), is also likely to lead to a marginal shift or increase in anoxic conditions. Frequency and amplitude of floods also reduced (by 15 and 8 % respectively) compared to previous scenario. Collectively, Invertebrate biomass more stable and less variable compared to natural state. | 65<br>L | Because of the increased intertidal area compared to natural (30 %) and increased detrital material (increased macrophyte coverage), the relative importance of individual species will also shift in the community. |

| Scenario | Species richness ( % similarity in brackets) | | 2a. Abundance | | 2b.Community composition | |
|---|---|---|---|---|---|---|
| | Score L/M/H | Summary of change | Score L/M/H | Summary of change | Score L/M/H | Summary of change |
| 3 | 100<br>L | No change | 68<br>L | There is an increase in intertidal area by about 10 % (lower sandbank) and increased food availability in form of detritus (10 %). However, there is likely to be a reduction in recruitment success to the estuarine population because salinity values now hover around the breeding threshold – moving along a trajectory towards the natural state.<br>The increase in State 3 (greater water exchange with the marine environment) by approximately 5 % will reduce anoxic conditions marginally, moving the invertebrate fauna along a trajectory towards an increase in average biomass and hence away from natural conditions. | 68<br>L | Because of the increased intertidal area compared to natural (30 %) and increased detrital material (increased macrophyte coverage), the relative importance of individual species will also shift in the community. |
| 4 | 100<br>L | No change | 60<br>L | There is an increase in intertidal area by about 10 % (lower sandbank) and increased food availability in form of detritus (10 %). However, there is likely to be a reduction in recruitment success to the estuarine population because salinity values now hover around the breeding threshold – moving along a trajectory towards the natural state.<br>The increase in State 3 (greater water exchange with the marine environment) is similar to Scenario 3 and anoxic conditions therefore, will also be similar. Floods however, are reduced significantly (frequency and magnitude will decrease by 14 and 11 % respectively), leading to a more stable intertidal sandbank compared to the previous scenario. Thus, benthic invertebrate biomass will be more stable and average biomass will be higher compared to the previous scenario. In comparison to the natural state, variability and average biomass is much reduced. | 60<br>L | Because of the increased intertidal area compared to natural (30 %) and increased detrital material (increased macrophyte coverage), the relative importance of individual species will also shift in the community. |

| Scenario | Species richness ( % similarity in brackets) | | 2a. Abundance | | 2b.Community composition | |
|---|---|---|---|---|---|---|
| | Score L/M/H | Summary of change | Score L/M/H | Summary of change | Score L/M/H | Summary of change |
| 5 | 100<br>L | No change | 65 | Food availability utilized by invertebrates and in the form of phytoplankton biomass and detritus biomass would reduce, moving along a trajectory closer to the natural condition – invertebrate biomass would decline. | 65 | Because of the increased intertidal area compared to natural (30 %) and increased detrital material (increased macrophyte coverage), the relative importance of individual species will also shift in the community. |
| 6 | 100<br>L | No change | 75 | Abundance levels of the invertebrate community (particularly the benthos) would decline because of reduced recruitment to the dominant species (*Callianassa kraussi*) as salinity levels remain around the threshold required for successful reproduction. | 75 | Because of the increased intertidal area compared to natural (30 %) and increased detrital material (increased macrophyte coverage), the relative importance of individual species will also shift in the community. Recruitment however, will be more variable under this scenario, moving along a trajectory that approached the natural condition. |

### 5.3.3.3 Macrocrustaceans

| Scenario | 1. Species richness ( % similarity in brackets) | | 2a. Abundance | | 2b.Community composition | |
|---|---|---|---|---|---|---|
| | Score | Summary of change | Score | Summary of change | Score | Summary of change |
| Present | 100<br>L | No change | 100<br>L | No change predicted – biomass also at a very low level, even under natural conditions | 100<br>L | No change predicted – biomass also at a very low level, even under natural conditions |
| 1 | 100<br>L | No change | 100<br>L | No change predicted – biomass also at a very low level, even under natural conditions | 100<br>L | No change predicted – biomass also at a very low level, even under natural conditions |
| 2 | 100<br>L | No change | 100<br>L | No change predicted – biomass also at a very low level, even under natural conditions | 100<br>L | No change predicted – biomass also at a very low level, even under natural conditions |
| 3 | 100<br>L | No change | 100<br>L | No change predicted – biomass also at a very low level, even under natural conditions | 100<br>L | No change predicted – biomass also at a very low level, even under natural conditions |
| 4 | 100<br>L | No change | 100<br>L | No change predicted – biomass also at a very low level, even under natural conditions | 100<br>L | No change predicted – biomass also at a very low level, even under natural conditions |
| 5 | 100<br>L | No change | 100<br>L | No change predicted – biomass also at a very low level, even under natural conditions | 100<br>L | No change predicted – biomass also at a very low level, even under natural conditions |
| 6 | 100<br>L | No change | 100<br>L | No change predicted – biomass also at a very low level, even under natural conditions | 100<br>L | No change predicted – biomass also at a very low level, even under natural conditions |

| Scenario | Minimum score Species richness | Minimum score Abundance | Minimum score Community composition | Overall score |
|---|---|---|---|---|
| Present | 100 | 65 | 65 | 65 |
| 1 | 100 | *70* | *70* | *70* |
| 2 | 100 | 65 | 65 | 65 |
| 3 | 100 | 68 | 68 | 68 |
| 4 | 100 | 60 | 60 | 60 |
| 5 | 100 | 65 | 65 | 65 |
| 6 | 100 | 75 | 75 | 75 |

This section provides a summary of the parameters used as a proxy for change for invertebrates.

| Parameters | Present | Future Scenario 1 | Future Scenario 2 | Future Scenario 3 | Future Scenario 4 | Future Scenario 5 | Future Scenario 6 |
|---|---|---|---|---|---|---|---|
| States 1 and 2 | ⇧ 26% | ⇧ 25% | ⇧ 26% | ⇧ 27% | ⇧ 31% | ⇧ 26% | ⇧ 12% |
| Reduction in floods, intertidal sandbank expansion and stability | ⇧ 10% | ⇧ 10% | ⇧ 10% | ⇧ 10% | ⇧ 10% | ⇧ 10% | ⇧ 10% |
| Salinity | 4%⇩ | 4%⇩ | 3%⇩ | 3%⇩ | 3%⇩ | 4%⇩ | 0.8%⇩ |
| Reduction in open sandy habitat as a result of increased macrophyte coverage. | ⇩ 10% | ⇩ 10% | ⇩ 10% | ⇩ 10% | ⇩ 10% | ⇩ 10% | ⇩ 10% |
| Anoxic conditions | 15%⇧ | 15%⇧ | 16%⇧ | 16%⇧ | 18%⇧ | 15%⇧ | 9%⇧ |
| Increased production of detritus | ⇧ 5% | ⇧ 5% | ⇧ 10% | ⇧ 10% | ⇧ 5% | ⇧ 5% | ⇧ 5% |

### *5.3.4 Fish*

This section describes the changes in fish for the different run-off scenarios.

| | |
|---|---|
| **Scenario 1** | No real change in salinity, so unlikely to have been any change in numbers due to opportunistic species entering the estuary, or change in community structure according to salinity preferences or tolerances. Similarly, water clarity remains high enough for visual foraging by selective feeders e,g, *A, breviceps* and those feeding on benthic invertebrates e.g. *L. lithognathus*. Hypoxia increases by 15 % but there's unlikely to be much change in the fish assemblage from Reference where the frequency of hypoxic/anoxic "events" was already sufficiently high to exclude benthic species such as *Caffrogobius* spp. from the deeper parts of the estuary. Phytoplankton biomass close to the natural low but a 11 % increase in benthic microalgae will have favoured mullet species and provided an alternative food source to phytoplankton for *G. aestuaria* and *A. breviceps*. The latter two species and all juveniles <30 mm of all the species in the estuary would have benefited by a 10 % increase in zooplankton. A 214 % increase in occurrence of macroalgae, the preferred habitat for *S. temminckii* and *R. holubi,* would have allowed these species to persist for longer periods in the estuary. However, the abundance of all species would depend on the relationship between algal biomass and oxygen levels. A 135 % increase in macroinvertebrate biomass (*C. kraussi*) likely to favour species such as *L. lithognathus* and *R. globiceps,* but the extent is likely to depend on the relationship between freshwater flow and prey availability.<br><br>In the short-term, closed conditions are not persistent enough to hinder recruitment into the estuary during the peak recruitment period of August-September. Although semi-closed conditions occur for at least 5 months of the year, most fish species will cue to, and recruit through, the freshwater outflow, provided that there is sufficient depth (5-10cm) through which to navigate. On a longer time scale, large (and exploited) fish species are long-lived with a high age at maturity (6 years average), both adaptations to an arid climate with drought cycles of 4-7 years. Under Reference, Present day and Scenario 1, the probability of a successful spawning remains high with droughts of 2-5 years. The probability of success decreases through scenarios 2-4. |
| **Scenario 2** | Similar to Scenario 1, with no real change in salinity, so unlikely to have been any change in numbers due to opportunistic species entering the estuary, or change in community structure according to salinity preferences or tolerances. Water clarity high, therefore no change in visual foragers or selective feeders. Hypoxia increases by 16 % but little change in the fish assemblage from Reference where the frequency of hypoxic/anoxic "events" was already sufficiently high to exclude most benthic species from the deeper parts of the estuary. Phytoplankton biomass ⇩9 % but ⇧14 % in benthic microalgae⇒ mullet⇧, alternative food for *G. aestuaria* and *A. breviceps*. The latter two species, and all juveniles <30 mm of all the species in the estuary would have benefited by a 10 %⇧ in zooplankton. Macroalgae 221 %⇧⇒ ⇧*S. temminckii* and *R. holubi* habitat but nocturnal⇩$O_2$. Macroinvertebrate biomass 140 %⇧⇒ ⇧*L. lithognathus* and *R. globiceps* but the extent is likely to depend on the relationship between freshwater flow and prey availability. Fish recruit during August-September window and throughout semi-closed conditions but frequency and duration (2-10years) of droughts⇧⇒ ⇩recruitment success. |
| **Scenario 3** | Similar to Scenario 1 and 2, with no real change in salinity, so unlikely to have been any change in numbers due to opportunistic species entering the estuary or change in community structure according to salinity preferences or tolerances. Water clarity high, therefore no change in visual foragers or selective feeders. Hypoxia increases by 16 % but little change in the fish assemblage from Reference where the frequency of hypoxic/anoxic "events" was already sufficiently high to exclude most benthic species from the deeper parts of the estuary. Phytoplankton biomass ⇩11 % but ⇧15 % in benthic microalgae⇒ mullet⇧, alternative food for *G. aestuaria* and *A. breviceps*. The latter two species, and all juveniles <30 mm of all the species in the estuary would have benefited by a 10 %⇧ in zooplankton. Macroalgae 224 %⇧⇒ ⇧*S. temminckii* and *R. holubi* habitat but nocturnal⇩$O_2$. Macroinvertebrate biomass 137 %⇧⇒ ⇧*L. lithognathus* and *R. globiceps* but the extent is likely to depend on the relationship between freshwater flow and prey availability. Fish recruit during August-September window and throughout semi-closed conditions, but frequency and duration (2-12years) of droughts⇧⇒ ⇩recruitment success and some species e.g. *L. lithognathus* will be either of very low abundance or no longer occur. |
| **Scenario 4** | Similar to Scenario 1,2 and 3, with no real change in salinity, so unlikely to have been any change in numbers due to opportunistic species entering the estuary or change in community structure according to salinity preferences or tolerances. Water clarity high therefore no change in visual foragers or selective feeders. Hypoxia increases by 18 % but little change in the fish assemblage from Reference where the frequency of hypoxic/anoxic "events" was already sufficiently high to exclude most benthic species from the deeper parts of the estuary. Phytoplankton biomass ⇩21 % but ⇧18 % in benthic microalgae⇒ mullet⇧, alternative food for *G.* |

| | |
|---|---|
| | *aestuaria* and *A. breviceps*. The latter two species, and all juveniles <30 mm of all the species in the estuary would have benefited by a 10 %⇧ in zooplankton. Macroalgae 245 %⇧⇒ ⇧*S. temminckii* and *R. holubi* habitat but nocturnal⇩$O_2$. Macroinvertebrate biomass 145 %⇧⇒ ⇧*L. lithognathus* and *R. globiceps* but the extent is likely to depend on the relationship between freshwater flow and prey availability. Fish recruit during August-September window and throughout semi-closed conditions, but frequency and duration (2-19years) of droughts⇧⇒ ⇩recruitment success and some species e.g. *L. lithognathus* will be either of very low abundance or no longer occur. |
| **Scenario 6** | Similar to scenario 1,2 and 3, with no real change in salinity, so unlikely to have been any change in numbers due to opportunistic species entering the estuary or change in community structure according to salinity preferences or tolerances. Water clarity high therefore no change in visual foragers or selective feeders. Hypoxia increases by 9 % but little change in the fish assemblage from Reference where the frequency of hypoxic/anoxic "events" was already sufficiently high to exclude most benthic species from the deeper parts of the estuary. Phytoplankton biomass ⇧6 % and ⇧28 % in benthic microalgae⇒ mullet⇧, alternative food for *G. aestuaria* and *A. breviceps*. The latter two species, and all juveniles <30 mm of all the species in the estuary would have benefited by a 10 %⇧ in zooplankton. Macroalgae 157 %⇧⇒ ⇧*S. temminckii* and *R. holubi* habitat but nocturnal⇩$O_2$. Macroinvertebrate biomass 125 %⇧⇒ ⇧*L. lithognathus* and *R. globiceps* but the extent is likely to depend on the relationship between freshwater flow and prey availability. Fish recruit during August-September window and throughout semi-closed conditions. Under Reference, Present Day, Scenarios 1 and 6, the probability of a successful spawning and recruitment remains high with droughts of 2-5 years. |

| **Scenario** | **Species richness (% similarity in brackets)** | | **Abundance** | | **Community composition** | | **Overall score** |
|---|---|---|---|---|---|---|---|
| | **Score** | **Summary of change** | **Score** | **Summary of change** | **Score** | **Summary of change** | |
| Present | 80 (90%) M | Alien predation ⇩in catadromous (eels), facultative catadromous (e.g. *Monodactylus falciformis*) spp. that have to migrate past the head of the estuary. | 95 M | Benthic microalgae⇧, macroalgae⇧, $O_2$⇩, ⇧prey availability. ⇧ *Mugillidae, ⇧ weed loving spp. e.g. S. temminckii*, ⇧juvenile zooplankton feeders e.g. *L. lithognathus.* ⇩benthic spp. e.g. *Caffrogobius* | 90 M | Detritivore⇧, selective feeder⇧, benthic invert feeder⇧, ⇩benthic spp. | 80 M |
| 1 | 80 (90%) M | Alien predation Alien predation ⇩in catadromous (eels), facultative catadromous (e.g. *Monodactylus falciformis*) spp. that have to migrate past the head of the estuary. | 95 M | Benthic microalgae⇧, macroalgae⇧, $O_2$⇩, ⇧prey availability. ⇧ *Mugillidae, ⇧ weed loving spp. e.g. S. temminckii*, ⇧juvenile zooplankton feeders e.g. *L. lithognathus.* ⇩benthic spp. e.g. *Caffrogobius* | 90 M | Detritivore⇧, selective feeder⇧, benthic invert feeder⇧,⇩benthic spp. | 80 M |

| Scenario | Species richness (% similarity in brackets) | | Abundance | | Community composition | | Overall score |
|---|---|---|---|---|---|---|---|
| | Score | Summary of change | Score | Summary of change | Score | Summary of change | |
| 2 | 65 (80%) M | ⇧Drought, ⇩ recruitment of estuarine dependent marine species. Alien predation ⇩in catadromous (eels), facultative catadromous (e.g. *Monodactylus falciformis*) spp. that have to migrate past the head of the estuary. | 70 M | Benthic microalgae⇧, macroalgae⇧, $O_2$⇩, ⇩prey availability, ⇧drought. ⇧ *Mugillidae,* ⇧ weed loving *spp. e.g. S. temminckii*. ⇩juvenile zooplankton feeders and recruitment of estuarine dependent marine species e.g. *L. lithognathus.* ⇩benthic spp. e.g. *Caffrogobius* | 80 M | ⇩Recruitment, ⇩prey availability, ⇩all except detritivorous mullet | 70 M |
| 3 | 65 (80%) M | ⇧Drought, ⇩ recruitment of estuarine dependent marine species. Alien predation ⇩in catadromous (eels), facultative catadromous (e.g. *Monodactylus falciformis*) spp. that have to migrate past the head of the estuary. | 60 M | Benthic microalgae⇧, macroalgae⇧, $O_2$⇩, ⇩prey availability, ⇧drought. ⇧ *Mugillidae,* ⇧ weed loving *spp. e.g. S. temminckii*. ⇩juvenile zooplankton feeders and recruitment of estuarine dependent marine species e.g. *L. lithognathus.* ⇩benthic spp. e.g. *Caffrogobius* | 70 M | ⇩Recruitment, ⇩prey availability, ⇩all except detritivorous mullet | 60 M |

| Scenario | Species richness (% similarity in brackets) | | Abundance | | Community composition | | Overall score |
|---|---|---|---|---|---|---|---|
| | Score | Summary of change | Score | Summary of change | Score | Summary of change | |
| 4 | 50 (70%) M | ⇧Drought, ⇩ recruitment of estuarine dependent marine species. Alien predation ⇩in catadromous (eels), facultative catadromous (e.g. *Monodactylus falciformis*) spp. that have to migrate past the head of the estuary. | 50 M | Benthic microalgae⇧, macroalgae⇧, $O_2$⇩, ⇩prey availability, ⇧drought. ⇧ *Mugillidae,* ⇧ weed loving *spp. e.g. S. temminckii*. ⇩juvenile zooplankton feeders and recruitment of estuarine dependent marine species e.g. *L. lithognathus.* ⇩benthic spp. e.g. *Caffrogobius* | 60 M | ⇩Recruitment, ⇩prey availability, ⇩all except detritivorous mullet | 50 M |
| 6 | 80 (90%) M | ⇧ $O_2$ , ⇧ benthic spp. E.g. *Caffrogobius* but ⇩weed loving spp. E.g. *S. Temminckii.* Alien predation ⇩in catadromous (eels), facultative catadromous (e.g. *Monodactylus falciformis*) spp. that have to migrate past the head of the estuary. | 95 M | Nutrient⇩, benthic microalgae⇩, macroalgae⇩, $O_2$⇧, ⇧ benthic spp.e.g. *Caffrogobius*, ⇧ benthic prey, ⇧ benthic feeders e.g. *R. holubi*, ⇧prey availability, ⇧ most spp. | 95 M | Detritivore⇧, selective feeder⇧, benthic invert feeder⇧,⇩benthic spp. | 80 M |

This section provides a summary of the parameters used as a proxy for change for fish.

| Parameters | Present | Future Scenario 1 | Future Scenario 2 | Future Scenario 3 | Future Scenario 4 | Future Scenario 5 | Future Scenario 6 |
|---|---|---|---|---|---|---|---|
| Drought length | 2-5 years | 2-5 years | 2-10 years | 2-12 years | 2-19 years | 2-5 years | 2-10 years |
| Subtidal/intertidal area | 30%⇩ | 30%⇩ | 30%⇩ | 30%⇩ | 40%⇩ | 30%⇩ | 30%⇩ |
| Salinity | 4%⇩ | 4%⇩ | 3%⇩ | 3%⇩ | 3%⇩ | 4%⇩ | 0.8%⇩ |
| Hypoxia/anoxia | 15%⇧ | 15%⇧ | 16%⇧ | 16%⇧ | 18%⇧ | 15%⇧ | 9%⇧ |
| Phytoplankton | 8%⇩ | 0∆ | 9%⇩ | 11%⇩ | 21%⇩ | 27%⇩ | 6%⇩ |
| Benthic microalgae | 14%⇧ | 11%⇧ | 14%⇧ | 15%⇧ | 18%⇧ | 4%⇧ | 14%⇧ |
| Macroalgae occurrence | 38%⇧ | 35%⇧ | 37%⇧ | 37%⇧ | 42%⇧ | 36%⇧ | 23%⇧ |
| Zooplankton | 10%⇧ | 10%⇧ | 10%⇧ | 10%⇧ | 10%⇧ | 10%⇧ | 10%⇧ |
| Benthic invertebrates | 40%⇧ | 35%⇧ | 40%⇧ | 37%⇧ | 45%⇧ | 40%⇧ | 20%⇧ |

### *5.3.5 Birds*

This section describes the changes in fish for the different run-off scenarios. It is, however, difficult to generalise for a system that has small numbers of birds, apart from the gull and tern roost, and for which numbers are naturally highly variable. Thus estimates are of a low confidence.

| | |
|---|---|
| **Scenarios 1 and 5** | Scenario 1 has slightly improved hydrology and hydrodynamics (moving back towards reference), and though most groups are still elevated in abundance relative to present state, they are not as elevated as at present. Changes in fish are negligible. No significant changes in birds expected relative to present. From a bird perspective, characteristics of the estuary under scenario 5 are similar to scenario 1. |
| **Scenarios 2-4** | Scenarios 2 to 4 entail a decrease in flow and flooding, and increase in mouth closure relative to present, which makes it less attractive to birds. For scenarios 2 and 3, these changes do not have a significant impact relative to present, but by Scenario 4, the changes are sufficient to have a measurable negative effect on fish abundance. Invertebrate abundance changes very little compared to present day. Overall, there will be slightly lower numbers of birds, but overall composition does not change markedly. |
| **Scenario 6** | In this scenario mouth condition is closer to natural than any other scenario, including present day. There is little change in the intertidal area, invertebrates are closer to natural, ie. not as abundant as in present day. Fish are as under natural and present conditions. |

| Scenario | 1. Species richness (% similarity in brackets) | | 2a. Abundance | | 2b.Community composition | | Overall score |
|---|---|---|---|---|---|---|---|
| | Score | Summary of change | Score | Summary of change | Score | Summary of change | |
| Present | 100 (100%) L | None | 81 L | Invertebrate feeders 1%⇩ Gulls and terns 21%⇩ Other piscivores no change | 100 L | Because of dominance of gulls and terns, overall impacts on community are negligible for all scenarios | 93 L |
| 1 | 100 (100%) L | None | 81 L | Invertebrate feeders 5%⇩ Gulls and terns 20%⇩ Other piscivores no change | 100 L | | 93 L |
| 2 | 100 (100%) L | None | 79 L | Invertebrate feeders 1%⇩ Gulls and terns 21%⇩ Other piscivores 30%⇩ | 100 L | | 92 L |
| 3 | 100 (100%) L | None | 78 L | Invertebrate feeders 5%⇩ Gulls and terns 22%⇩ Other piscivores 40%⇩ | 100 L | | 91 L |
| 4 | 100 (100%) L | None | 74 L | Invertebrate feeders 1%⇩ Gulls and terns 26%⇩ Other piscivores 50%⇩ | 100 L | | 89 L |
| 5 | 100 (100%) L | None | 80 L | Invertebrate feeders 1%⇩ Gulls and terns 21%⇩ | 100 L | | 80 L |
| 6 | 100 (100%) L | None | 93 L | Invertebrate feeders 7%⇩ Gulls and terns 7%⇩ | 100 L | | 93 • L |

This section provides a summary of the parameters used as a proxy for change for birds.

| Parameters (Abundance) | Present | Future Scenario 1 | Future Scenario 2 | Future Scenario 3 | Future Scenario 4 | Future Scenario 5 | Future Scenario 6 |
|---|---|---|---|---|---|---|---|
| Change in time mouth open | 26%⇩ | 25%⇩ | 26%⇩ | 27%⇩ | 31%⇩ | 26%⇩ | 12%⇩ |
| Change in intertidal area | 10%⇧ | 10%⇧ | 10%⇧ | 10%⇧ | 15%⇧ | 10%⇧ | 10%⇧ |
| Benthic invertebrates | 40%⇧ | 35%⇧ | 40%⇧ | 37%⇧ | 45%⇧ | 40%⇧ | 20%⇧ |
| Fish | 0%⇩ | 0%⇩ | 30%⇩ | 40%⇩ | 50%⇩ | 0% | 0% |
| Birds | 7%⇩ | 7%⇩ | 8%⇩ | 9%⇩ | 11%⇩ | 26%⇩ | 12%⇩ |

# 6 RECOMMENDED ECOLOGICAL FLOW REQUIREMENT FOR THE PALMIET ESTUARY

The individual EHI Scores, as well as the corresponding categories for the scenarios are listed in Table 6.1:

**Table 6.1 Summary of individual EHI Scores and resultant category for Scenarios 1 to 6**

| Variable | Weight | Present | Scenario | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 |
| Hydrology | 25 | 67 | 72 | 66 | 65 | 57 | 67 | 74 |
| Hydrodynamics and mouth condition | 25 | 46 | 47 | 43 | 43 | 36 | 46 | 77 |
| Water quality | 25 | 75 | 74 | 75 | 76 | 76 | 81 | 75 |
| Physical habitat alteration | 25 | 78 | 78 | 78 | 78 | 69 | 78 | 78 |
| **Habitat Health Score** | | **66** | **67** | **65** | **65** | **60** | **68** | **76** |
| Microalgae | 20 | 74 | 75 | 74 | 73 | 69 | 73 | 72 |
| Macrophytes | 20 | 45 | 47 | 45 | 45 | 41 | 45 | 64 |
| Invertebrates | 20 | 60 | 70 | 65 | 68 | 55 | 65 | 75 |
| Fish | 20 | 80 | 80 | 65 | 60 | 50 | 80 | 80 |
| Birds | 20 | 81 | 81 | 79 | 78 | 74 | 80 | 93 |
| **Biotic Health Score** | | **68** | **71** | **66** | **65** | **58** | **69** | **77** |
| **EHI** | | **67** | **69** | **66** | **66** | **59** | **68** | **76** |
| **Category** | | **C** | **C** | **C** | **C** | **D** | **C** | **B** |

The evaluation of the simulated runoff scenarios was used to derive the recommended EWR, which is defined as the runoff scenario (or a slight modification thereof) that represents the highest reduction in river inflow that will protect the aquatic ecosystem of the estuary and maintain it in the REC.

There is some concern that the structural habitat of the estuary may be on a negative trajectory of change, since the sedimentary processes may not yet have reached equilibrium following the construction of dams in the upper catchment.

In evaluating Scenarios 1 to 4, it was assumed that only river inflow would be modified and that other anthropogenic activities (e.g. fishing, bait collection and human disturbance) would remain the same as the present situation. Scenario 5 is similar to Present State in freshwater flows, but it assumes a 66 % reduction in inorganic nutrient and anthropogenic organic matter inputs to the estuary. Scenario 6 is similar to the Scenario 2 in freshwater flows, but it requires that baseflows to the estuary not be less than 1.0 $m^3s^{-1}$ for longer than 3 months a year to reduce the likelihood of macroalgae blooms and related anoxic/hypoxic conditions developing.

Scenarios 1 to 3 will maintain the estuary in its present health status (i.e. **Category C**). Scenario 1 represent a slight improvement from the present, with a 3 % increase in the health of the biota, while Scenarios 2 and 3 will reduce the health of the system slightly. Of concern here was the further loss of variably in flow for needed for controlling the macroalgae blooms and the development of low oxygen conditions. Scenario 4 will degrade the condition to a **Category D**.

Scenario 5 (similar to present but with reduced nutrient input) only improve the health of the system marginally to maintain it in a **Category C**, with a slight improvement from the present, but it would be a challenge to achieve the level of nutrient reduction required under this scenario. Scenario 6 will improve the health of the estuary to a **Category B**.

Taking the above into account, **Scenario 6 is the recommended EWR for the Palmiet Estuary**. A summary of flow distributions for the recommended ecological flow scenario (Scenario 6) is provided below in Table 6.2.

**Table 6.2 Summary of flow distributions (in $m^3s^{-1}$) of the recommended Ecological Flow Scenario (Scenario 6) for the Palmiet Estuary**

| | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 99%ile | 20.44 | 8.79 | 3.58 | 2.81 | 2.35 | 2.44 | 6.71 | 12.85 | 25.23 | 43.50 | 36.36 | 27.49 |
| 90%ile | 10.43 | 3.90 | 1.43 | 0.82 | 0.83 | 1.05 | 3.53 | 7.91 | 19.45 | 22.70 | 26.15 | 17.93 |
| 80%ile | 6.61 | 2.52 | 1.00 | 0.57 | 0.68 | 0.81 | 2.06 | 5.38 | 12.39 | 17.16 | 19.62 | 13.37 |
| 70%ile | 5.89 | 1.98 | 1.00 | 0.52 | 0.54 | 0.56 | 1.50 | 4.34 | 9.39 | 13.35 | 16.73 | 11.27 |
| 60%ile | 4.52 | 1.66 | 1.00 | 0.52 | 0.52 | 0.51 | 1.19 | 3.78 | 8.25 | 11.40 | 15.80 | 9.75 |
| 50%ile | 3.66 | 1.47 | 1.00 | 0.52 | 0.49 | 0.44 | 1.00 | 3.12 | 7.03 | 9.91 | 13.54 | 7.91 |
| 40%ile | 3.17 | 1.36 | 1.00 | 0.45 | 0.34 | 0.33 | 1.00 | 2.56 | 5.46 | 8.88 | 11.20 | 6.58 |
| 30%ile | 2.81 | 1.20 | 1.00 | 0.35 | 0.32 | 0.30 | 1.00 | 2.13 | 4.14 | 6.64 | 9.94 | 6.05 |
| 20%ile | 2.40 | 1.00 | 1.00 | 0.32 | 0.29 | 0.27 | 1.00 | 1.60 | 3.57 | 5.43 | 8.43 | 5.67 |
| 10%ile | 1.76 | 1.00 | 1.00 | 0.28 | 0.26 | 0.25 | 1.00 | 1.30 | 2.56 | 4.63 | 7.01 | 5.05 |
| 1%ile | 1.22 | 1.00 | 1.00 | 0.10 | 0.08 | 0.12 | 1.00 | 1.00 | 1.27 | 3.00 | 5.02 | 3.95 |

Note that an increase in river inflow in itself (i.e. Scenario 6) would not be sufficient to ensure the recommended level of estuarine functioning. The following restoration measures are required to improve the present health of the Palmiet Estuary:

- Manage anthropogenic nutrient and organic matter inputs to the estuary through improved agricultural and urban landscape management;
- Improve the compliance monitoring of fishing and bait collection activities on the estuary. This will assist in controlling illegal harvesting of the estuarine living resources. At present, recreational angling (and the occasional gillnetting) accounts for approximately 0.2 tonne annually. This includes the requirement for improved control of the harvesting of eels from the catchment.
- Restrict bait collection when the mouth is closed, since recruitment cannot occur during extended periods of mouth closure as it leads to the depletion of important food resources in the estuary.
- Install a fish ladder at the gauging weir, and an eelway at the dams, to facilitate migration of fishes into the lower river reaches.

Any assessment of future water resources development will also have to include an evaluation of the success of the implementation of these non-flow related mitigation measures in restoring the habitat, and protecting biota before being passed.

# 7 COOPERATIVE GOVERNANCE

The setting and achievement of national management objectives for the Palmiet Estuary will require a high level of co-operative governance between the various management authorities. For example, there needs to be:

- Agreement between DWA, DEA, DAFF and SANBI on the overall level of biodiversity protection for the Palmiet Estuary, i.e. Management Class.
- A matching allocation of freshwater from DWA, as the DWA Ecological Management Class is directed towards the water resource and may be lower than the overall Biodiversity Management Class, which may be higher as a consequence of effective management of other anthropogenic activities in the estuarine environs.
- DWA to establish a long-term health monitoring programme for the Palmiet Estuary.
- Co-operation from local farmers and the Department of Agriculture on improved farming practices in the catchment.
- Increased compliance monitoring by DAFF: MCM regarding fishing and bait collection in the system, and agreement and implementation of the restriction on bait collection during periods of mouth closure.

Lastly, it is recommended that the Palmiet Estuarine Management Plan be developed based on findings of this study and on the guidelines for the estuaries of the Cape Floral Region (Van Niekerk and Taljaard 2007). This will provide a framework for implementing the proposed mitigation measures for improving the health of the estuary, and will assist in the allocation of roles and responsibilities among the authorities managing activities in and around the system.

# 8 ECOLOGICAL SPECIFICATIONS

Ecological Specifications are clear and measurable specifications of ecological attributes (in the case of estuaries - hydrodynamics, sediment dynamics, water quality and different biotic components) that define a specific ecological reserve category, in this case a **Category B** (Table 8.1).

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

**Table 8.1 Palmiet: Ecological Specifications for the Recommend Ecological Category B.**

| Component | Ecological Specification | Threshold of Potential Concern | Potential Causes |
|---|---|---|---|
| **Water Quality** | Salinity distribution not to exceed TPCs for fish, invertebrates, macrophytes and microalgae (see above). | WQ1: Salinity values below 10 ppt for longer than three months in a year. | Illegal abstractions from the river upstream, operational releases not executed correctly or drought conditions. |
| | System variables (Temperature, pH, turbidity, dissolved oxygen, suspended solids and turbidity) not to exceed TPCs for biota (see above). | WQ2: River inflow: Summer temperature <20 $^{o}$C; pH >8; Dissolved oxygen <4 mg/l.<br><br>WQ3: Average Secchi disc depth in estuary <2 m<br><br>WQ4: pH > 8.5 in estuary<br><br>WQ5: Average DO concentration in water column of estuary <4 mg/l (except in deeper areas during closed mouth or semi-closed states). | Potential bottom releases for a dam during summer (low temperature water)<br><br>Inappropriate agricultural practices in catchment (organic loading). |
| | Inorganic nutrient concentrations not to exceed TPCs for macrophytes and microalgae (see above). | WQ7: River inflow: Average DIN concentration >100 µg/l (dry season) or >500 µg/l (wet season);<br><br>WQ8: Average DIP concentration >10 µg/l (dry season) and >50 µg/l (wet season).<br><br>WQ9: Average DIN concentrations in freshwater section >100 µg/l (dry season) (marine waters may have higher conc's linked to upwelling) and >500 µg/l (wet season)<br><br>WQ10: Average DIP concentrations >10 µg/l (dry season) (marine waters may have higher conc's linked to upwelling) and >50 µg/l (wet season). | Inappropriate agricultural practices in catchment (e.g. fertilizers). |

| Component | Ecological Specification | Threshold of Potential Concern | Potential Causes |
|---|---|---|---|
| | Presence of toxic substances not to exceed TPCs for biota (see biotic components above). | WQ11: Trace metals concentrations in estuary exceed target values as per *SA Water Quality Guidelines for coastal marine waters* (DWAF 1995). TPCs for trace metals in sediments still need to be established.<br><br>WQ12: Pesticides/herbicides: baseline studies to be undertaken before TPCs can be set. | Inappropriate agricultural practices in catchment (e.g. pesticides/herbicides). |
| **Hydrodynamics** | Maintain a flow regime to create the required habitat for birds, fish, macrophytes, microalgae and water quality. | H1: River inflow distribution patterns differ by more than 5 % from that of Scenario 6. (i.e. recommended flow scenario for the Palmiet).<br><br>H2: Monthly average river inflow below 1.0 $m^3$/s persists for longer than three months in a row.<br><br>H3: Mouth closure occurs more than one month in a row in a year and semi-closure occurs for more than three months in a row.<br><br>H4: Total annual inflow <175 million m3 for more than 5 years in a row. | Illegal abstractions from rivers upstream, operational releases not executed correctly or drought condition. |

| Component | Ecological Specification | Threshold of Potential Concern | Potential Causes |
|---|---|---|---|
| **Sediment dynamics** | Flood regime to maintain the sediment distribution patterns and aquatic habitat (instream physical habitat) so as not to exceed TPCs for biota (see above). | S1: River inflow distribution patterns (flood components) differ by more than 20 % (in terms of magnitude, timing and variability) from that of the present state (2009).<br><br>S2: Suspended sediment concentration from river inflow deviates by more than 20 % of the sediment load-discharge relationship to be determined as part of baseline studies (present state 2009).<br><br>S3: Findings from the bathymetric surveys undertaken as part of the Palmiet Monitoring programme indicate changes in the sedimentation and erosion patterns in the estuary have occurred (± 0.5 m) in the lower reaches. | Modification to inflow at head of estuary.<br><br>Significant reduction in floods to the Palmiet Estuary.<br><br>Changes in mouth breaching techniques. |
| | Changes in sediment grain size distribution patterns not to exceed TPCs in benthic invertebrates (see above). | S4: The median bed sediment diameter deviates by more than a factor of two from levels to be determined as part of baseline studies (present state 2009).<br><br>S5: Sand/mud distribution in the middle and upper reaches change by more than 10 % from present state (2009).<br><br>S6: Changes in tidal amplitude at the tidal gauge of more than 20 % from present state (2009). | Modification to inflow at head of estuary; Catchment activities; Estuary mouth changes. |
| **Phytoplankton** | Maintain low phytoplankton biomass. Maintain microalgal group diversity as measured for the baseline survey. | A1: Increase in phytoplankton biomass to 20% greater than the baseline concentrations.<br><br>A2: Deviation in phytoplankton group diversity to 20 % of that found for baseline conditions. | Elevated nutrient concentrations in the inflowing freshwater.<br><br>Reduced freshwater inflow. |

| Component | Ecological Specification | Threshold of Potential Concern | Potential Causes |
|---|---|---|---|
| **Benthic microalgae** | Maintain high subtidal benthic microalgal biomass during the closed mouth phase and low intertidal benthic microalgal biomass during the open phase. Epipelic diatoms indicative of brackish conditions should be found during the closed phase. | A3: Deviation in benthic microalgal biomass by 20 % compared to baseline concentrations.<br><br>A4: No brackish epipelic diatoms are found during the closed phase. | Elevated nutrient concentrations in the inflowing freshwater.<br><br>Change in mouth condition.<br>Increase in salinity. |
| **Macrophytes** | Maintain the distribution of plant community types i.e. macroalgae (*Cladophora* and *Ulva* spp.) during closed/semi-closed mouth brackish conditions (~1 ha) and intertidal salt marsh (~0.1 ha). No invasive species e.g. *Spartina alterniflora* present on the salt marsh. | M1: Greater than 20 % change in the area covered by different plant community types for baseline open and closed mouth conditions.<br><br>M2: Presence of invasive species. | Change in flow and mouth condition resulting in low (near fresh) salinity.<br><br>Change in mouth condition and associated water level fluctuations. |
| | Prevent excessive filamentous macroalgal growth. Area covered should be less than 50 % of the open water surface area. | M3: Macroalgae cover greater than 50 % in 1 $m^2$ quadrats. Macroalgae cover greater than 50 % of the open water surface area in the eastern channel and above sand bank in the lower reaches of the estuary. Macroalgal wet biomass is greater than 500 g $m^{-2}$. | Elevated nutrient concentrations.<br><br>Prolonged closed mouth conditions and lack of freshwater floods and flushing. |
| | Maintain the zonation of salt marsh and distribution of different species along an elevation gradient. Ensure the long-term persistence of intertidal salt marsh species such as *Triglochin striata* and *Cotula coronopifolia*. | M4: Loss of *Triglochin spp.* and *Cotula coronopifolia* from the small saltmarsh area. | Reduced freshwater inflow and high salinity.<br><br>Increased closed mouth conditions, high water levels and loss of intertidal habitat. |
| | Prevent hypersaline sediment and groundwater conditions in the salt marsh. Sediment electrical conductivity should be approximately 30 mS and similar to groundwater values. | M5: Sediment and groundwater electrical conductivity is greater than 30 mS for the salt marsh area. | Reduced freshwater inflow and high salinity.<br><br>Reduced floods and flushing of salts from supratidal and floodplain salt marsh areas. |

| Component | Ecological Specification | Threshold of Potential Concern | Potential Causes |
|---|---|---|---|
| **Invertebrates** | Density of sandprawn burrow openings should exceed 75 per $m^2$ in the highest density areas in the lower estuary.<br><br>Amphipods should numerically dominate the benthic fauna (*Grandidierella* sp.and *Corophium triaenonyx*) living on the sediment surface in the middle and upper estuarine reaches respectively.<br><br>In the zooplankton, the density of *Pseudodiaptomus hessei* should range between 100 and 5000 $m^3$ in the summer in the mid-estuary region. | I1: The abundance of *Callianassa kraussi* burrows in the lower estuary drops below 50 counts per $m^2$ in the highest density areas.<br><br>I2: Amphipods do not dominate the surface dwelling benthic fauna.<br><br>I3: *Pseudodiaptomus hessei* disappears from the zooplankton for prolonged periods (months). | The mouth remains closed or semi-closed for extended periods, leading to persistent low salinity values (<5 ppt) throughout the estuary. |
| **Fish** | Retain the following fish assemblages in the estuary (based on abundance):<br>- Estuarine species (10-20 %);<br><br>- Estuarine associated marine species (80-90 %); and<br><br>- Indigenous freshwater species (±1 %).<br><br>- All numerically dominant species are represented by 0+ juveniles. | F1: Level of estuarine species increases above 60 % of total abundance.<br>F2: Level of estuary associated marine species drops below 60 % of total abundance.<br>F3: Alien *Lepomis macrochirus* and *Micropterus* spp. dominate in the upper reaches.<br>F4: Absence of 0+ juveniles of any of the dominant fish species. | Recruitment failure due to prolonged drought, mouth semi-/closure and extension of these conditions into the August-December peak recruitment period⇒proportion estuary breeders ⇑<br><br>Have eaten all the indigenous fish, high predation on recruiting elvers.<br><br>-Breeding failure or impaired recruitment. |
| **Birds** | Retain regular representation of waders, gulls, and terns, and overall waterbird species richness of seven or more species. | B1: Estuary becomes regularly used by waterfowl species such as Redknobbed Coot.<br><br>B2: Waders or terns are absent from the estuary for five consecutive counts. | Regular or prolonged periods of mouth closure, high water levels, proliferation of weed and loss of intertidal foraging areas. |

# 9 MONITORING REQUIREMENTS

Sustainable management of the Palmiet Estuary can only be achieved through a sound understanding of its biophysical process based on appropriate and reliable quantitative data. However, the collection, processing and interpretation of such data is often time consuming, and costly, and often requires considerable scientific expertise.

Recommendations for the monitoring of the Palmiet Estuary's biophysical processes have been based on: 1) current data collection methods, 2) the baseline data requirements for the Resource Directed Measures methods for estuaries addressing the Ecological Reserve (Version 2) (DWAF 2003) and 3) the guidelines and procedures to design resource monitoring programmes for estuaries as part of the Ecological Reserve Determination process for estuaries (Taljaard *et al.* 2003).

Resource monitoring programmes can be sub-divided (Taljaard *et al.* 2003) into:

- ***Baseline surveys (or studies)*** the purpose of which is to collect data and information to characterise and understand the ecosystem functioning of a specific system. The baseline studies that are carried out for an Ecological Reserve determination study at a comprehensive level are suitable for long-term monitoring of estuaries. If the EWR study is carried out at a rapid or intermediate level, as was the case for the Palmiet Estuary, additional 'baseline' work is required to produce sufficient baseline data for long-term monitoring.
- ***Long-term (or compliance) monitoring programmes*** to assess (or audit) whether management objectives are being achieved. The purpose of long-term monitoring programmes, in this context, is to assess (or audit) whether the Ecological Specifications are being complied with and to improve and refine the measures, including Resource Quality Objectives, in the longer-term through an iterative process (Taljaard *et al*. 2003). Although baseline studies and long-term monitoring programmes have different purposes, it is extremely important that long-term monitoring programmes follow on from similarly structured baseline studies. In essence, the monitoring activities selected for the long-term monitoring programme should be derived from the monitoring activities conducted as part of the baseline studies, but implemented on less intensive spatial and/or temporal scales (Taljaard *et al*. 2003).

It is important to note the difference between conducting surveys and monitoring. Surveys normally refer to short-term or once-off, intensive investigations on a wide range of parameters to obtain a better understanding of estuarine processes. Monitoring refers to ongoing data collection of a selection of indicator parameters in order to determine long-term change and trends. Long-term monitoring can be done for several reasons, one of which is for compliance monitoring.

A list of abiotic indictors that should always be included in long-term monitoring programmes to allow for proper identification of 'cause and effect' links with regard to river inflow and water quality are (Taljaard *et al.* 2003):

- River inflow (i.e. flow gauging);
- continuous water level recording at the estuary mouth (recording the state of the mouth, a key driver for most biotic components);
- water quality of river inflow;
- water quality and flow rate of effluent discharges into the estuary; and
- salinity distribution patterns under different river flow ranges.

Aerial photographs collected on a regular basis, are also considered as key components in the long-term monitoring of estuaries, as these provide useful information on both abiotic and biotic components (Taljaard et al. 2003).

Criteria that should be considered in the selection and prioritisation of biotic indicators for long-term monitoring programmes include:
The biotic indicators should be particularly sensitive to potential impacts associated with changes in river inflow and water quality, such as state of the mouth, tidal variation, sedimentation/erosion, salinity distribution patterns and deterioration in water quality.

- Biotic components considered to be on a 'trajectory of change' or that are particularly sensitive to abiotic components that are on a 'trajectory of change' (e.g. long term sedimentation), should also be considered for inclusion as indicators in long-term monitoring programmes.
- Biotic components that are of regional or national biodiversity importance are also suitable indicators, particularly when also sensitive to changes in river inflow and water quality.
- Biotic indicators should also be representative of the important food chains present in a particular system.
- The selection of biotic indicators should also present a balance between indicators that provide 'early warning' signals and those that reflect longer-term, more cumulative effects. For example, fish are often considered to be useful 'early warning' indicators, while macrophyte distribution patterns are often better indicators of cumulative, longer-term changes in estuaries.
- Biotic indicators should include economic important indicators where relevant.

A list of the data requirements and the status of the availability of data for the RDM project undertaken in 2007 and 2008 is included in Appendix A for background information.

Based on the above mentioned and the results described in the Review Report (CSIR 2003), the following monitoring programme is recommended (also see summary in Appendix B).

## 9.1 HYDRO- AND SEDIMENT DYNAMICS

### *9.1.1 Sampling Procedure*

- Continuous flow recording of river inflow. There is a continuous record available from the DWA gauging station G4H007 just upstream of the Palmiet Estuary.
- Continuous water level recordings. A continuous water level recorder is installed on the north bank in the middle of the estuary (Station G4R009-A01).
- Daily observations. Where possible, daily mouth observations should be made of the state of the Palmiet Estuary mouth. These observations assist tremendously in the operational management of the estuary mouth and determining when the additional water releases are required.
- Wave conditions. Data on current wave conditions is available online at http://www.fnmoc.navy.mil/PUBLIC/.
- Aerial photographs. Full colour geo-referenced rectified aerial photographs (1: 5 000 scale) covering the entire estuary based on the geographical boundary at low tide every 5 years. The photographs must include the breaker zone near the mouth.

- Topographical surveys. Should be made of the mouth area at 20 m intervals and bathymetrical surveys of cross-sections every 0.1 km upstream of the estuary to the full extent of tidal variation.

### *9.1.2 Baseline data*

Bathymetric/topographical surveys: Surveys should be conducted using Differential Global Positioning System (D-GPS) and echo-sounding to monitor berm height, mouth sediment dynamics and cross section profiles upstream of the mouth.

Sediment grabs: Grab samples should be collected using a Van Veen or a Zabalocki-type Eckman grab (to characterise recent sediment movement) for particle size analysis.

Sediment cores: Core samples should be collected using a corer (for historical sediment characterisation)

Sediment load at head of estuary (including detritus component – particulate carbon/loss on ignition)

Comprehensive Reserve. Sediment dynamics are evaluated in detail for a comprehensive level Reserve study. For such a study, data from seasonal sediment grab samples (spring, summer, autumn and winter) for one year, a once-off set of sediment cores and daily measurements of the sediment load at head of estuary are required. Bathymetric/topographical surveys are required at five year intervals, with an additional three surveys (every two months) after a major flood event to establish the rate of deposition in the system.

### *9.1.3 Long-term monitoring*

It is crucial that a continuous record be kept of freshwater inflow into the estuary. Moreover, it is essential that the continuous water level recorder, near the estuary mouth, be maintained. Lastly, the most recent full colour aerial photographs of the Palmiet Estuary are nearly four years old, and it is recommended that the practice of taking aerial photographs be resumed on a three yearly basis, using DGPS technology. Topographic/bathymetric surveys and grab samples should be repeated at five year intervals.

## 9.2 WATER QUALITY

### *9.2.1 Sampling Procedure*

Water quality samples need to be taken of the river inflow near the head of the estuary (i.e. at weir - DWA Station G4H007) for analysis of system variables (TDS, temperature, pH, DO, Turbidity/Suspended solids[2]), inorganic nutrients (DIN [nitrite, nitrate and ammonia], DIP and DRS), toxic substances (in particular herbicides/pesticides) and organic nutrients (dissolved and particulate).

Water quality in the estuary should be measured at 5 stations distributed geographically along the entire estuary at fixed intervals. A sampling station is defined as a location at a specific 'distance from the mouth'. The following samples should be collected:

[2] Palmiet is typically a clear water systems, but turbidity/suspended solids needs to be included when there is evidence that this status changed, i.e. system is becoming turbid

- Salinity and temperature profiles (also required for hydrodynamics);
- System variables (pH, DO, Secchi depth); and
- Inorganic nutrients (nitrate/nitrite, ammonia, reactive phosphate and reactive silicate)

Salinity and temperature data must be collected at 0.5 m depth intervals, while other water quality parameters are collected in surface and bottom waters.

Where toxic substances are suspected (e.g. from contaminated agricultural runoff), sediment samples should be collected and analysed for toxic substances (in this case herbicides and pesticides). To assist with the interpretation of results, samples should also be analysed for sediment grain size distribution and organic content. A grid of sediment sampling stations should be selected across estuary, specifically targeting depositional areas (characterised by finer sediment grain sizes and/or higher organic content

**Notes:**

The analytical techniques used in the processing of marine and estuarine water quality samples vary greatly from those used in the analysis of fresh water samples. It is therefore crucial that an accredited marine analytical laboratory conducts the analyses of water quality samples.

Estuaries receive water from two sources, i.e. the river and sea, each with distinctively different water quality characteristics, particularly in terms of system variables and nutrients. It is therefore also crucial that water samples from the two sources, i.e. river and sea be taken are included in the monitoring programmes as indicated. The water quality characteristics in an estuary depend on the extent of the influences of each of these sources (governed by hydrodynamic processes), but also biochemical processes (e.g. organic degradation and eutrophication). The influence of such biochemical processes is particularly evident where residence times of water are longer, in this case the closed and semi-closed states.

For toxic substances (e.g. herbicides/pesticides) it is considered more appropriate to sample environmental components that tend to integrate or accumulate these toxins over time, such as sediments.

### *9.2.2 Baseline data*

Additional baseline data required for the Palmiet Estuary (see Appendix A and B):

- Toxic substances (herbicides/pesticides) in river inflow
- Organic nutrients (C, N and P) (dissolved and particulate) in river inflow
- Organic nutrients (C, N and P) input from the sea
- Extent of benthic accumulation of toxic substances (herbicides/pesticides) in the estuary - should input from river be significant - as well as benthic accumulation of particulate organic nutrients (C, N and P)matter in the estuary (see above)

### *9.2.3 Long-term monitoring*

Water quality samples need to be taken of the river inflow near the head of the estuary (i.e. at weir - K2H002Q01). Water quality in the estuary should preferably be measured in conjunction with other biotic components. Where possible, water quality should be measured at intervals of about three years (see Appendix B).

For long-term monitoring programmes, water quality monitoring in the estuary is particularly important for the interpretation of specific biological responses and, therefore must be collected along with the relevant biotic components, as indicated during their sampling surveys. Sediment surveys (toxic substances and organic accumulation) should ideally be conducted very 3-6 years if deemed necessary in future (e.g. depending on findings of baseline surveys) (see Appendix B).

## 9.3 MICROALGAE

### *9.3.1 Sampling Procedure*

Phytoplankton. To estimate phytoplankton biomass, collect duplicate samples for chlorophyll *a* at the surface and at 0.5 m depth intervals. Use a spectrophotometer for sample analysis before and after acidification. Do cell counts (at 400X magnification) on dominant phytoplankton species to establish species distribution and composition, i.e. green algae, flagellates, dinoflagellates, diatoms and blue-green algae.

Benthic microalgae. Collect intertidal and subtidal benthic core samples for chlorophyll *a* (biomass) analysis. Collect five samples at each station (generally a minimum of five stations). Analyse samples using a recognised technique, e.g. HPLC. Record the relative abundance of dominant algal groups, i.e. green algae, dinoflagellates, diatoms and blue-green algae and identify the dominant species.

At each station also measure:
- Water salinity and inorganic nutrients.
- Sediment particle size distribution and organic content.
- Light penetration PAR or Secchi disk depth.

A sampling station is defined as a location at a specific 'distance from the mouth' that can be sampled at different depth intervals (e.g. in the case of phytoplankton). For larger estuaries (> 5.0 km long), ten to 15 stations selected geographically along the entire length of the estuary, covering the different salinity zones, can be used as the guideline. Stations should preferably be set at fixed intervals. A rough estimate for setting the distance between stations is to divide the length of the estuary by ten (i.e. if an estuary is 30 km long, the distance between stations should be about three km).

Salinity zones in estuaries typically include:
- Fresh (river water)
- 0 – 10 ppt.
- 10 – 20 ppt.
- 20 – 35 ppt.

### *9.3.2 Baseline data*

Comprehensive Reserve. Sampling should be conducted seasonally, (i.e. during spring, summer, autumn and winter) for two years with river inflow being representative of a particular season. Sampling should coincide with the water quality survey and the invertebrate surveys in year one.

### *9.3.3 Long-term monitoring*

**Phytoplankton (water column)**. Conduct a summer and winter survey, followed by a summer, to be repeated every three years.

**Benthic microalgae**. Conduct a summer and winter survey, followed by a summer, to be repeated every three years.

**Notes:**
Measurements of (water -) salinity, temperature, other physico-chemical properties and inorganic nutrients need to be made during the microalgal surveys. Combining water and sediment quality surveys on a particular estuary with the microalgal survey does this most cost-effectively.

The temporal scale of the microalgal sampling needs to match that of the invertebrates (zooplankton) to link the response patterns of these biotic components as best as possible. Microalgae may be used in long-term monitoring to indicate whether there is a functional river-estuary interface zone, but baseline data is needed to verify if this is an issue in the Palmiet estuary. Microalgae can also be used effectively in long term monitoring as an indicator of water quality problems.

## 9.4 MACROPHYTES

### *9.4.1 Sampling Procedure*

The following information needs to be captured from recent and any available historical aerial photographs and ortho-photographs covering the entire estuary as defined by the geographical boundaries, including:

- The number of different habitats (plant community types).
- The area covered by each plant habitat.
- Any historical change in area covered by plant habitat.
- The extent of anthropogenic impacts (agriculture, flood plain development).

Field data need to be collected for ground truthing of aerial photographs:

- The number of different plant habitats (plant community types).
- The area covered by each plant habitat.
- A species list for each plant habitat.
- The extent of anthropogenic impacts such as grazing, trampling, alien vegetation, boating, bait digging.

Permanent transects (sampling stations) need to be set up for long term monitoring of changes in plant habitats, including:

- Transects set up along an elevation gradient
- Duplicate quadrats (1 $m^2$) along the elevation transects, which record the percentage cover of each plant.

The saltmarsh area in the Palmiet Estuary is small, so the following data from at least one transect need to be collected:

- Elevation profile and water level.
- Water column salinity and turbidity.
- Sediment salinity, moisture content and sediment composition.

In large supratidal salt marsh areas, boreholes are required to measure the depth to the water table and ground water salinity. A sampling station is defined as a transect across the estuary (at a specific ‘distance from the mouth’), with a number of quadrats arranged along the transect.

Aerial photos. The entire estuary needs to be covered, as defined by the geographical boundaries.

Transects and quadrats. As a guide, the larger estuarine plant habitats in a system (e.g. salt marsh), representing the lower two transects and the middle two transects, should be covered. Other plant habitats, particularly those sensitive to changes in freshwater inflow, could also be monitored.

### *9.4.2 Baseline data*

Comprehensive Reserve. A survey of the permanent transect/s needs to be conducted during an open and a closed phase, to develop an understanding of the relationship between the macrophytes and the mouth conditions.

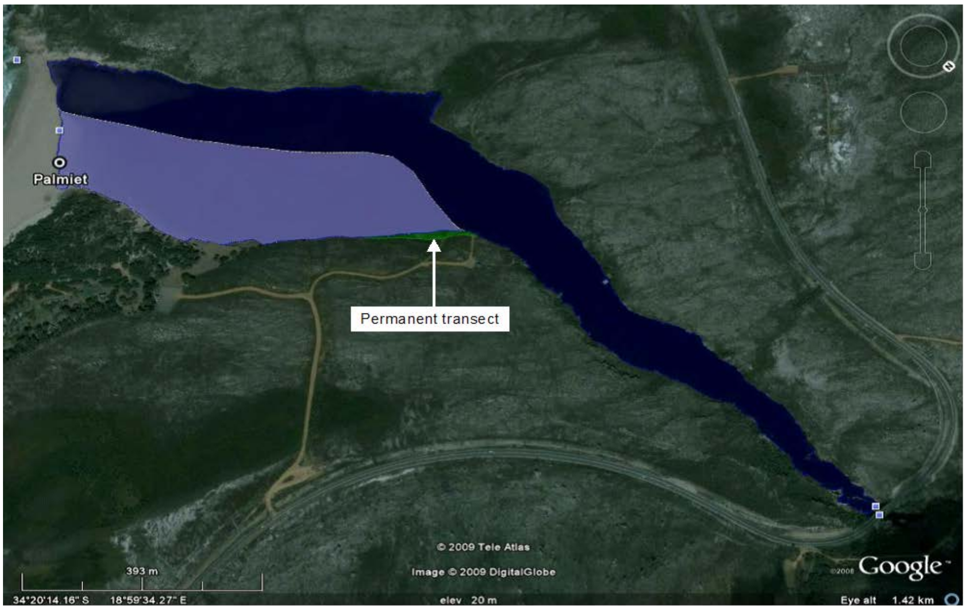



**Figure 9.1 Map of the Palmiet Estuary indicating the recommended location of the transect to be used for the vegetation survey**

An assessment of any changes to the areas occupied by intertidal and supratidal salt marsh may be made from aerial photographs, GIS mapping and perhaps satellite images. This is necessary because Transects A and B do not represent the supratidal salt marsh areas of the estuary, and species may occur outside of the areas sampled by the transects. A holistic mapping exercise is therefore essential.

### *9.4.3 Long-term monitoring*

An open and closed mouth survey should be undertaken every three years, but additional aerial photographs taken during intermediate years should also be analysed. Generally, a temporarily open/closed estuary (TOCE) is sampled in the stable open phase but the Palmiet Estuary should also be sampled during the closed phase to examine the extent and biomass of the macroalgal bloom.

Past surveys have investigated transects in the lower reaches of the estuary. An understanding of the freshwater requirements of the large supratidal salt marsh area in the Palmiet Estuary is also required. An assessment of the relationship between plant cover and depth to groundwater, the role of tidal and freshwater inflow in influencing water table depth, and the availability of water to the plants is needed. Hence transects should also be placed in the middle reaches of the estuary. Long-term data are now available for Transects A, B and C, as indicated in Figure 9.1. These transects should be monitored in the future.

There are four different habitat types (see Table 9.1) recognised for the Palmiet Estuary and these should be mapped to assess changes over time.

**Table 9.1 Palmiet Habitat types and indicator species**

| **Habitat Type** | **Indicator, indicator species** |
|---|---|
| Open surface water area | Indicates available habitat for phytoplankton |
| Intertidal sandflats | Indicates available habitat for intertidal benthic microalgae |
| Macroalgae | *Cladophora* spp., *Ulva* spp. |
| Intertidal salt marsh | Dominant species were the rush, *Juncus kraussii* and the grass *Sporobulus virginicus*. Other species present include *Triglochin striata*, *Cotula coronopifolia*, *Stenotaphrum secundatum*, *Plantago crassifolia, Samolus porosus and Isolepis verrucosula.* |

## 9.5 INVERTEBRATES

### *9.5.1 Sampling Procedure*

Zooplankton. Collect quantitative samples after dark, preferably during neap tides (mid to high tide), because currents are less strong and zooplankton will be more active in the water column. The sample is therefore more representative. Sampling should be done at mid-water level, i.e. not at the surface. Two net trawls (WP2 and 200 micron mesh) representing two replicate samples should be taken at each station. The net should be pulled for three minutes per station (10.0 -12.0 $m^3$ of water) at 0.15 knots diagonally across the estuary at each site. Record the abundance (density per volume) of each species in each trawl and average the results over the two replicates for each station. At each station phytoplankton samples (i.e. water column sample) and benthic microalgae samples need to be collected for chlorophyll-*a* analyses.

Benthic invertebrates. Collect (subtidal) samples using a Zabalocki-type Eckman grab sampler with six to nine randomly placed grabs (replicates) at each station. Collect intertidal samples at spring low tide using a core sampler with a minimum diameter of 150 mm and depth of 250 mm, with six to nine replicates at each site along the transect. Grab/core sample should then be placed in a 500-micron sieve bag and the contents gently sifted so as to remove fine particles. Animals and any other relatively coarse material are then stored in formalin for identification in the laboratory. At least six replicates are required per station. For intertidal benthic invertebrates that are not well quantified by core sampling (e.g. mud prawns, sand prawns, some crabs), count overall density for each species in 0.25m$^2$ minimum quadrat areas, with five replicates at each station.

The following must be completed at each site:

- Identify fauna to the lowest taxon possible.
- Record animal density and species abundance (animals per m$^2$).
- Record the presence of *Zostera* or other macrophytes at the site.

At each station, sediment samples need to be collected for particle size analysis (250 ml) and organic content (250 ml) using standard techniques. Other parameters that must be measured at each site are temperature, salinity, oxygen, conductivity, turbidity, chlorophyll-*a* and pH. Measurements should be taken at the surface, 0.5 m 1.0 m from the surface and thereafter at 1.0 m depth intervals.

<u>Macrocrustaceans.</u> Quantitative sampling for macrocrustaceans should be conducted during neap tides (mid to high tide), at the same stations used for zooplankton. Use a benthic sled (80 cm x 80 cm, with a 500 micron mesh) attached to a flow meter to collect the sample; tow for 30 metres diagonally across the estuary. Take two samples at each station. Set two prawn/crab traps per station overnight (more applicable to sub-tropical areas).

Identify fauna to the lowest taxon possible. Record the number of species and determine densities for each species.

A sampling station is defined as a specific location in the estuary (at a specific 'distance from the mouth') from where a number of replicates are collected.

Sampling stations must take into account the salinity zones characteristic of a particular estuary, which typically include:

- Fresh (river water)
- 0 – 10 ppt.
- 10 – 20 ppt.
- 20 – 35 ppt.

These zones should be indicated on a map and, within each of the salinity zones, the following habitat representatives need to be sampled:

- Submerged macrophytes (e.g. *Zostera* beds).
- Soft sediments (sand, muddy sand and fine mud), hard (rocky areas) and organic rich areas.
- Benthic invertebrate stations must also include intertidal bird feeding areas.

As a guideline 10 to 15 stations should be selected in larger systems. In small estuaries (<4-5 km in length) the minimum number of sites should not be less than five. These should be located geographically along the entire length of the estuary, covering the salinity zones and habitat types as described above. This may vary depending on the diversity of habitats in the estuary. Stations should preferably be set at fixed intervals or positions. A rough estimate for setting the distance between stations is to divide the length of the estuary by ten (i.e. if an estuary is 30 km long, the distance between stations should be about three km).

### *9.5.2 Baseline data*

Currently no baseline data exists for subtidal invertebrates. The current breaching policy of keeping the mouth open from late September/October to April is best suited to the current understanding of intertidal invertebrates that require a marine phase of development during their respective life cycles.

Intermediate Reserve. Subtidal invertebrates. Conduct one invertebrate survey during a low flow and one during a high flow season. A stable closed phase must be sampled as well as a stable open phase. Further samples should also be taken during other sampling programmes if possible.

Zooplankton, benthic invertebrates and macrocrustaceans. One survey in summer/spring and one survey in winter to be taken each year over a period of two years. It is important that samples be taken during a state of the estuary (determined by the extent of saline intrusion and the state of the mouth) that is representative of the particular season that sampling is taking place. In addition, one survey needs to be conducted in a stable closed phase and one in a stable open phase or wet and dry.

Comprehensive Reserve. Subtidal invertebrates. Similar to the intermediate level Reserve requirements, except that sampling should be conducted seasonally, (i.e. during spring, summer, autumn and winter) for two years with the level of river inflow being representative of that particular season. Sampling should coincide with other sampling programmes whenever possible.

Zooplankton, benthic invertebrates and macrocrustaceans. To be conducted in four seasons over two years (i.e. in spring, summer, autumn and winter in each year). At the time of sampling, the state of the estuary, as represented by the extent of saline intrusion and the state of the mouth, must be representative of that particular season. At least one survey must be conducted in a stable closed phase, and at least two surveys in the stable open phase.

### *9.5.3 Long-term monitoring*

*Macrocrustaceans.* Conduct a summer and winter survey every three years.

*Zooplankton.* Conduct a summer and winter survey every three years.

*Benthic invertebrates.* Conduct a summer and winter survey every three years.

These surveys should be conducted during the open and closed phases of the estuary. Common estuarine copepods will be used as indicators of estuarine condition.

**Notes:**
Data collected during this study has indicated an inherent diversity of the larger invertebrates. Although some species were not monitored in the past, the policy of current mouth management appears to be successfully sustaining the current level of invertebrate diversity.

Longer-term data sets are also critical, as natural spatial and temporal fluctuations in population densities are accommodated. It is therefore recommended that further surveys continue, although focusing only on two transects may be sufficient in the future. Species that have a marine phase of development in their life cycle should also be monitored, especially the proportion of juveniles and females with eggs. This information is important to evaluate a population's response to mouth management.

As a result of high variability of invertebrate abundances in response to flow, it is important to sample over two years, in order to obtain the required confidence level (medium for intermediate level and high for comprehensive assessments).

An intense sampling regime with an extended temporal component has been proposed due to a total lack of information on invertebrates in most of South Africa's estuaries. There may also be a rapid change in community composition and abundance over shorter periods of time (weeks to months). Zooplankton respond even more rapidly in the short term, thus the proposed sampling regime is even more intensive.

As far as possible, the invertebrate, microalgal and macrophyte sampling stations should be matched to be able to link habitats with invertebrate characteristics.

Water characteristics (salinity, temperature, pH, dissolved oxygen and turbidity), and sediment quality (sediment grain size and organic content) measurements should also be collected during the invertebrate surveys. Combining water and sediment quality surveys on a particular estuary with the invertebrate surveys was found to be more cost-effective.

For invertebrate surveys, seven sediment grain size categories should be used, ranging from mud to very coarse sand. Each category relates to a particular size diameter in the following manner:

- >2.0 mm: very coarse sand;
- 2.0 – 1.0 mm: very coarse sand;
- 1.0 - 0.5 mm: coarse sand;
- 0.5 – 0.25 mm: medium sand;
- 0.25 – 0.125 mm: fine sand;
- 0.125 – 0.0625 mm: very fine sand; and
- <0.0625 mm: mud (silt and clay).

The percentage organic content of sediments can roughly be classified as:

- <0.5 %: Very low;
- 0.5 – 2 %: Low;
- 1 – 2 %: Moderately low;
- 2 –4 %: Medium; and
- > 4 %: High.

## 9.6 FISH

### *9.6.1 Sampling Procedure*

The Palmiet Estuary is shallow and small enough to allow sampling to be restricted to the use of seine and gillnets as primary gears.

Seine nets. Seine nets should be 30 m long and 2.0 m in depth. The cod end (bag and purse) and the wings 5.0 m to either side should be 5.0 mm bar mesh, whereas the remaining 15 m of each wing may be 15 mm bar mesh. This is required to adequately sample estuarine and 'faster moving' marine species. The net should be weighted such that it sinks below the surface when set in water deeper than 2.0 m (i.e. the distance between the lead and cork lines). A light net makes it more difficult to obtain a representative sample from weed and sandy areas, e.g. flatfish species tend to burrow in the sand and escape under a light seine.

Gill nets. Monofilament gill nets should comprise at least three different mesh sizes between 40 - 150 mm stretch mesh. Monofilament gill nets should comprise at least four nets (or panels) of which one net comprises 44, 48, 51 and 54 mm mesh, and an additional three nets made in the range 75 - 150 mm stretched mesh (e.g. 75 100 and 145 mm stretched mesh). If time permits, either fyke nets or longlines should be used to sample eels in the freshwater reaches immediately above the estuary.

At each sampling station the following data need to be recorded:

- Species present.
- Number of each species.
- Size frequency distributions in total length.

The estuary needs to be sampled from the mouth to the weir at the head of the estuary. An additional seine above the weir to gauge if any estuarine fish manage to bypass it would be ideal. Because the system is small six seine sites 200-300 m apart would be sufficient. Three gillnet sites would be sufficient; the mouth region, middle reaches and head of the estuary.

The following habitat representatives should be sampled:

- Submerged macrophytes (e.g. *Cladophera, Enteromorpha*).
- Sandy/muddy/rocky areas (representing different food sources).
- Near or in saltmarsh areas.

### *9.6.2 Baseline data*

Comprehensive Reserve. Samples should be taken seasonally (i.e. each quarter during spring, summer, autumn and winter) over one year. The temporal scale needs to address recruitment patterns as well as species distribution within habitats in different seasons. Also, at the time of sampling, the state of the estuary must be representative of the season in which samples are collected, as indicated by the extent of saline intrusion and the state of the mouth. At least one survey must be conducted in a stable closed phase.

### *9.6.3 Long-term monitoring*

For TOCEs, such as the Palmiet, late summer and spring surveys should be conducted within a three-year period to ensure that conditions representative of stable open and closed phases are captured.

Sampling should be done immediately after any fish kill, followed by another one to two months after the event. This should be budgeted for in a contingency fund.

**Notes:**

Fish are one of the most reliable indicators of the health of an estuary. Different estuary types (e.g. TOCEs) have typical fish assemblages. The response of fish to any environmental or anthropogenic influences is usually more rapid and more easily measured than other biotic variables such as vegetation. Consequently, problems are detected sooner, and mitigatory measures more rapidly implemented.

The Palmiet is a typical blackwater south coast estuary in the cool/warm temperate transition zone, and is an important nursery area for at least 20 fish species. The first pulse of recruitment of the juveniles of many important species, such as white steenbras (*Lithognathus lithognathus*), usually occurs during September but may be as early as late August. It is imperative that the mouth remains open from September onwards to facilitate recruitment of these species.

Gill nets are valuable in determining the seasonal changes in the distribution of the adults of larger fish species along-stream. For example, it has been found that 44, 48, 51 and 54 mm mesh sizes are needed to obtain a representative sample of the different mullet species in the south-western Cape. The 44 mm mesh catch tends to be dominated by *Liza dumerilii*, the 48 mm by *L. richardsonii* and the 51 and 54 by *L. tricuspidens*, *Myxus capensis* and *Mugil cephalus*. Monofilament nylon nets should be used rather than woven nylon nets, as the latter have a completely different capture efficiency.

Non-destructive sampling should be practiced whenever possible. The survival rate of larger fish is much greater if they are removed from a gill net by cutting the mesh as this is easily repaired afterwards, whereas most seined fish can be measured and released alive. If there are abundant fish in a sample 100 individuals per species should be measured, the rest counted and released. However, it must be accepted that some fish, especially clupeids, die very easily.

The primary goal of fish sampling is to obtain the species composition and size class frequencies of the different fish species present in the system. Gill nets are necessary to sample those fast swimming species and larger individuals that are not captured in the seine nets.

Water quality measurements (salinity, temperature and other physico-chemical properties) need to be collected during the fish surveys. Combining water quality surveys on a particular estuary with the fish surveys was found to be most cost-effective. Fish are more responsive to flow changes, than for example estuarine invertebrates or vegetation, making these good indicator species.

In TOCEs, not all pre-selected sites may be assessed using the same equipment during various sampling trips, for example protective backwater areas. This is acceptable, as long as representative sites are monitored in the same salinity regime to allow for extrapolation to other habitat types.

## 9.7 BIRDS

The Palmiet Estuary is not a particularly important estuary for birds. Nevertheless, it is recommended that birds be included in the monitoring programme, since they contribute to the attraction of the area and because the estuary has been identified as a core estuary for conservation (Turpie and Clark 2007).

### *9.7.1 Sampling Procedure*

Undertake full bird counts of all water-associated birds. If the mouth is open, this should take place during a spring low tide. The estuary should be divided into three counting areas – the upper estuary above the intertidal flats, the lower estuary and the supratidal sandspit at the mouth. The following should be recorded:

- The number of birds of each species (at low tide)
- The number of people on the estuary at time of counting.
- Take note of any roosting aggregations.
- The state of the mouth and water levels.

The area covered must include the entire estuary and its floodplain, incorporating all habitats used by water-associated birds for feeding, breeding or roosting.

The upper boundary of the study area is the same as that for the overall study, i.e. the weir just above the road bridge. The seaward boundary should be taken as the high tide mark on the beach side of the berm and the point that the estuary meets the sea.

Any major bird roost site in close proximity to the estuary should be counted and mapped.

### *9.7.2 Baseline data*

Birds should be counted every month for one year.

### *9.7.3 Long-term monitoring*

Conduct a summer and a winter count of all the waterbirds on the estuary every year. Because of the low numbers and high variability, more counts would be better.

**Notes:**

The summer count should take place in February or preferably March, but not later. Counts earlier than February would might be compromised in quality by the presence of summer holiday-makers. Human disturbance on estuaries is known to have a significant impact on bird numbers.

Because of the small number of birds and easy access for counting (which can be done on foot), if is recommended that this be carried out or co-ordinated by Cape Nature as part of their normal monitoring and patrols, possibly with the help of a local resident amateur birdwatcher. These data could be submitted to the Animal Demography Unit's Coordinated Waterbird Counts (CWAC) programme. The data should nevertheless be housed with a local committee and made freely accessible to specialists working on the conservation of the area.

# 10 LONG-TERM MONITORING DECISION SUPPORT SYSTEM (DSS)

The proposed Monitoring Decision Support System (MDSS) to be applied in the long-term monitoring of estuaries, as part of the RDM process, is illustrated in Figure 10.1. It is assumed that the baseline requirements for aiotic (drivers) and biological components have been specified in terms of their relation to the Recommended Ecological Category (REC), in this case a Category C+.

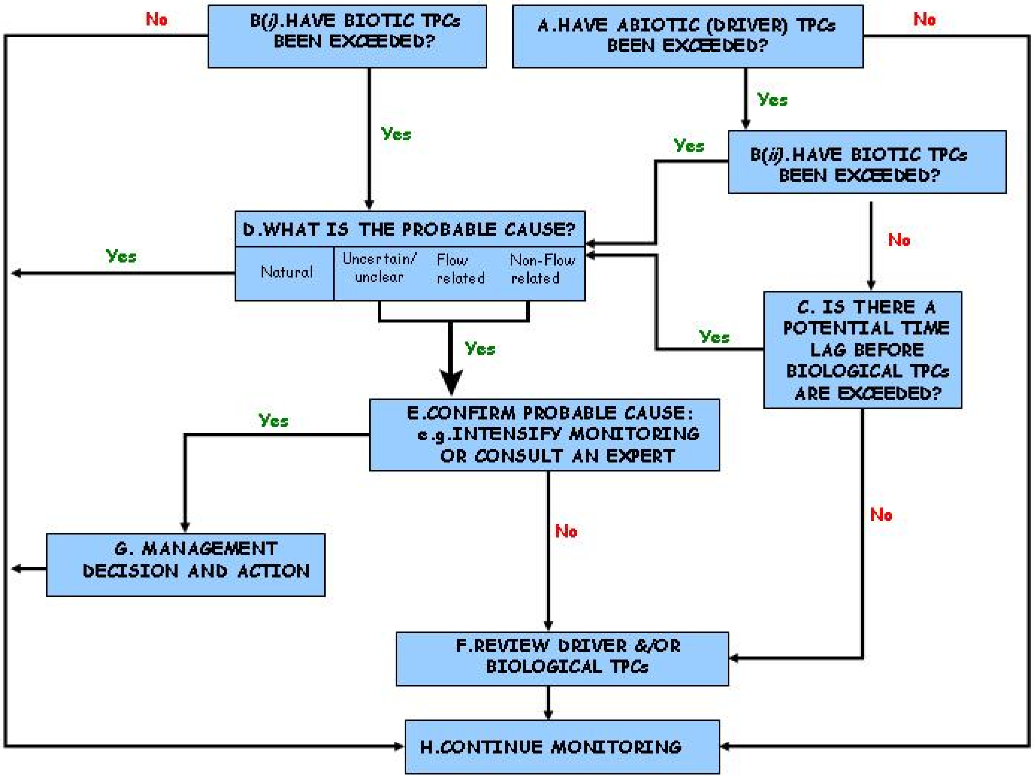



**Figure 10.1 Proposed Monitoring Decision Support System (MDSS) to be applied in the long-term monitoring of estuaries**

# 11 REFERENCES

Barnes, K.N. 2000. The Eskom Red Data Book of birds of South Africa, Lesotho and Swaziland.

Bennett, B.A. 1981 – Ecology of the fish in the Palmiet River Estuary. Report to the Department of Environmental Planning and Energy

Bennett, B.A. 1989a – A comparison of the fish communities in nearby permanently open, seasonally open and normally closed estuaries in the south-western Cape, South Africa. S. Afr. J. mar. Sci. 8: 43 –55.

Bennett, B.A. 1989b – The diets of fish in three south-western Cape estuarine systems. S. Afr. J. Zool. 24(3): 163-177.

Branch, G.M. and Day, J.A. 1984. Ecology of southern African estuaries: Part XIII. The Palmiet River estuary in the south-western Cape. *S. Afr. J. Zool.* **19**(2): 64 - 77.

Clarke, B.C. 1989. Estuaries of the Cape: Part II. Synopses of available information on individual systems. Rep. No. 37 Palmiet (CSW 12). Heydorn A E F and Morant P D (Eds). Stellenbosch, *CSIR Research report* **436**.

CSIR 1980. Effect of the proposed Hangklip Dam on Palmiet River mouth. Stellenbosch, *CSIR report* **C/SEA 8048**. Stellenbosch.

CSIR 1988. Dynamics of the Palmiet River mouth. Stellenbosch, *CSIR Report* **EMA/T 8802**. Stellenbosch.

CSIR 1992. The freshwater requirements of the Palmiet Estuary - A first assessment. Contract report submitted to Ninham Shand Consulting Engineers. *CSIR Report* **EMAS-C 92019**. Stellenbosch.

CSIR 2000. Palmiet River water resource management plan. Summary Report: Requirements of the estuary. CSIR Report ENV-S-C 2000-48. Stellenbosch.

Department of Water Affairs and Forestry (DWAF) 2004. Water resource protection and assessment policy implementation process. Resource directed measures for protection of water resources: Methodology for the Determination of the Ecological Water Requirements for Estuaries. Version 2. Pretoria.

Dollar, E.S.J., Brown, C.A., Turpie, J.K., Joubert, A.R., Nicolson, C.R. and Manyaka, S. (2006) The development of the Water Resource Classification System (WRCS). Volume 1. Overview and 7-step classification procedure. CSIR Report No., Department of Water Affairs and Forestry, Pretoria, 70pp.

DWA 1995. South African water quality guidelines for coastal marine waters. Volume 1: Natural Environment. Pretoria.

Heydorn and Morant (eds) (1989) Estuaries of the Cape: Part II. Synopses of available information on individual systems. Rep. No. 37 Palmiet (CSW 12). Stellenbosch, *CSIR Research report* **436**.

Huizinga, P. and Smith, C.J. 1987. Computation of flow through the Palmiet Estuary mouth. *CSIR Report* **T/Sea 8706**. Stellenbosch.

Largier, J.H. and Taljaard, S. 1991. The dynamics of tidal intrusion, retention and removal of seawater in a bar-built estuary. *Estuarine, Coastal and Shelf Science* **33**: 325-338.

Largier, J.L. 1986. Structure and mixing in the Palmiet Estuary, South Africa. *S. Afr. J. mar. Sci.* **4**: 139-152.

Largier, J.L., Slinger, J.H. and Taljaard, S. 1992. The stratified hydrodynamics of the Palmiet - a prototypical bar-built estuary. In: *Dynamics and exchanges in estuaries and the coastal zone*. Prandle, D. (Ed.) Coastal and Estuarine Studies 40. New York, Springer and Verlag. pp. 135-153.

Morant, P.D. 1984. Estuaries of the Cape Part II: Synopsis of available information on individual systems (A.E.F. Heydorn and J.R. Grindley Eds.). Report No. 26: Olifants. *CSIR Research Report* **425**. Stellenbosch.

Slinger, J.H. and Largier, J.L. 1990. The evolution of thermohaline structure in a closed estuary. *Sth. Afr. J. Aquat. Sci.* **16**(1/2): 60-77.

Taljaard, S. 1987. Nutrient circulation in the Palmiet River Estuary: A summer study. *CSIR Research Report* **633**. Stellenbosch. 113 pp.

Taljaard, S. and Largier, J.L. 1989. Water circulation and nutrient distribution in he Palmiet River Estuary: A winter study. *CSIR Research Report* **680**. Stellenbosch. 38 pp.

Taljaard, S. Eagle, G.A.and Hennig, H.F.-K.O. 1986. The Palmiet Estuary: A model for water circulation using salinity and temperature measurements over a tidal cycle. *Water SA* **12**(3): 119-126.

Taljaard, S., Van Niekerk, L., Huizinga, P., Joubert, W. 2003. Resource Monitoring Procedures for Estuaries for Application in the Ecological Reserve Determination and Implementation Process. CSIR Report ENV-S-C 2003-059.

Turpie, J.K. 1995. Prioritising South African estuaries for conservation: a practical example using waterbirds. *Biological Conservation* **74**: 175-185.

Turpie, J.K. 1998. Potential impacts of altered river flows on the birds of the Palmiet River estuary. Unpublished report to CSIR Environmentek.

Turpie, J.K. and Clark, B.M. 2007. The health status, conservation importance, and economic value of temperate South African estuaries and development of a regional conservation plan. Report to CapeNature.

Underhill, L.G. and Cooper, J. 1984. *Counts of waterbirds in southern African coastal wetlands.* Unpublished computer printout. Western Cape Wader Study Group and Percy FitzPatrick Institute of African Ornithology, University of Cape Town. 252pp.

Van Ballegooyen R., Taljaard S., van Niekerk L. and Huizinga P. (2004). Using 3D modelling to predict physico-chemical responses to variation in river inflow in smaller, stratified estuaries typical of South Africa. *Journal of Hydraulic Research* Vol. 42, No. 6, pp. 563–577.

Van Niekerk, L & Taljaard, S. 2007. Proposed generic framework for Estuarine Management Plans. Report submitted to C.A.P.E. Estuaries Programme.

Whitfield, A.K. 1994 - An estuary-association classification for the fishes of southern Africa. *S. Afr. J. Sci*. 90: 411-417.

# APPENDIX A: SUMMARY OF DATA AVAILABLE FOR THE RDM INVESTIGATIONS UNDERTAKEN DURING 2007 AND 2008

## A1. ABIOTIC COMPONENTS

| Data Required | Current Status |
|---|---|
| Simulated monthly runoff data (at the head of the estuary) for Present State, Reference Conditions and the selected future runoff scenarios over a 50 to 70 year period. | Provided for 77-year period by Auercon Consulting Engineers (low confidence in runoff data). |
| Simulated flood hydrographs for Present State, Reference Conditions and future runoff scenarios:<br>• 1:1 1:2 1:5 floods (influencing aspects such as floodplain inundation);<br>• 1:20 1:50 1:100 1:200 year floods (influencing sediment dynamics). | No new hydrographs were available. |
| Series of sediment core samples for the analysis of particle size distribution (PSD) and origin (i.e. using microscopic observations) taken every five years along the length of an estuary (200 m intervals). | No data |
| Series of cross-section profiles (collected at about 50 to 100 m intervals) taken every five years to monitor the sediment deposition rate in an estuary. | Last survey used in this study was 1999. |
| Set of cross-section profiles and a set of sediment grab samples for analysis of particle size distribution (PSD) and origin (i.e. using microscopic observations) need to be taken immediately after a major flood. | No data |
| Aerial photographs of estuary (earliest available year as well as most recent). | Historical photos available. |
| Measured river inflow data (gauging stations) at the head of the estuary over a five - 15 year period. | Continuous river inflow measured at DWA Station G4H007 at the Welgemoed (weir) just upstream of estuary |
| Continuous water level recordings near mouth of the estuary. | Data records available from DWA water level recorder G4R009-A01 near the mouth. |
| Water level recordings at about five locations along the length of the estuary over a spring and a neap tidal cycle (i.e. at least a 14 day period). | None. |
| Longitudinal salinity and temperature profiles (*in situ*) collected over a spring and neap tide during high and low tide at:<br>• end of low flow season (i.e. period of maximum seawater intrusion);<br>• peak of high flow season (i.e. period of maximum flushing by river water). | Dec 1979 (Branch and Day 1984) ; Feb 1985 (Taljaard et al 1986 ; Taljaard 1987) ; Aug 2006 (Taljaard and Largier 1989); Jan, Feb, Mar April 1998 (CSIR 2000) |
| Water quality measurements (i.e. system variables, and nutrients) taken along the length of the estuary (surface and bottom samples) on a spring and neap high tide at:<br>• end of low flow season;<br>• peak of high flow season. | Dec 1979 (Branch and Day 1984) ; Feb 1985 (Taljaard et al 1986 ; Taljaard 1987) ; Aug 1986 (Taljaard and Largier 1989); Jan, Feb, Mar April 1998 (CSIR 2000) |
| Diurnal time series data of the oxygen concentration in the estuary at three stations along the system during the periods that the fish and invertebrates are samples. | No data |
| Measurements of organic content and toxic substances (e.g. trace metals and hydrocarbons) in sediments along length of the estuary. | Station G4H007Q01 at the weir just upstream of estuary |
| Water quality (e.g. system variables, nutrients and toxic substances) measurements on river water entering at the head of the estuary. | Available data (DWAF 1995) |
| Water quality (e.g. system variables, nutrients and toxic substances) measurements on near-shore seawater. | Dec 1979 (Branch and Day 1984) ; Feb 1985 (Taljaard et al 1986 ; Taljaard 1987) ; Aug 2006 (Taljaard and Largier 1989); Jan, Feb, Mar April 1998 (CSIR 2000) |

## A2. BIOTIC COMPONENTS

| Micro Algae – Data Required For Comprehensive Level | Current Status |
|---|---|
| Phytoplankton: Chlorophyll-*a* measurements taken at the surface, 0.5 m and 1 m depths. Cell counts of dominant phytoplankton groups, i.e. flagellates, dinoflagellates, diatoms and blue-green algae.<br>Measurements must be taken coinciding with typically high and low flow conditions. | Branch and Day 1984;<br>Adams and Bate (unpub. data). |
| Benthic microalgae: Intertidal and subtidal benthic chlorophyll-*a* measurements.<br>Epipelic diatoms need to be collected for identification.<br>These measurements must to be taken coinciding with a typical high and low flow condition. | |

| Macrophytes - Data Required For Comprehensive Level | Current Status |
|---|---|
| Aerial photographs of the estuary (ideally 1: 5000 scale) reflecting the present state, as well as the reference condition (if available). Available orthophotographs. | Some collected by DEAT. |
| Number of plant community types, identification and total number of macrophyte species, number of rare or endangered species or those with limited populations documented during a field visit. | Branch and Day 1984 |
| Permanent transects:<br>- Measurements of percentage plant cover along an elevation gradient.<br>- Measurements of salinity, water level, sediment moisture content and turbidity. | None. |

| Invertebrates- Data Required For Comprehensive Level | Current Status |
|---|---|
| Collect a set of six benthic samples each consisting of five grabs. Collect two each from sand, mud and interface substrates. If possible, spread sites for each between upper and lower reaches of the estuary. One mud sample should be in an organically rich area. Species should be identified to the lowest taxon possible and densities (animals/$m^2$) must also be determined. Seasonal (i.e. quarterly) data sets for at least one year are required, preferably collected at spring tides. | Only available data collected in the early 1980's (Branch and Day 1984) and rapid, follow up check by Bickerton in 1998. |
| Collect two sets of beam trawl samples (i.e. mud and sand). Lay two sets of five, baited prawn/crab traps overnight, one each in the upper and lower reaches of the estuary. Species should be identified to the lowest taxon possible and densities (animals/$m^2$) must also be determined. Survey as much shoreline as possible for signs of crabs and prawns and record observations. Seasonal (i.e. quarterly) data sets for at least one year are required, preferably collected at spring tides. | |
| Collect three zooplankton samples, at night, one each from the upper, middle and lower reaches of the estuary. Seasonal (i.e. quarterly) data sets for at least one year are required, preferably collected at spring tides. | |

| Fish - Data Required For Comprehensive Level | Current Status |
|---|---|
| Sampling should be representative of small fish (seine nets) and large fish (gill nets). Sampling should be done in all four seasons for the full extent of the system (as far as tidal variation) to allow for predictive capabilities.<br>In a larger estuary (>5 km) sampling can either be at fixed intervals (every 2 km) or have the upper, middle and lower reaches subdivided into at least a further three sections each. The samples should be representative of the different estuarine habitat types, e.g. *Zostera* beds, prawn beds, sand flats. At least one of the sample sets should be in the 0 - 1 ppt. reach of the system. | Bennett, B.A. 1981. Ecology of the fish in the Palmiet River Estuary. Report to the Department of Environmental Planning and Energy.<br>Bennett BA (1989a) A comparison of the fish communities in nearby permanently open, seasonally open and normally closed estuaries in the south-western Cape, South Africas *Afr. J Mar Sci.* **8**:43–55<br>Bennett BA (1989b) The diets of fish in three south-western Cape estuarine systems. *S. Afr. J. Zool*. **24**(3): 163-177.<br>Branch, G.M. and J.A. Day 1984 – Ecology of southern African estuaries: Part XIII. The Palmiet River Estuary in the south-western Cape. *S. Afr. J. Zool*. **19**(2):64-67.<br>Clarke, B.C. 1989 - Estuaries of the Cape Part II: Synopses of available information on individual systems (A.E.F Heydorn and P.D. Morant, Eds.). Report No. 37: *Palmiet. (CSW 12) CSIR Research Report* 436: 82 pp.<br>Harrison TD (1999a) A preliminary survey of the estuaries on the south-west coast of South Africa, Cape Hangklip-Cape Agulhas, with particular reference to the fish fauna. *Trans Roy Soc S Afr* **54**:257–283.<br><br>Limited sampling 1997/1998 Lamberth unpublished. |

| Birds - Data Required For Comprehensive Level | Current Status |
|---|---|
| Undertake one full count of all water associated birds, covering as much of the estuarine area as possible. All birds should be identified to species level and the total number of each counted.<br>Monthly data sets for at least one year are required. If this is not possible, a minimum of four summer months and one winter month will be required (decisions on the extent of effort required will depend largely on the size of the estuary, extent of shallows present, as well as extent of tidally exposed areas). | Summer counts available for 1981 and 1997. |

## APPENDIX B: Summary of baseline data requirements and the long-term monitoring programme

Summaries of the Baseline Data Requirements and the Long-Term Monitoring Programme are included in Tables B1 and B.2 respectively. These take the earlier described details into account and also include the specific actions and associated human resources to obtain such data.

The activities have been prioritised in the tables, using colour coding, as follows:

| | |
|---|---|
| (orange) | High priority, considered as a minimum requirement for a suitable baseline data set (blue indicates data sets linked to the closed state, a condition that was supposed to be sampled as part of the Intermediate RDM study, but which has not occurred). |
| (yellow) | Medium Priority, will improve the confidence of the baseline, and should be added if funding is available. |
| (white) | Low priority, will further improve the confidence of the baseline, but is not considered to be a critical factor in the case of the Palmiet Estuary. |

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

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

## Table B.1 Summary of data requirements to set a baseline for long-term monitoring in the Palmiet Estuary

| Ecological Component | Monitoring Action | Temporal Scale (Frequency and When) | Spatial Scale (No. of Stations) |
|---|---|---|---|
| Water Quality | Toxic substances (herbicides/pesticides) in river inflow | Monthly over a wet and dry season | DWA Station G4H007 |
| | Organic nutrients (C, N and P) (dissolved and particulate) in river inflow | Monthly for one year | DWA Station G4H007 |
| | Organic nutrients (C, N and P) flux across the estuary-sea boundary | Intensive survey during marine dominated state (State 3) | Mouth of estuary |
| | Accumulation of benthic organic nutrients (C, N and P) in estuary | Once-off intensive survey during closed/semi-closed states | Entire estuary, focussing on depositional areas. |
| | Accumulation of toxic substances (e.g. selected pesticides/herbicides) in sediments (if contamination in river inflow is significant) | Once-off intensive survey during closed/semi-closed states | Entire estuary, focussing on depositional areas. |
| Hydrodynamic | Continuous water level recordings. | Continuous. | At Station G4R009 near mouth. Already undertaken by DWA. |
| | Accurate flow gauging of river inflow to estuary. | Continuous. | At Station G4H007, weir just upstream of estuary. Already undertaken by DWA. |
| | Aerial photographs of estuary (photographed at spring low tide) at 1:2000 scale. | Every five years. | Entire estuary. |
| | Near-shore wave data records (only if available). | | |
| Sediment dynamics | Bathymetric survey: series of cross-sections and a longitudinal profile collected at about 300m intervals, but in some locations a previous survey. More detailed at the mouth. Vertical accuracy should be better than 2 cm. | Five years, with an additional three surveys (every two months) after a major flood event to establish the rate of deposition in the system | Entire estuary. |
| | Set of sediment grab samples at cross-sections for grading analysis. | Once off. | Entire estuary. |
| | Set of core samples (2.0 m) save at cross-sections for grading analysis, age and origin (Isotope analysis). | Once off. | Entire estuary say every 1.0 km. |
| | Sampling of suspended sediment (and organic matter) required to quantify actual sediment and organic yield and variability. | Weekly, but daily during floods, for at least five years. | Upstream of estuary. |
| Macrophytes | Two field visits to update the GIS vegetation map by identifying the distribution of the different plant community types and species. However this would not capture the dynamics of the submerged macrophytes or macroalgal that would need to be monitored on at least a monthly basis. | At least once during an open and closed mouth condition. | Entire estuary. |

| Ecological Component | Monitoring Action | Temporal Scale (Frequency and When) | Spatial Scale (No. of Stations) |
|---|---|---|---|
| Microalgae | Phytoplankton and Benthic microalgae: sample for biomass and species composition during an open and closed mouth condition to establish baseline conditions. For phytoplankton chlorophyll *a* measurements taken at the surface, 0.5 m and 1 m depths. Cell counts of dominant phytoplankton groups, i.e. flagellates, dinoflagellates, diatoms, chlorophytes and blue-green algae completed for the different sites. For benthic microalgae measure intertidal and subtidal benthic chlorophyll *a* and epipelic diatoms need to be collected for identification. | At least once during an open and closed mouth condition. | Five stations along the length of the estuary. |
| Invertebrates | Collect quantitative samples for zooplankton after dark. Zooplankton samples to be collected at mid-water level where possible. Chlorophyll-*a* data must be collected at all sites and on all sampling occasions. | Samples to be collected in the dry and wet season over two years. Times should be selected to maximise low and high flow conditions. | Collections at five sites. |
| | Subtidal benthic samples to be collected using a grab sampler and sieved through 500 micron aperture mesh. | Samples to be collected in the dry and wet season over two years. Times should be selected to maximise low and high flow conditions. | Collections at five sites that correspond to the zooplankton stations. |
| | Setting of prawn and crab traps. | Samples to be collected in the dry and wet season over two years. Times should be selected to maximise low and high flow conditions. | Collections to be done in the uppermost part and in the lower reaches. |
| **Fish** | Conduct fish surveys using both seine and gill nets as primary gear. | Quarterly over one year, covering all four seasons and representative of temperature and average river inflow of that season. Both open and closed mouth phases need to be monitored in a particular year, with particular emphasis on juvenile marine fish recruitment. | Entire estuary (6). |
| **Birds** | Waterbird counts for the whole estuary. | Monthly counts over a period of one year and counting at low tide when open. A high level of replication is justified by the variability of the system, and the ease with which it can be counted. | Entire estuary (divided into three sections). |

## Table B.2 Long-term monitoring programme proposed for the Palmiet Estuary

| Ecological component | Monitoring action | Related TPC | Temporal scale (frequency and timing) | Spatial scale (no. of stations) | Human Resources (as days/year) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Sampling | | Analysis | | Reporting | |
| | | | | | Scientist | Tech | Scientist | Tech | Scientist | Tech |
| Water Quality | Conductivity, temperature, suspended matter, dissolved oxygen, pH, inorganic nutrients and organic content in river inflow. | WQ3 | At least monthly | At Station K2H002Q01, weir just upstream of estuary | Already included in DWA's water quality monitoring programme. | | | | | |
| | Longitudinal salinity and temperature profiles (*in situ*) | WQ1 WQ2 | Measured when biotic surveys require information for interpretation, alternatively every three years | Entire estuary (5 stations) | - | 2 | - | - | 1 | - |
| | Water quality measurements along length of estuary (surface and bottom samples) for pH, dissolved oxygen, suspended solids/turbidity/Secchi, inorganic nutrients and particulate organic nutrients. | WQ4 to WQ9 | Measured when biotic surveys require information for interpretation, alternatively every three years | Entire estuary, plus sampling points in river and sea (7 stations). | See related biotic components - samples can be collected as part of biotic survey. | | *In situ* measurements. Accredited analytical laboratory. | | 1 | - |
| | Survey on benthic organic nutrients and toxic substances accumulation (e.g. selected pesticides). | WQ10 to WQ11 | Every six years, if deemed necessary in future | Focus on depositional areas | - | 2 | Depend on parameters selected. Accredited analytical laboratory. | | 1 | - |
| Hydrodynamics | Water level recordings. | H1 to H4 | Continuous | At causeway near mouth. | Included in DWA national monitoring programme. | | | | 1 | - |
| | Flow gauging. | H1 to H4 | Continuous | One station at position representative of inflows to estuary. | Include in DWA national monitoring programme. | | | | 1 | - |
| | Aerial photographs of estuary (spring low tide). | H1 to H4 | Five years | Entire estuary | Should be recommended for inclusion in DEAT national coastal survey programme. | | | | 1 | - |
| Sediment | Bathymetric survey: series of cross-section profiles and a longitudinal profile collected at fixed 300 m intervals, but more detailed in the mouth (vertical accuracy better than 2 cm). | S1 - S3 | Five years | Entire estuary | 1 | | | | 4 | |
| | Set sediment grab samples (at cross section profiles) for analysis of particle size distribution (PSD) and origin (i.e. using microscopic observations. | S4 – S6 | Five years | Entire estuary | | | | | 1 | |

| Ecological component | Monitoring action | Related TPC | Temporal scale (frequency and timing) | Spatial scale (no. of stations) | Human Resources (as days/year) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Sampling | | Analysis | | Reporting | |
| | | | | | Scientist | Tech | Scientist | Tech | Scientist | Tech |
| | Suspended sediment and organic matter. | | Weekly, but daily during floods | Upstream of estuary | | | | | 10 | |
| Phytoplankton | Phytoplankton biomass (chlorophyll *a*) measurements taken at the surface, 0.5 m and 1.0 m depths. Cell counts of dominant phytoplankton groups, i.e. flagellates, dinoflagellates, diatoms, chlorophytes and blue-green algae. Measurements for the open and closed mouth condition. | A1 and A2 | One year after reserve implementation thereafter every three years | Five stations | 2 | | | | 2 | 3 |
| Benthic microalgae | Benthic microalgae biomass (intertidal and subtidal benthic chlorophyll *a*) measurements. Epipelic diatoms need to be collected for identification. Measurements for the open and closed mouth condition. | A3 and 4 | One year after reserve implementation thereafter every three years | Five stations | 2 | | | | 2 | 3 |
| Maccrophytes | Use aerial photographs to quantify area covered by different plant community types and produce a vegetation map for the open mouth condition. Conduct field surveys during the closed and open mouth condition to document the species composition and area covered by the different plant community types. Measure salt marsh and macroalgal (isubmerged macrophyte if present) percentage cover in 1.0 $m^2$ quadrats along three permanent transects (one for saltmarsh/macroalgae and two macroalgae transects. Sample for macroalgal biomass in the lower reaches of the estuary. Measure sediment characteristics, depth to groundwater and groundwater salinity along the salt marsh transects. | M1– M5 | One year after reserve implementation thereafter every three years. | Entire estuary | 2 | | | | 2 | 3 |
| Invertebrates | Collect quantitative samples for zooplankton after dark. Zooplankton samples to be collected at near-surface and mid-water level, depending on water depth. Chlorophyll-*a* data must be collected at all sites and on all sampling occasions. High priority. | I1 and I2 | Samples to be collected twice a year. Times should be selected to maximise low and high flow conditions. | All five or six sampling sites | 2 | | | | 4 | - |

| Ecological component | Monitoring action | Related TPC | Temporal scale (frequency and timing) | Spatial scale (no. of stations) | Human Resources (as days/year) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Sampling | | Analysis | | Reporting | |
| | | | | | Scientist | Tech | Scientist | Tech | Scientist | Tech |
| | Subtidal benthic samples to be collected using a grab sampler and sieved through 500 micron aperture mesh. High priority. | I1 and I2 | Samples to be collected twice a year. Times should be selected to maximise low and high flow conditions. | All five sampling sites. | 2 | | | | 4 | - |
| | Hole counts to establish sand prawn densities. A representative sample of the population to establish size class distribution. High priority. | | Once a year at the end of summer after the dry season. | At sites in the middle and lower estuary. | 2 | | | | 2 | - |
| | Collect shrimps and prawns that are non-burrowers | I1 and I2 | Samples to be collected twice a year. Times should be selected to maximise low and high flow conditions. | In uppermost section of the estuary, abd in the lower reaches. | 2 | | | | 2 | - |
| Fish | Conduct fish surveys using both seine and gill nets as primary gear. | F1 - 4 | Two years after implementation conduct a closed/semi-closed and open phase survey, followed by two surveys every three years thereafter. | Entire estuary (6 stations) | 2 | | | | 3 | 1 |
| Birds | Bi-annual bird counts of the estuary. | B1 and 2 | Mid-summer and mid-winter. | Whole estuary | 1 | | | | 0 | 1 |