# HYDRODYNAMICS OF TEMPORARY OPEN ESTUARIES, WITH CASE STUDIES OF MHLANGA AND MDLOTI

**By: Ingrid Zietsman**

Submitted in fulfilment of the requirements for the degree of
Master of Science in Engineering
in the
Civil Engineering Programme
University of Kwa-Zulu Natal
All work for this thesis was completed at the former
University of Natal, Durban

Supervisor: Professor D. D. Stretch
Co-supervisor: Professor R. Perissinotto
Date of Submission: 5 January 2004

**Abstract**

Estuaries are unique coastal bodies of water where water derived from land meets the sea. In order to preserve estuaries and minimise the effects of human interference in these sensitive areas, an understanding of the hydrodynamics is essential. South Africa has 259 estuaries, of which approximately 70% are temporary open. The aim of the project was to provide data to analyse the effect of different flow scenarios on the frequency, timing and duration of mouth closure for temporary open estuaries. To achieve the project aim, two case studies were undertaken, namely Mhlanga and Mdloti Estuaries.

Achieving the terms of reference required monitoring of the mouth state, water level, flow rates and developing an understanding of breaching mechanisms. Observations of the mouth were used to monitor its state and initially photographs were used to monitor the water level within each estuary. During 2003 a continuous water level monitor was developed and placed in each estuary. Velocity readings were taken upstream of the estuaries at discrete time intervals and converted to flow rates using the velocity area method. A photographic survey of the berm at Mhlanga Estuary was used to observe the effect of beach processes on the mouth area. The survey observed the estuary as it shifted from closed through to open, then partially open and finally closed again, providing information on mouth mechanisms.

The continuous water level monitoring provides useful information for Mhlanga Estuary in terms of breaching patterns, tidal exchange when in the open state and an indication of the time scales involved in mechanisms which change the mouth state. Similar information for Mdloti Estuary was not available as the estuary did not breach since the installation of the water level monitors, however salinity profiles from 2002 provided qualitative information on the existence of a saline intrusion into the estuary.

The relationship between flow and mouth state is complex and relies on other influences such as water level and systems losses. In general estuaries will breach under high flows and remain closed under low flows, however in between these two regimes the estuary mouth state is less predictable based on flow alone. Mhlanga Estuary repeatedly breached at low tide. During the open phase tidal influence was both observed and captured by water level monitors despite the perched nature of the estuary. Closure generally occurred at high tide trapping saline water within the estuary. The two case studies provided a good basis for exploring the affects of different flow conditions on estuaries, with Mdloti Estuary experiencing the effects of the Hazelmere Dam and abstractions, while Mhlanga Estuary has increased flow due to the discharge of treated effluent to the system.

**Preface**

I, Ingrid Zietsman, hereby declare that the whole of this research is my own work and has not been submitted in part, or in whole to any other university. Where use has been made of the work of others, it has been duly acknowledged in the text. This research was carried out under the supervision of Professor D. D. Stretch, in the School of Civil Engineering, Survey and Construction, University of Kwa-Zulu Natal, Durban.

Zietsman — Signature

13 April 2004 — Date

As the candidates supervisor I have approved this dissertation for submission.

Prof. D. D. Stretch

13 April 2004 — Date

**Acknowledgements**

I would like to thank:

- Water Research Commission (WRC), the KZN Wildlife association, the CSIR and the University of Natal, Durban (UND) for making this project possible;
- Jeffares and Green inc. for their guidance and support;
- Professor D. D. Stretch for supervision and guidance;
- Professor R. Perissinotto and his team for their assistance and support;
- Rob van Zyl for his invaluable assistance developing the water level monitor;
- Mr P. Huizinga for sharing his wisdom and support;
- Mr C. Meyer (OPTRON) for his assistance with the GPS survey;
- David Mardon and Mark Griffith for accompanying me to the estuary and retrieving the water level monitors under less than favourable conditions;
- The UND Civil Engineering Laboratory Staff, in particular Logan, Craig and Sydney for their assistance;
- Last but not least, my family and Jon for their support and understanding.

## Table of Contents

**List of Figures**

**List of Tables**

**List of plates**

**Abbreviations**

CSIR – Council for Scientific and Industrial Research
DWAF – Department of Water Affairs and Forestry
EMWS – eThekweni Municipality Water and Sanitation
FDC – Flow Duration Curve
KZN – KwaZulu Natal
LOICZ – Land Ocean Interactions in the Coastal Zone
MAE – Mean Annual Evaporation
MAP – Mean Annual Precipitation
MAR – Mean Annual Runoff
MAS – Mean Annual Streamflow
MSL – Mean Sea Level
PPDC – Provincial Planning and Development Commission
ppt – Parts per Thousand
RDM – Resource Directed Measures
TOC – Temporary Open/Closed
UND – University of Natal, Durban
UNP – University of Natal, Pietermaritzburg
UPE – University of Port Elizabeth
WWTW – Waste Water Treatment Works

# 1. INTRODUCTION

## 1.1. Introduction

The National Water Act (Act 36, 1998) was introduced in 1998 to ensure the sustainable management of resources to meet both the human and ecological requirements. These requirements place a large demand on the quality and quantity of South Africa's water resources. An estuary is important in terms of ecology as it is a unique environment of high biodiversity which serves as a nursery for juvenile fish. Humans require the estuarine environment for subsistence fishing, recreation and tourism. Therefore this research is aimed at obtaining an understanding of the hydrodynamics of the estuarine system, which is a driving force behind the functioning and sustainability of the estuary.

Barnhart and Barnhart (1992) define an estuary as the broad mouth of a river, into which tide flows. Temporary open estuaries function in this manner when in the open state. The closed state of the estuary results when the mouth is blocked by a sand bar, forming a lagoon in place of the estuary. This behaviour exhibited by estuaries such as Mhlanga and Mdloti is important as it creates a unique environment.

There are many different levels of detail concerning the role of hydrodynamics in an estuary. Schumann, Largier and Slinger (1999) provide an overview, including flow rates, water levels, tidal fluctuations, turbulence, stratification, etc. These hydrodynamic components determine the physio-chemical environment of an estuary. In temporary open estuaries the greatest impact on the estuarine system is caused by changes in mouth state. Therefore it is important to understand the driving forces behind mouth state and this was the primary focus of this research.

## 1.2. Motivation for the study

This research forms part of a project funded by the Water Research Commission (WRC) and was done in collaboration with KZN Wildlife, the CSIR and the University of PE. The focus for this part of the research was to obtain data on the affect of flow on the mouth state of temporary open estuaries, with case studies of the Mhlanga and Mdloti Estuaries. This research was conducted concurrently with research on the biotic components of the estuary (undertaken by UND, Biology), allowing for the possibility that the information could be integrated to help in predicting estuarine health and productivity. The information collected is required for the design and implementation of management procedures to protect both the human and biotic interest in estuaries.

## 1.3. Objectives of the study

The main objective of this study is to determine the effects of flow on mouth state. In order to achieve this objective several facets needed to be explored, such as the mechanisms involved in breaching and closure. Both Mhlanga and Mdloti Estuaries are perched, temporary open estuaries. Several key questions were raised about perched temporary open estuaries, in particular Mhlanga and Mdloti Estuaries, which needed to be answered:

1. Is there a definite relationship between flow and mouth state? i.e. Are specific flow regimes associated with specific mouth states?

2. Can rainfall be linked directly to mouth state?

3. What, if any, tidal influence exists during the open mouth state, given that the estuaries are perched above mean sea level (MSL)?

4. What are the mechanisms involved in breaching and closure of the mouth and what are the timescales?

All four questions are related to the influence of flow on the frequency and duration of mouth opening, which is a key aspect in the biological functioning of temporary open estuaries.

## 1.4. Outline of the dissertation

The remainder of this dissertation may be outlined as follows:

Chapter 2: BACKGROUND & LITERATURE REVIEW

This chapter provides a general understanding of estuarine characteristics, particularly those relating to perched, temporary open estuaries which was required as background for this research. Some of the hydrological characteristics are explored including the water balance, breaching mechanisms and closing mechanisms. Some biological information is introduced to establish the links between the physical dynamics and biotic responses. Chapter 2 also includes literature on the physical characteristics of estuaries as well as studies which include the effects of flow on mouth state. The studies reviewed include those conducted by the CSIR on the Mhlanga and Mdloti Estuaries based on the RDM process, with the study of the Great Brak providing an example of studies on flow and mouth state outside of the RDM process.

Chapter 3: CASE STUDIES

In this chapter Mhlanga and Mdloti Estuaries provide a basis to explore the effects of flow on mouth state in the field. Although they experience similar climatic conditions and share similar characteristics, in that they are both temporary open, and perched estuaries, they have different histories. The different forms of human impact on each estuary are explored in this chapter, particularly in terms of the affects on flow.

Chapter 4: FIELD WORK METHODOLOGY

Water levels, flow rates and mouth state are the three main aspects of the field monitoring program discussed in this chapter. This chapter provides a description of the techniques or approaches used to meet these requirements as well as giving an indication of the accuracy associated with the various techniques.

Chapter 5: DISCUSSION OF FIELDWORK

The main issue discussed in this chapter is the effect of flow on the mouth state. The flows are discussed under three regimes: low, intermediate and high. These regimes are defined in terms of the water balance, using the storage dependant losses from the system. As data on rainfall is generally more readily available than stream-flow data, analysis was done to determine whether there is a direct link between mouth state and rainfall.

Mouth state is an important feature of this research, therefore the breaching and closure mechanisms of the estuary are analysed. The timescales and mechanisms involved in the breaching and closure of the estuary are analysed using continuous water level data and observations.

Chapter 6: CONCLUSIONS

Finally conclusions concerning the key questions outlined in the objectives of this research are discussed.

# 2. BACKGROUND & LITERATURE REVIEW

## 2.1. Introduction

Estuaries are important as they provide nursery areas for marine fish which is essential for both industry and subsistence fishing. Estuaries are also important for tourism as the estuarine areas have high biodiversity and aesthetic appeal. The health and sustainability of estuarine systems is largely dependant on the driving forces within the system, namely hydrodynamics, sediment dynamics and biogeochemistry (Whitfield & Smith, 1999).

South Africa's coast is divided into three climatic regions, namely cool temperate along the west coast, warm temperate to the south and sub-tropical along the east coast. Whitfield (2000) reported that 4% of South Africa's 259 estuaries are found in the cool temperate region, 49% are found in the warm temperate region and the remaining 47% in the sub-tropical region. The southern coast of South Africa is less supportive of estuarine environments as it is dominated by rocky and aeolian type coastlines, (Reddering, 1988). Of the 259 estuaries in South Africa approximately 70% are temporary open (Whitfield, 2000). A temporary open estuary generally has a sand bar which forms across the mouth preventing free connection with the sea for portions of the year. Figure 2-1 shows the locations of the temporary open estuaries of South Africa. This plot was derived from a combination of sources (e.g. Whitfield, (2000) and a variety of maps of South Africa).

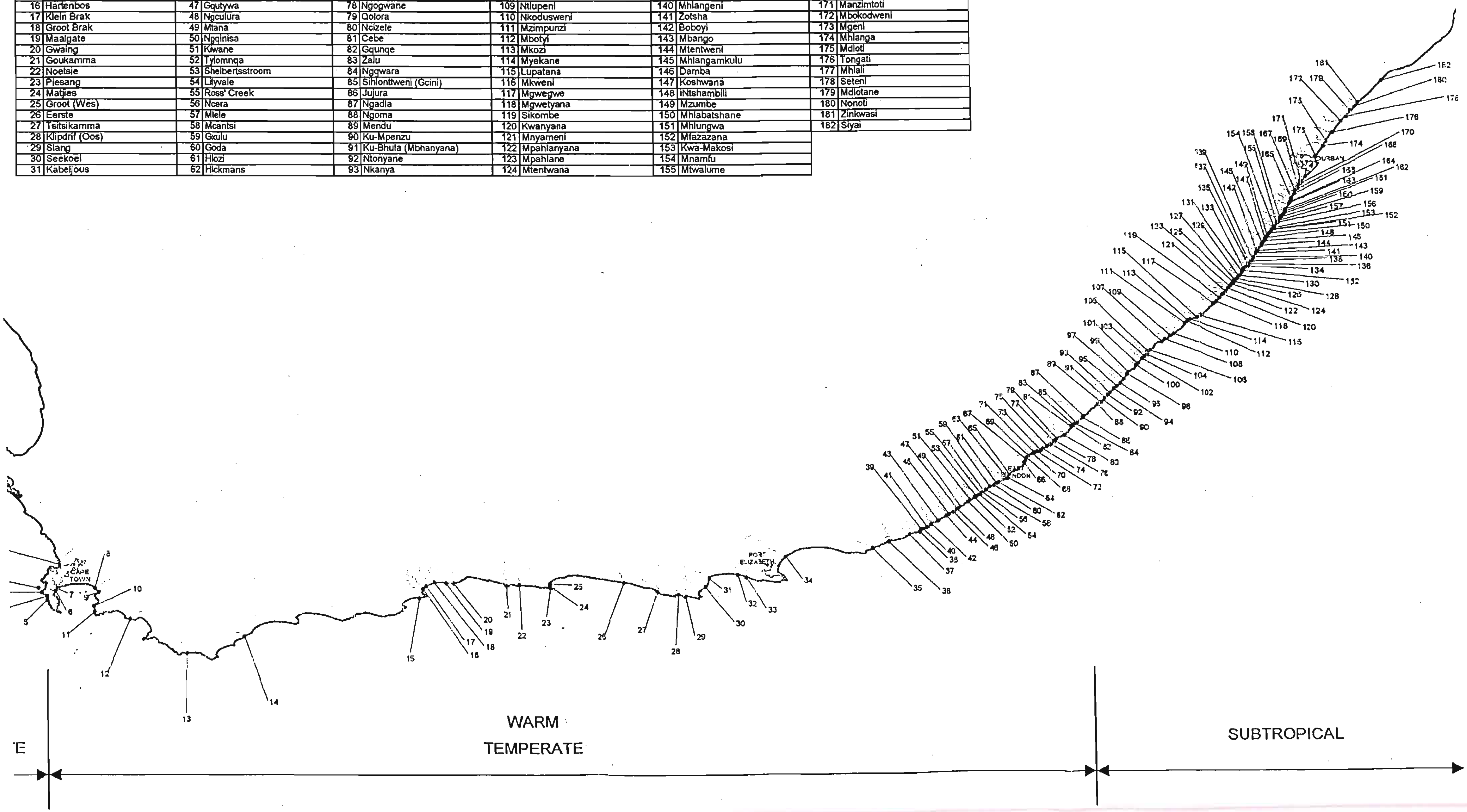
The main aim of this project was to obtain an understanding of the effects of flow on the mouth state of temporary open estuaries. To achieve this aim, both flow and mouth state need to be explored and understood. In order to understand the flow dynamics the water balance for the estuarine system needs to be explored. This can be found in 2.3.

The mouth dynamics of the estuary include breaching and closure mechanisms. The different mechanisms are explored in sections 2-5 and 2-6. Sections 2-7 through to 2-9 explore the dynamic coastal environment which affects the estuary.

However before discussing the hydrodynamic component of the project section 2.2 disscusses the importance of such a study in the biological context.

**Figure 2-1: Map of temporary open estuaries around South Africa.**

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Diep/RietVlei | 32 | van Stadens | 63 | Blind | 94 | Bulungula | 125 | Mtamvuna | 156 | Mvusi |
| 2 | Wildevoel | 33 | Maitland | 64 | Hlaze | 95 | Ku-Amanzimzama | 126 | Zolwane | 157 | Fafa |
| 3 | Bokramspruit | 34 | Coega (Ngcura) | 65 | Qinira | 96 | Mncwasa | 127 | Sandlundlu | 158 | Mdesingane |
| 4 | Schuster | 35 | Boknes | 66 | Bulura | 97 | Mpako | 128 | Ku-Boboyi | 159 | Sezela |
| 5 | Krom | 36 | Kasuka | 67 | Cunge | 98 | Nenga | 129 | Tongazi | 160 | Mkumbane |
| 6 | Silwermyn | 37 | Rufane | 68 | Cintsa | 99 | Mapuzi | 130 | Kandandlovu | 161 | Mzinto |
| 7 | Sand | 38 | Riet | 69 | Cefane | 100 | Lwandilana | 131 | Mpenjati | 162 | Mzimayi |
| 8 | Lourens | 39 | Wes-Kleinemond | 70 | Kwenxura | 101 | Lwandile | 132 | Umhlangankulu | 163 | Mpambanyoni |
| 9 | Sir Lowry's Pass | 40 | Oos-Kleinemond | 71 | Nyara | 102 | Hluleka | 133 | Kaba | 164 | Mahlongwa |
| 10 | Rooiels | 41 | Klein Palmiet | 72 | Haga-haga | 103 | Mnenu | 134 | Mbizana | 165 | Mahlongwana |
| 11 | Buffels (Oos) | 42 | Old Woman's | 73 | Mtendwe | 104 | Mtonga | 135 | Mvutshini | 166 | Ngane |
| 12 | Onrus | 43 | Mpekweni | 74 | Quko | 105 | Mpande | 136 | Bilanhlolo | 167 | uMgababa |
| 13 | Ratel | 44 | Mtati | 75 | Morgan | 106 | Sinangwana | 137 | Uvuzana | 168 | Msimbazi |
| 14 | Klipdrifsfontein | 45 | Mgwalana | 76 | Cwili | 107 | Bulolo | 138 | Kongweni | 169 | Lovu |
| 15 | Blinde | 46 | Bira | 77 | Gxara | 108 | Mtambane | 139 | Vungu | 170 | Little Manzimtoti |
| 16 | Hartenbos | 47 | Gqutywa | 78 | Ngogwane | 109 | Ntlupeni | 140 | Mhlangeni | 171 | Manzimtoti |
| 17 | Klein Brak | 48 | Ngculura | 79 | Qolora | 110 | Nkodusweni | 141 | Zotsha | 172 | Mbokodweni |
| 18 | Groot Brak | 49 | Mtana | 80 | Ncizele | 111 | Mzimpunzi | 142 | Boboyi | 173 | Mgeni |
| 19 | Maalgate | 50 | Ngqinisa | 81 | Cebe | 112 | Mbotyi | 143 | Mbango | 174 | Mhlanga |
| 20 | Gwaing | 51 | Kiwane | 82 | Gqunqe | 113 | Mkozi | 144 | Mtentweni | 175 | Mdloti |
| 21 | Goukamma | 52 | Tylomnqa | 83 | Zalu | 114 | Myekane | 145 | Mhlangamkulu | 176 | Tongati |
| 22 | Noetsie | 53 | Shelbertsstroom | 84 | Ngqwara | 115 | Lupatana | 146 | Damba | 177 | Mhlali |
| 23 | Piesang | 54 | Lilyvale | 85 | Sihlontlweni (Gcini) | 116 | Mkweni | 147 | Koshwana | 178 | Seteni |
| 24 | Matjies | 55 | Ross' Creek | 86 | Jujura | 117 | Mgwegwe | 148 | iNtshambili | 179 | Mdlotane |
| 25 | Groot (Wes) | 56 | Ncera | 87 | Ngadla | 118 | Mgwetyana | 149 | Mzumbe | 180 | Nonoti |
| 26 | Eerste | 57 | Mlele | 88 | Ngoma | 119 | Sikombe | 150 | Mhlabatshane | 181 | Zinkwasi |
| 27 | Tsitsikamma | 58 | Mcantsi | 89 | Mendu | 120 | Kwanyana | 151 | Mhlungwa | 182 | Siyai |
| 28 | Klipdrif (Oos) | 59 | Gxulu | 90 | Ku-Mpenzu | 121 | Mnyameni | 152 | Mfazazana | | |
| 29 | Slang | 60 | Goda | 91 | Ku-Bhula (Mbhanyana) | 122 | Mpahlanyana | 153 | Kwa-Makosi | | |
| 30 | Seekoei | 61 | Hlozi | 92 | Ntonyane | 123 | Mpahlane | 154 | Mnamfu | | |
| 31 | Kabeljous | 62 | Hickmans | 93 | Nkanya | 124 | Mtentwana | 155 | Mtwalume | | |



## 2.2. Biotic component

### 2.2.1. Biotic background

The following is a summary of the many different life forms such as invertebrates, fish, birds, other vertebrates and plants supported by the estuarine environment as reported by Breen & McKensie (2001).

Invertebrates include the benthic species, which consists of creatures like crown crabs and sand prawns that live on or in the sediment, and nektonic species, such as swimming prawns that are active throughout the water column. Small nekton known as zooplankton are barely visible to the naked eye. Invertebrates are important as they make energy and nutrients available for other creatures by processing living and dead plant material.

Estuaries function as nurseries for juvenile fish, supporting a variety of species some of which are more dependant on estuaries than others. A diversity of bird life may also be found around estuaries, for example waders, waterfowl, kingfishers, cormorants, gulls, terns, egrets, herons and fish eagles. Other vertebrates found in or around estuaries include otters and the water mongoose as well as hippopotamuses and crocodiles.

Plant life within South African estuaries is made up of six communities; microalgae (small algae), macroalgae (large algae), macrophytes or large submerged plants, reeds and sedges, salt marshes and mangroves. Large populations of microalgae give surfaces a green or brown tinge, and restrict light penetration when suspended in the water column. Phytoplankton microalgae in the water column provide an indication of the pollution and status of nutrients in the estuary. Macroalgae consists of two groups, filamentous or threadlike in appearance and thalloid or leafy in appearance.

Macrophytes have roots stems and leaves and grow in beds. These beds are important as they provide habitat for organisms such as fish. Salt marshes provide shelter for crabs and other invertebrates and are formed in flood plains and other areas of higher elevation in estuaries. Stems and roots of small shrubs and trees known as mangroves provide surface area for small organisms to use for colonization. They are also useful sources of energy and nutrients.

Reeds and sedges grow in fresh or slightly saline water. These plant species are important as they provide nutrients and energy within the estuary and because they supply materials which can be used in craftwork and construction.

Wetlands forming around estuaries are responsible for filtering and cleaning the water by removing sediments and pollutants, soaking up flood waters and dispersing surges as well as stabilizing the shoreline and preventing erosion.

### 2.2.2. Biological importance of hydrodynamics

To fully understand the importance of a study such as this the influence of hydrodynamics on the biotic components needs to be introduced. Mouth state directly or indirectly influences several abiotic factors within an estuary, such as salinity, light penetration, turbidity, nutrient concentrations and oxygenation. Mouth state is also directly linked to water level which in turn determines habitat availability. Under the closed state salinity begins to decrease as freshwater inflow persists. As the water level within the estuary rises the velocities decrease, leading to a clearer, less turbid water column with greater light penetration. Wind and fresh water flow into the estuary generally mixes oxygen into the surface waters, however after long periods of closure the oxygen levels in the bottom waters drops. The longer the residence time of the estuary the more sediment and nutrients accumulate as well as any pollution introduced into the river, such as heavy metals.

Under open mouth conditions, river and tidal driven mixing leads to the estuary becoming well oxygenated, however with the increased turbulence comes an increase in turbidity with reduced light penetration. Sometimes the marine influence can cause a decrease in turbidity. The estuary can become predominantly fresh under high flow conditions however as the flows subside saline intrusions increase.

All these abiotic factors either directly or indirectly impact the biotic component of the estuarine environment. These impacts on specific components in the food chain, are further explored in the rest of this section based on information obtained from CSIR (2002 & 2003).

**Microalgae**

A governing influence on the biomass, productivity and diversity of microalgae is the state of the mouth of the estuary. For instance, open mouth conditions generally result in an initial loss of microalgae, followed by the establishment of a diverse range of marine and fresh water species. The closed state, on the other hand, leads to less diversity with more abundance. Mouth dynamics determines the duration of open and closed conditions. Short closed periods do not provide favourable conditions for microalgae as nutrients are repeatedly flushed from the estuary, while long periods of closure result in higher productivity due to nutrient accumulation. Salinity also causes drastic changes within the community structures. In the case of zooplankton, decreases in salinity cause some species to disappear while increases in salinity cause them to reappear. Turbidity in the water column reduces the light availability which is necessary for photosynthesis. Microalgae are the primary producers in the food web, therefore any impacts on the microalgae population dynamics has an impact on the entire food chain.

**Macrophytes**

Macrophytes are not submerged therefore factors such as turbidity do not influence these communities. In contrast to microalgae, macrophytes are not significantly influenced by mouth state in the long term. However increased nutrient availability under closed conditions may result in higher productivity. Salinity intrusions into the estuary have little or no effect on macrophytes as these communities are generally tolerant of brackish conditions.

**Invertebrates**

The mouth state of the estuary has a major affect on the biomass, productivity and diversity of zooplankton, with a decrease in macrobenthos typically occurring during open, high flow conditions. Closed conditions are also responsible for the exclusion of inter-tidal organisms. Salinity can cause radical changes in the zooplankton community structure, while macrobenthos favours higher salinities for diversity and abundance. Eutrophication in estuaries, leading to oxygen depletion can be problematic particularly during sustained closed periods.

**Fish**

Some of the largest factors governing fish communities are abiotic. The mouth state of the estuary has a large impact on the fish community, with the open state mouth state allowing small fish to enter the estuary while the closed state allow the fish to grow in a sheltered environment. When the estuary reopens these fish return to the sea. The influences of mouth state, turbidity and salinity indirectly impact the fish communities through the food chain, starting with the primary producers. However should algal blooms result in oxygen depletion, the end result is fish kills.

**Birds**

As with the fish communities, the bird community is indirectly impacted by abiotic factors via the food chain. Some species however prefer specific conditions. For example waders prefer low water levels, occurring during the open mouth state, while diving fish feeders prefer higher water levels such as those under closed conditions.

## 2.3. Water Balance

According to Reddering (1988) estuaries exist where there is river discharge into the sea, tidal interaction and sediment availability. This only occurs during the open phase for temporary open estuaries. The water balance of temporary open estuaries during the closed phase is depicted schematically in figure 2-2.

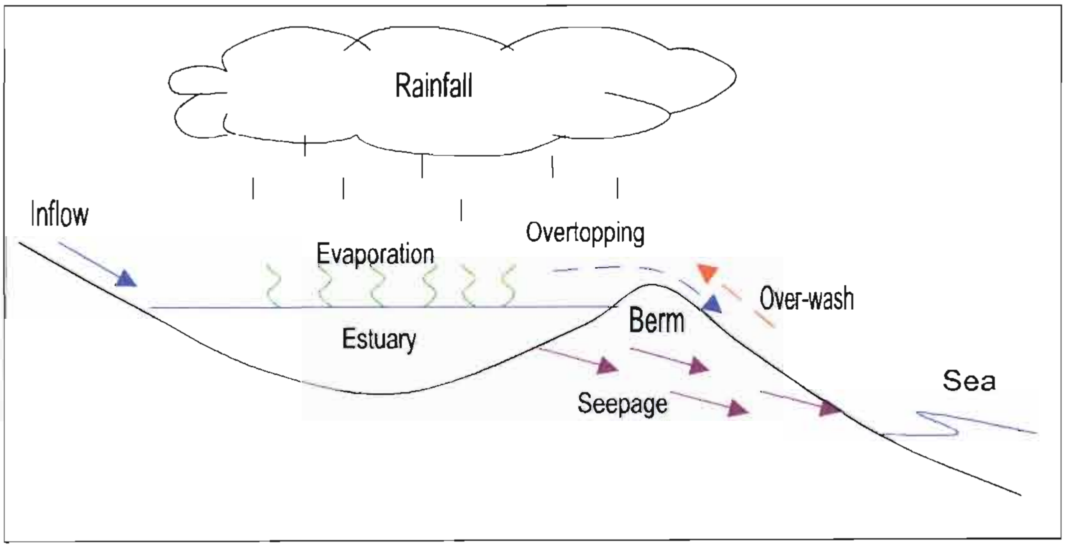



**Figure 2-2: The water balance.**

This concept is based on continuity and is not unique to estuarine systems, but can be applied to other water bodies and is also the basis of the Land Ocean Interactions in the Coastal Zone (LOICZ) water budget for estuaries (IGBP, 2001). The basic continuity equation is represented by:

$$\boxed{\frac{dS}{dt} = I - O}$$

Where change in storage (dS) over change in time (dt) is equal to the inputs (I) to the system less the outputs (O).

Inputs into the estuary can consist of a combination of the following:

- Inflow;
- Rainfall;
- Groundwater flow;
- Over-wash and
- Tidal influx.

The inflow refers to the stream-flow entering the head of the estuary. This inflow can be estimated by summing together the freshwater resulting from runoff within the catchment; discharges from waste water treatment works (WWTW), storm-water outfalls, etcetera; less the abstractions for irrigation and domestic use. The source of the waste water discharges and the destination of water abstractions do not necessarily lie within the same catchment area as the estuary. Other factors also influence inflow into an estuary; these include structures such as dams and changes in land-use.

Rainfall not only reaches the estuarine system via runoff which becomes stream-flow, but also enters the estuary directly. Groundwater flow from the area directly surrounding the estuary is also an input into the estuarine system.

Over-wash is defined here as the introduction of sea water into the estuary through overtopping of the berm under closed conditions. Over-washing generally occurs during spring high tides. When the estuary is open there is a tidal influx which introduces both saline water and marine sediment into the estuarine system.

The system outputs consist of a combination of:

- Evaporation;
- Seepage;
- Overtopping and
- Outflow.

Seepage is particularly significant for perched estuaries where the low water levels are above mean sea level (MSL) and where the estuary's sand berm is narrow.

Where the inputs (I) exceed the outputs (O) from the system for a sustained period of time the water level within the estuary rises until it exceeds the level of the berm, leading to overtopping and possibly breaching. Under open conditions water flows out of the estuary and has free connection with the sea. Perched estuaries tend to almost completely empty upon breaching. Other inflows/outflows affecting the system are tidal and only occur during the open phase.

In temporary open estuaries flow may be classified into three general regimes: high, intermediate and low. Under high flow and flood conditions the inflows into the estuary far exceed the outflows from the system leading to the estuary filling up rapidly and breaching. In this instance a residence time ($T_R$), or time the estuary takes to fill, can simply be defined as the storage capacity of the estuary (S) divided by the inputs (I) into the system. In this instance the outputs from the system can be ignored as the outputs are relatively small in comparison to the inputs.

$$\boxed{T_R = \frac{S}{I}}$$

Under intermediate conditions the outputs (O) from the system are of similar magnitude to the inputs to the system and therefore impact the residence time significantly. Under these conditions the water level rises until an equilibrium is reached at a high water level. The residence time under intermediate flow conditions is therefore defined by:

$$\boxed{T_R = \frac{S}{I - O}}$$

Under drought and low flow input conditions the outputs either equal or exceed the inputs to the system leading to low or reducing water levels within the estuary which remains closed until such time as the inputs to the system are increased.

## 2.4. Climate

The South African climate also plays a role in the functioning of an estuary. The monthly distributions of precipitation for KwaZulu Natal, Eastern Cape and Western Cape are represented in figure 2-3. KwaZulu Natal has the largest annual rainfall of the three provinces, with peak rainfall in January (summer). The Western Cape differs from the other two provinces as the peak rainfall occurs in winter, and the rainfall pattern is less variable.

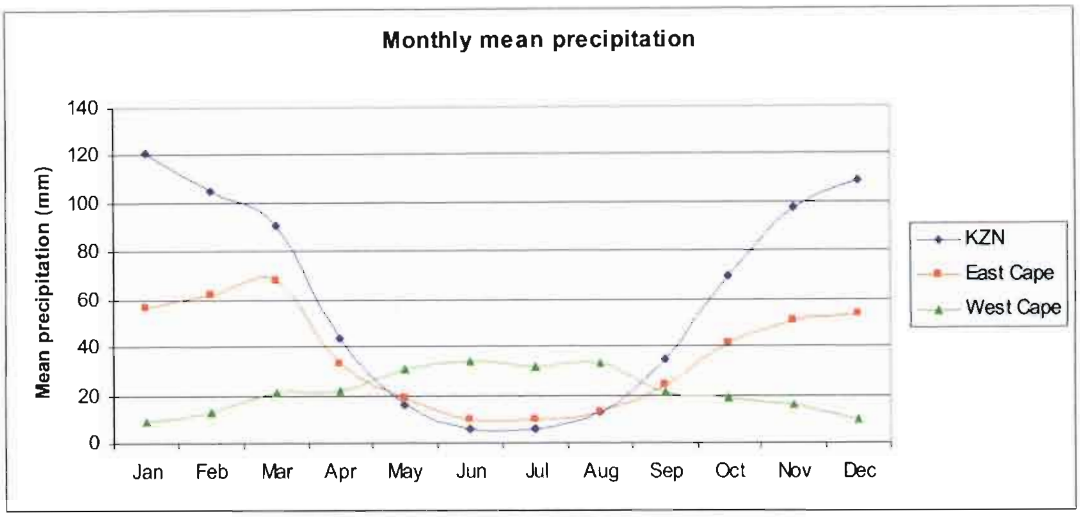



**Figure 2-3: Mean monthly precipitation for KwaZulu Natal, Eastern Cape and Western Cape based on data obtained from Schulze (1997).**

Schulze (1997) reports that runoff in South Africa is on average 9% of the precipitation, which is well below the world average of 35%. The province in South Africa with the highest runoff is KwaZulu Natal at 16.5% of the mean annual precipitation (MAP), yet this is still less than half the world average. South Africa is therefore a low runoff zone by world averages and this coupled with the high variability of the rainfall leads to competition for water with estuaries taking lower priority. The temporary open nature of a large portion of the estuaries found in South Africa can probably be attributed to the natural lack of water with humans imposing even greater strain on the estuarine water resources.

## 2.5. Mechanisms of breaching

The water level at which an estuary would normally breach naturally is important as this determines the storage capacity of the system and associated residence times, as well as determining the magnitude of sediment flushed from the estuary during breaching (Huizinga and van Niekerk, 2002). There are several mechanisms by which an estuary naturally breaches, including breaching due to seepage through the berm, overtopping with associated scour and wave action. Artificial breaching is also a factor which requires consideration.

### 2.5.1. Seepage through the berm:

The sand berm which forms the barrier between the estuary and the sea is porous, allowing for water to seep through the berm. Mhlanga and Mdloti Estuaries are both perched with a low water level of approximately 0,67m and 0,78m above MSL respectively, therefore it is expected that water will seep from the estuary to the sea. The berm is also relatively narrow in these examples.

Seepage through the berm is dependant on the hydraulic gradient (i) across the berm:

$$\boxed{i = \frac{\Delta h}{L}}$$

where Δh is the head difference and L represents the length of flow over which head difference occurs. See figure 2-4 for visual interpretation of this relationship.

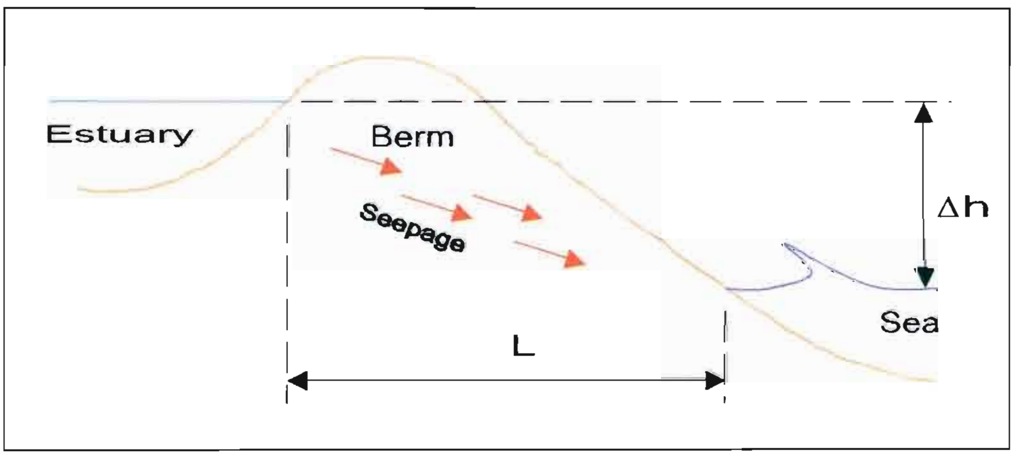



**Figure 2-4: Schematic diagram showing the seepage and variables used in determining the hydraulic gradient.**

As the hydraulic gradient increases the rate of seepage through the berm increases until the point is reached at which soil stability is lost. In order for the failure condition to occur and breaching to result, a critical hydraulic gradient must be reached. Therefore an increase in Δh or a decrease in L would aid in reaching the critical value.

Boiling or quicksand conditions are thought to have been observed at other estuaries. CSIR (1982) reported the occasional occurrence of quicksand at the Silwermine lagoon, with historical reports of a rider losing his horse in the quicksand.

The sea level is constantly changing between high and low tides, with a wider range of tidal fluctuation during a spring tide than during a neap tide. Although low spring tide provides the highest hydraulic gradient, this gradient is only sustained for a few hours. Neap tide, however provides a consistently lowered sea level providing a lower hydraulic head than at spring low. This hydraulic head, created during neap tide, is sustained over a period of days rather than hours. Breaching due to seepage failure may thus be expected to occur at neap tide, where the timescales required for seepage failure are greater than six hours. Impervious layers underlying the sand berm can aid seepage failure as the flow is constricted and thereby increased, leading to an increased rate of sand removal or piping.

A possible mechanism of breaching is that as seepage increases and sand is removed, through sand piping (eg. Gillette, 2003), from the lower end of the sea facing berm it causes the sea slope to slump reducing the width of the berm at this point. Figure 2-5 depicts this form of failure. Step 1 shows seepage through the berm, which increases with increasing water levels until such time as the seepage scours the base of the berm on the seaward side, as shown in step 2. This scour leads to the berm slumping and thereby allowing water from the estuary to overtop the berm and scour the remainder of the mouth, as shown in step 3.

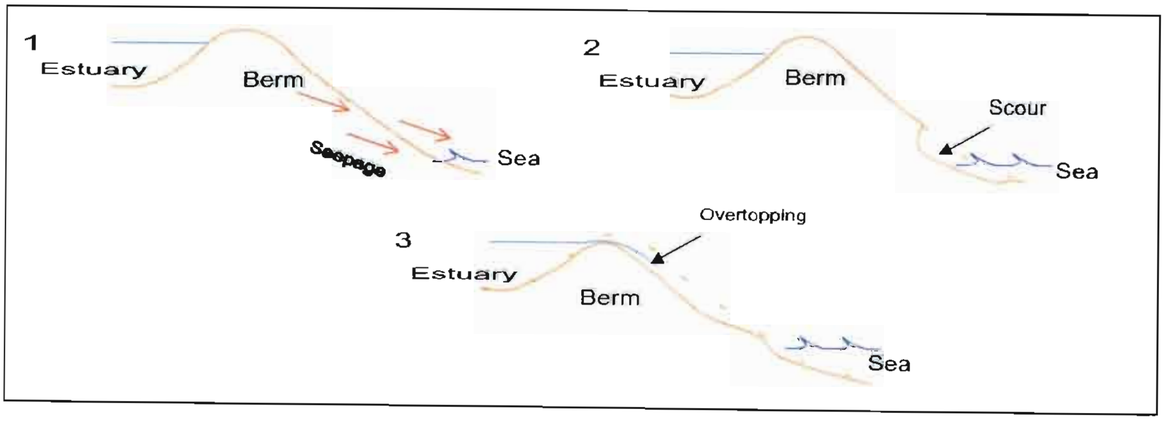



**Figure 2-5: The affect of seepage on the breaching mechanism.**

The initial foundation for this model of breaching comes from observations at Mhlanga Estuary. Prior to two specific breaching events, extensive seepage was present. Plate 2-1 is an example of the seepage observed, with plate 2-2 showing failure of the berm. Unfortunately the actual breaching of the berm was not observed during this study, as the breaching events occurred at night.

**Plate 2-1: Seepage at Mhlanga Estuary.**

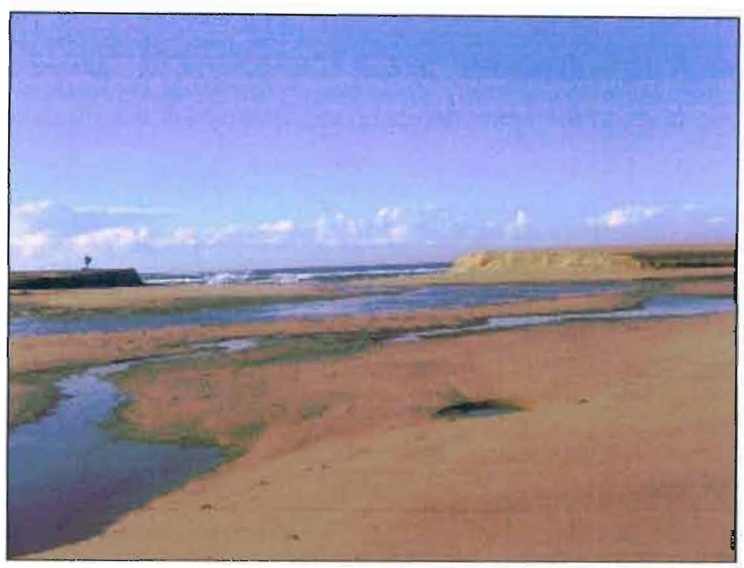


**Plate 2-2: Mhlanga Estuary after breaching.**

The piping failure mechanism is not unique to the estuarine environment, but is a common cause of failure in earth dams. Sand piping is defined by the Ohio Department of Natural Resources (1994) as the phenomenon beginning with soil erosion due to seepage on the downstream slope of an embankment and progressively eroding a path into the reservoir. An example of such a failure, reported by Gillette (2003), occurred at Teton Dam, Idaho, in 1976.

The failure began with several hours of seepage, shown in plate 2-3, which removed sediment from the dam. Once this erosive seepage reached the crest of the dam, plate 2-4, the breach occurred within minutes, continuing to expand, as seen in plate 2-5, for approximately an hour thereafter. Plate 2-6 was taken after the breaching event has subsided.

It is interesting to note the similarities between the estuary breaching event and the failure of an earth dam. These similarities are seen in the initial photographs of seepage and the later pictures of the breached estuary and failed dam. The berm of an estuary can in essence be seen as a small earth dam and therefore the seepage and overtopping failure mechanisms of earth dams become applicable to estuaries.

**Plate 2-3: Teton Dam, Idaho, several hours after seepage began. (Olson, 1976).**

**Plate 2-4: Seepage reaches crest of Teton Dam (Olson, 1976).**

**Plate 2-5: The failure of Teton Dam as breach widens (Olson, 1976).**

**Plate 2-6: Several hours after breaching began, the dam is almost empty (Ponce, 1976)**

The estimated time for breaching to develop at Teton Dam was reported as being approximately 6 hours. Although there are several differences between the failure of an earth dam and the breaching of an estuary, the principle behind failure is the same. Some of the differences between estuaries and earth dams include the soil type and compaction, the storage volume and the presence of wave action on the downstream face.

Similarities between the failure of estuaries and the failure of earth dams are not unique to seepage failure but also are observed in failure due to overtopping and scour.

### 2.5.2. Overtopping:

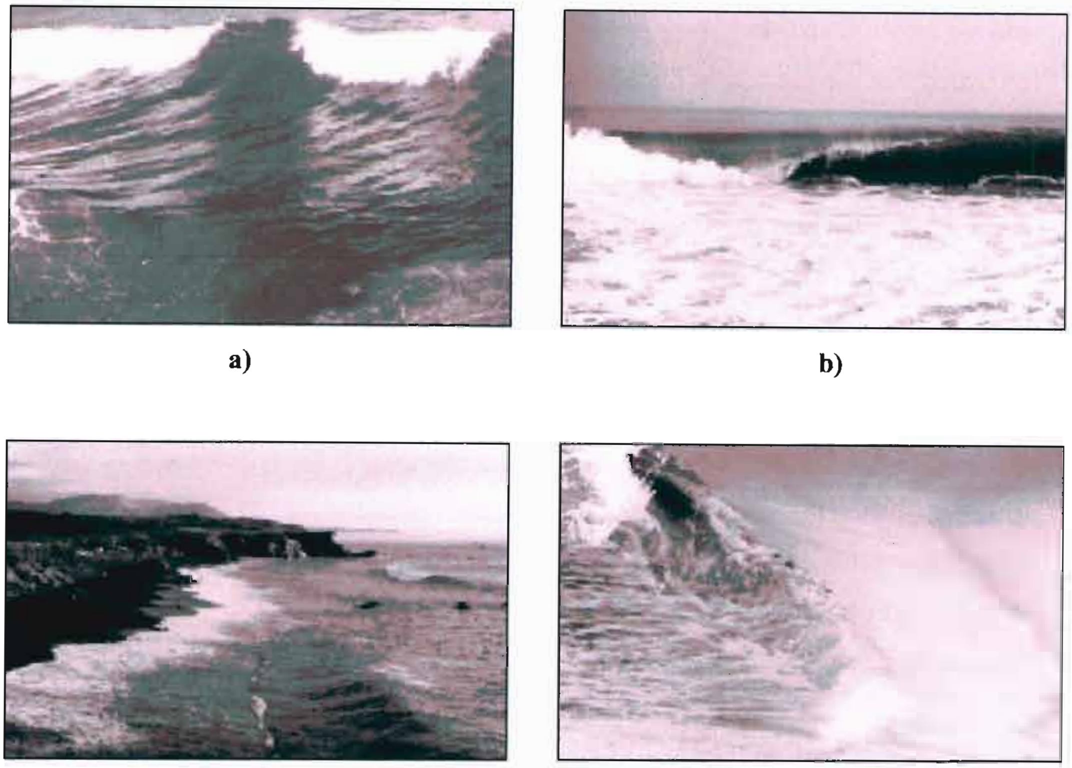
As the water level within an estuary rises above the level at the lowest point of the berm the water can overtop the estuary berm and scour a channel to the sea. The channel would become increasingly defined as the water exiting the estuary increases in momentum. This failure through overtopping is also a failure mechanism of earth dams, enforcing the concept of a berm behaving as a small earth dam.

It may be expected that estuaries will breach via overtopping, rather than due to seepage, when the time scale to overtop the estuary is shorter than the time required for seepage erosion to influence failure. It is important to note that this mechanism does not require a sustained high hydraulic gradient for failure.

Under flooding conditions the time taken to fill the estuary is expected to be shorter than the time scale for seepage failure, therefore this form of breaching is more likely. In extreme flooding conditions the flood wave would rapidly overtop the berm and generate strong scour, breaching the estuary.

### 2.5.3. Wave Action:

Breaking waves can be classified into four types, namely spilling, plunging, surging and collapsing. Examples of these 4 types of breaking waves are given in plate 2-7.



a) b) c) d)

**Plate 2-7: The different types of breaking waves are a) spilling, b) plunging, c) surging and d) collapsing (U.S. Army Corps of Engineers, 2002).**

Spilling breakers commonly occur on gently sloped beaches, when the wave steepness is high, conversely surging and collapsing breakers tend to occur where low steepness waves come into contact with steep beach slopes. Plunging breakers occur when high steepness waves are combined with steep beach slopes. The plunging and to a lesser extent surging and collapsing breakers are more effective at suspending sediment and therefore cause higher erosion on the beach face, than spilling breakers. As the east coast of South Africa has steep beach slopes, the coast is susceptible to highly erosive breakers.

Wave action on the seaward side of the berm aids in reducing the width of the berm through depletion. The regular alongshore pattern of alternating depletion and accretion is shown in plate 2-8, caused by currents alternating between rip and shore bound as observed at Mhlanga Estuary prior to breaching at the end of July. Where the depletion was evident, seepage was visible along the southern portion of the estuary. The reduction in berm width through depletion results in an increase in hydraulic gradient thereby increasing the effects of seepage.

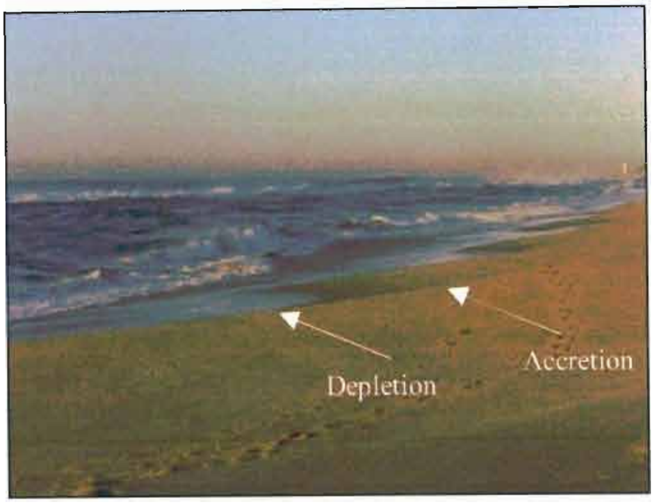



**Plate 2-8: Depletion and accretion as observed on Mhlanga beach.**

A second mechanism by which wave action can trigger breaching is by over-wash into the estuary, thereby reducing the berm height. Introduction of saline water into the estuarine environment not only occurs when the estuary is open but can occur during the closed phase too. Over-wash is most likely to occur during spring high or after a storm event.

The over-wash can be responsible for reducing the level of the berm to below that of the water level within the estuary allowing for water to flow out of the estuary. A reduction in berm height also leads to a reduction in soil pressure, enhancing seepage through the berm and the attainment of conditions required for sand piping. Furthermore, over-wash by wave action can also increase the water level within the estuary such that it surpasses the level of the berm, resulting in the breaching of the estuary.

Over-wash can also cause an increase in berm width, thereby decreasing the hydraulic gradient and impeding failure through seepage. Plate 2-9 and 2-10 shows the widened berm at Mhlanga and Mdloti Estuaries due to over-wash. The affect of over-wash is visible in the patterns created by the over-washing waves entering the estuary.

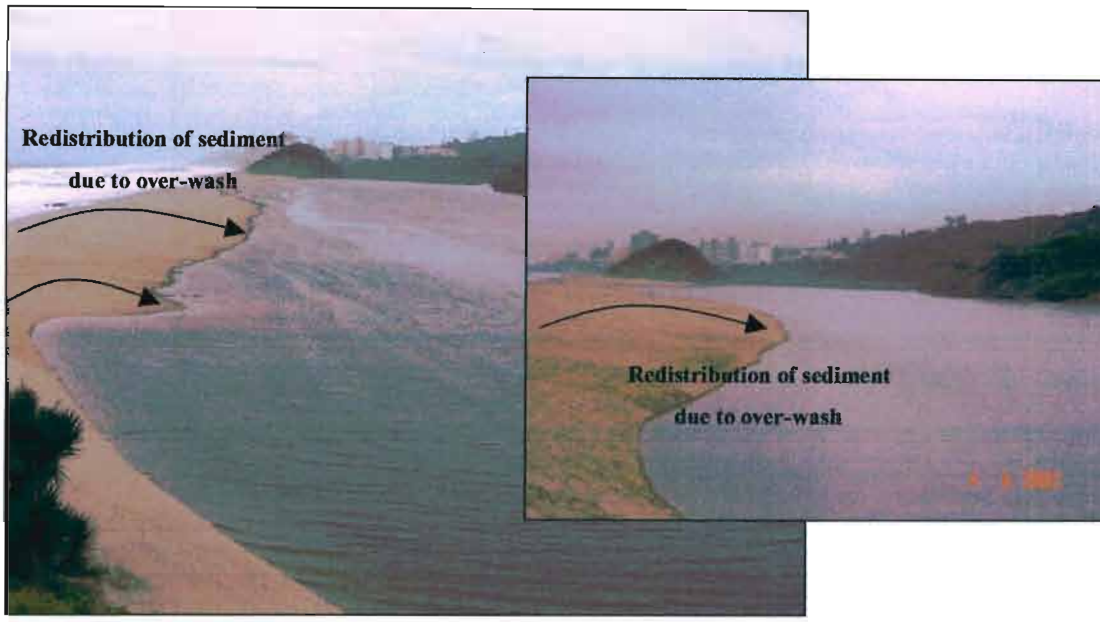



Plate 2-9: Over-wash has widened the berm at Mhlanga Estuary.

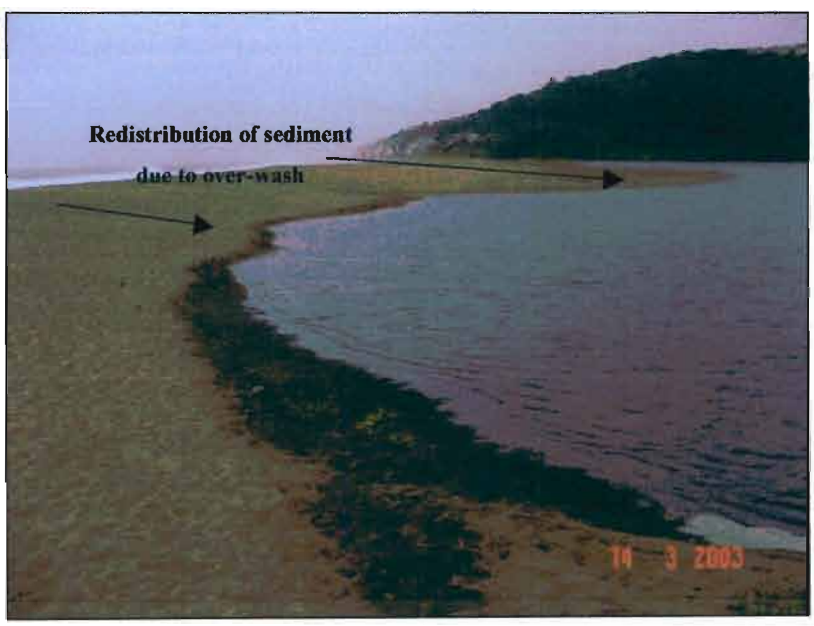



Plate 2-10: The effects of over-wash into Mdloti Estuary.

### 2.5.4. Artificial Breaching:

Artificial breaching of estuaries at water levels that are lower than the natural breaching water levels, causing a reduction in flushing of the estuary and resulting in sedimentation problems. (Huizinga and van Niekerk, 2002)

There are three main factors which drive artificial breaching practices:

1. To prevent the flooding of crops planted within the estuary flood plain,
2. To protect housing and amenities built too close to the edge of the estuary and
3. To improve the water quality of the estuary due to the build up of pollution and nutrients creating a health risk if an estuary is left stagnant for too long.

The increased sedimentation within estuaries is a problem which perpetuates itself until only a large flood event (or dredging) can restore the estuary to health. Historically many of South Africa's estuaries were artificially breached (Begg 1978 & 1984). Plate 2-11 shows a small channel dug by hand by children on the beach at Mhlanga Estuary. The estuary was very full and close to breaching naturally, therefore breaching due to a small perturbation such as this is unlikely to adversely affect the estuary.

**Plate 2-11: Hand dug channel from estuary to the sea.**

## 2.6. Mechanisms of closure

After breaching the estuary remains open for a period of time. This time period is determined by two competing forces: the first are flows which maintain an open state by scouring sediment from the mouth and the second are physical processes causing closure by rebuilding the sand bar. The fresh water inflows into the estuary can keep the estuary open by scouring the mouth. Each estuary would require a certain minimum flow to keep the inlet open (Huizinga, and van Niekerk, 2002). Tidal exchange flows can also play a role in keeping the estuary open by scouring sediment from the mouth.

There are two distinct sediment transport processes affecting the closure of an estuary: longshore sediment transport and cross-shore sediment transport (Huizinga and van Niekerk, 2002). Longshore sediment transport is the process whereby sediment is moved parallel to the coastline by wave and current action. The sediment is suspended by breaking waves in the surf zone and then transported along the coast by longshore currents generated by waves travelling at an oblique angle to the coastline (Schoonees, 2002). In larger estuaries longshore transport is responsible for the deposition of sediment in the inlet of an estuary, forming a sediment bypass bar which obstructs the inlet, closing the estuary off from the sea (Huizinga, 2000). While longshore sediment transport is an important process in the closing of inlets in the case of large estuaries, in small estuaries it is responsible for ensuring sediment availability. In small estuaries cross-shore transport was reported by Huizinga and van Niekerk, (2002) to be the driving force behind closure. Sediment is suspended in high waves through turbulence and deposited due to wave action. This wave action can cause a wave built sand bar within the surf zone to move towards the land and this sand bar eventually blocks the inlet. Tidal forces can also deposit sand in the inlet, as the tidal outflow may not be strong enough to remove sediment deposited during tidal inflow; particularly for asymmetrical flood dominated tidal exchange flows. This concept of sediment supplied by longshore transport and deposited in the mouth of an estuary through direct wave action was also reported in Reddering (1988).

According to Huizinga (2000) and Reddering (1988) wind blown sediment has little effect on closure. However in areas where there is a prevailing wind action parallel to the coastline wind can play a significant role in the elevation of the sand bar across the mouth.

## 2.7. Sediment availability

Table 2-1 indicates the volume of sediment transport along the South African coast on an annual basis. Moving up the east coast of South Africa an increase in longshore sediment transport is evident. The net longshore transport along the south coast is about half that of the east coast, implying less sediment availability and possibly increasing the time required for closure of estuaries in those regions.

**Table 2-1: Net longshore sediment transport as reported by Schoonees (2002).**

| Location | Net Longshore Transport ($m^3$/yr) | Net Longshore Transport ($m^3$/day) |
|---|---|---|
| Richard's Bay | 850 000 | 2 300 |
| Durban | 500 000 | 1 400 |
| East London | 300 000 – 500 000 | 820 – 1 400 |
| Port Elizabeth | 150 000 | 410 |
| Northern False Bay | 100 000 – 150 000 | 270 – 410 |
| Walvis Bay | 860 000 | 2 400 |

Another possible source of sediment is fluvial. The fluvial sediment yield for temporary open estuaries along the KwaZulu Natal coast ranges from about 1.7million tonnes per annum for large catchments such as that for Mgeni Estuary to as little as 1 800 tonnes per annum for smaller estuaries such as the Siyai and Ku-boboyi Estuaries (CSIR 1990). This translates to an approximate volumetric range of 3 to 2700m$^3$ per day, suggesting that larger catchment areas are capable of supplying the sediment required for closure. The distribution of sediment yield is shown in figure 2-6. However it is unlikely that fluvial sediment plays a large role in mouth closure as the sediment is very fine and easily flushed from the estuarine system.

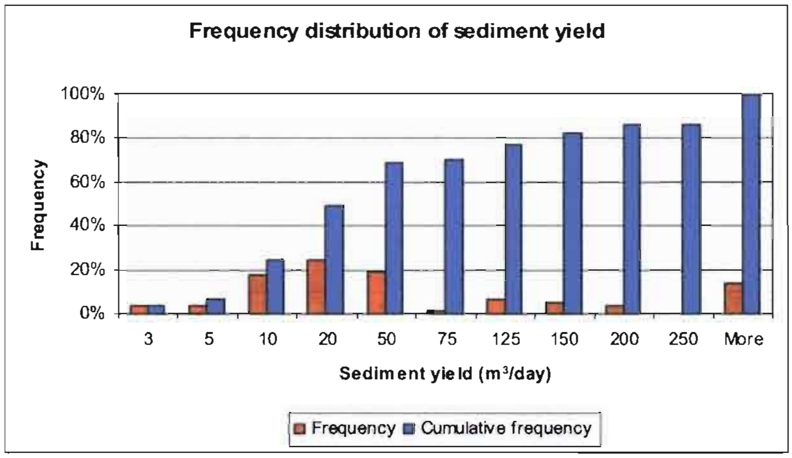



**Figure 2-6: Frequency distribution of sediment yield for temporary open estuaries in KwaZulu Natal (CSIR, 1990).**

## 2.8. Wave climate

The general wave direction at various locations around the coast of South Africa are given in figure 2-7, from which it can be seen the dominant wave direction along the east coast is south westerly in direction. These waves hit the coast at an oblique angle creating a longshore current in the nearshore zone and associated net transport of sediment up the coast.

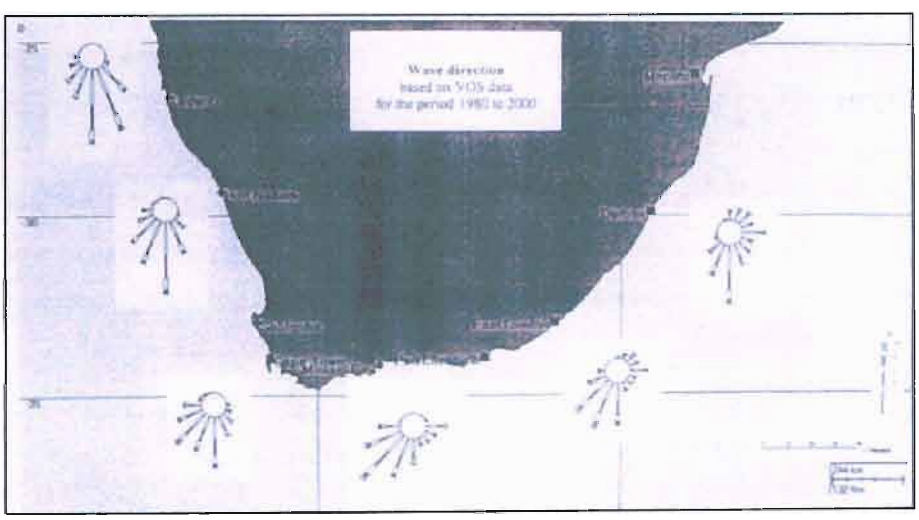


**Figure 2-7: Summary of wave direction around the coast of South Africa (Rossouw, 2002).**

Wave run-up on beaches is defined by U.S. Army Corps of Engineers, (2002) as being the maximum wave uprush above still water level. There are two components of run-up, setup or the super-elevation of mean water level due to wave action and swash, which is defined as fluctuations about that mean. The active portion of the beach profile is determined by the upper limit of the run-up.

This upper limit is also important in the determination of the height of the sand berm, with a lesser role played by wind action. Run-up is a function of beach slope, porosity, wave height and wave steepness (U.S. Army Corps of Engineers, 2002). A summary of the 50 percentile (median) and the 1 percentile significant wave heights (Hs), as reported by Rossouw (2002), for the coast of South Africa are listed in table 2-2.

**Table 2-2: Summary of wave height and period around the coast of South Africa (after Rossouw, 2002).**

| Location | $Hs^{50\%}$ | $Hs^{1\%}$ |
|---|---|---|
| **Port Nolloth** | 2.0 m | 4.5 m |
| **Saldanha** | 2.2 m | 5.5 m |
| **Agulhas Bank** | 2.5 m | 6.0 m |
| **Port Elizabeth** | 2.3 m | 5.3 m |
| **East London** | 1.8 m | 3.5 m |
| **Durban** | 1.8 m | 3.3 m |

From table 2-2 it can be determined that the significant wave height along the coast of South Africa is greater in the warm temperate zone, reducing in the subtropical zone. Along the east coast of South Africa CSIR (1990) states the water level at which KwaZulu Natal estuaries generally breach is between 2 and 2,5 m above MSL, which translates to 1.1 to 1.4 times the median wave height, reported by Rossouw (2002), for Durban.

Bagnold (1940) states that berm height (s) is proportional to the deep sea wave height (h), relative to the same datum. The berm height is also affected by the grain size of the beach sand. Table 2-3 presents the different relationships between berm height and wave height for three grain sizes. These relationships were determined through laboratory experiments.

**Table 2-3: The variance of berm height, dependant on grain size.**

| Grain size (mm) | Equation |
|---|---|
| 7 | $s = 1.68.h$ |
| 3 | $s = 1.78.h$ |
| 0.5 | $s \approx 1.8.h$ |

Therefore for a range of grain sizes the approximate range in sand berm height near Durban is 3 to 3.2 m (using $h = Hs^{50\%}$, Rossouw,2002).

## 2.9. Characteristics of temporary open estuaries

Whitfield (2000) provides information on estuary classification distinguishing between open estuaries, temporary open estuaries and estuarine lakes, which can also be temporary open. Characteristics of South African estuaries have been published by several sources, including Begg (1978 and 1984), Jezewski, et al. (1984), Ramm et al. (1985 - 1986), CSIR (1982) and CSIR (1990). The literature published by the CSIR (1982) pertains to estuaries in the Cape, while the rest of the literature afore mentioned pertains generally to estuaries on the east coast of South Africa in KwaZulu Natal. Jezewski, Pyke and Roberts (1984) cover a range of estuaries throughout South Africa. The characteristics given in these reports include catchment areas, estuary areas, mean annual precipitation (MAP), mean annual runoff (MAR) and mean annual evaporation (MAE). Summaries of data from Begg (1978 and 1984), Jezewski, Pyke and Roberts (1984), Ramm et al. (1985-1986) and CSIR (1990) are given in appendix A. Information on these characteristics can also be obtained from Midgely, Pitmann and Middleton (1994 and 1997) for quaternary catchment areas; however the catchment areas for a particular estuary may not be the same as that of its quaternary catchment. Combining data from the various sources a plot of average residence time against percentage closed, shown in figure 2-8, was obtained. Residence time is used as a base indicator of the hydrodynamic functioning of an estuary as well as defining the nature of the water balance. The average residence time was calculated using a simplified relationship of storage volume divided by Mean Annual Runoff (MAR), with the storage volume equal to average depth multiplied by lagoon area.

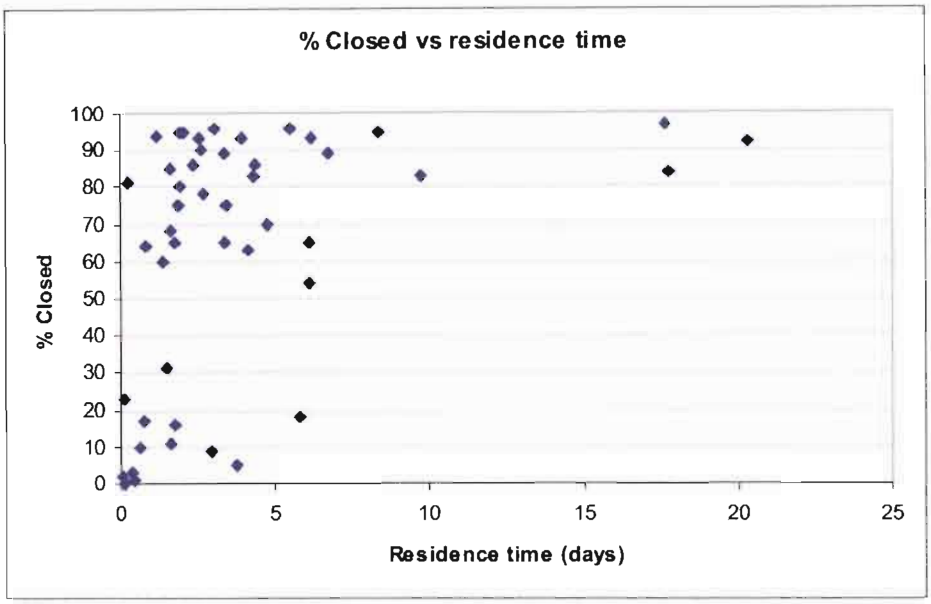



**Figure 2-8: Plot showing the distribution of % closed against residence time.**

In figure 2-8 there are three distinct groups of data. There are three data points representing estuaries with relatively higher residence times and are closed more than 80% of the time. Conversely there is a cluster of data points which are closed less than 30% of the time and have a relatively low residence time. The third group does not behave as expected. Although the majority of these data points lie in the region closed more than 60% of the time the range of residence times corresponding to these points are relatively low. Exploring the data further a plot of the ranks was produced, shown in figure 2-9.

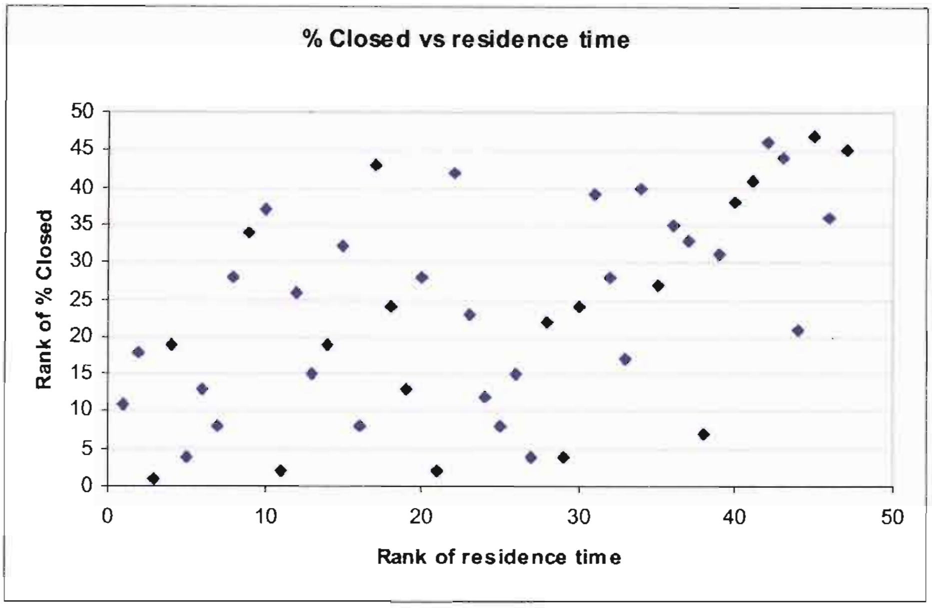



**Figure 2-9: Rank* of percentage of time an estuary is closed against the residence time of that estuary.**

*(Where a rank of 1 is assigned to the largest number)

There is a weak trend, determined from the ranked data, indicating the residence time increases with an increase in percentage closed (Spearman's rank correlation coefficient of 0.51, which is significant at 99% confidence level using a standard t-test (Helsel, and Hirsch, 1984)). Possible reasons for not achieving a stronger trend could be due to the approximation used in determining the residence times of the various estuaries. As there was insufficient data available on the outflows from each estuary the residence time was approximated on the assumption that the losses from the system are negligible in comparison to the inflows and that the inflows were estimated to be of the same order of the MAR. Therefore the residence time was determined by:

$$\boxed{T_R = \frac{S}{MAR}}$$

The storage capacity of the estuaries was determined by multiplying the estuary area by the depth. Although this is not an accurate method for determining storage, limited data was available, therefore one consistent method was applied.

Some general trends concerning the size of temporary open estuaries can be reviewed from the available information. Figure 2-10 and 2-11 explore the relationship between estuary area and catchment size, using data from Jezewski, Pyke and Roberts (1984). The expected trend is that, in areas of similar rainfall, the larger the catchment area, the larger the required storage capacity of the estuary should be. With an increase in storage capacity there should be an increase in surface area of the estuary. Presumably where estuaries have similar areas and morphology, those with larger catchment areas would breach more frequently under similar climatic conditions. Simply plotting the areas against each other did not show any obvious trend (figure 2-10), however a plot of the respective ranks for catchment area and estuary area does show a general trend (figure 2-11). The data points in figure 2-11 were ranked largest (rank = 1) to smallest.

The Spearman's rank correlation coefficient for the data shown in figure 2-11, is 0.72, which is significant at a 99 % confidence level.

As there is a significant positive correlation between catchment size and estuary size, the distribution of the catchment size will also give an indication of the distribution of estuary size. Jezewski, Pyke and Roberts (1984) provided information on catchment areas for 91 of the 182 temporary open estuaries of South Africa. Figures 2-12 and 2-13 show the distribution and range of catchment sizes for the warm temperate and subtropical regions. The cool temperate region has been omitted as there is only information available on one of the five temporary open estuaries in the region. Of the 91 temporary open estuaries 30% have a catchment area less than 25km$^2$ and 50% have a catchment area less than 50km$^2$. As indicated in figure 2-13, the majority (approximately 75%) of the estuaries in the subtropical area have catchment areas of less than 50km$^2$.

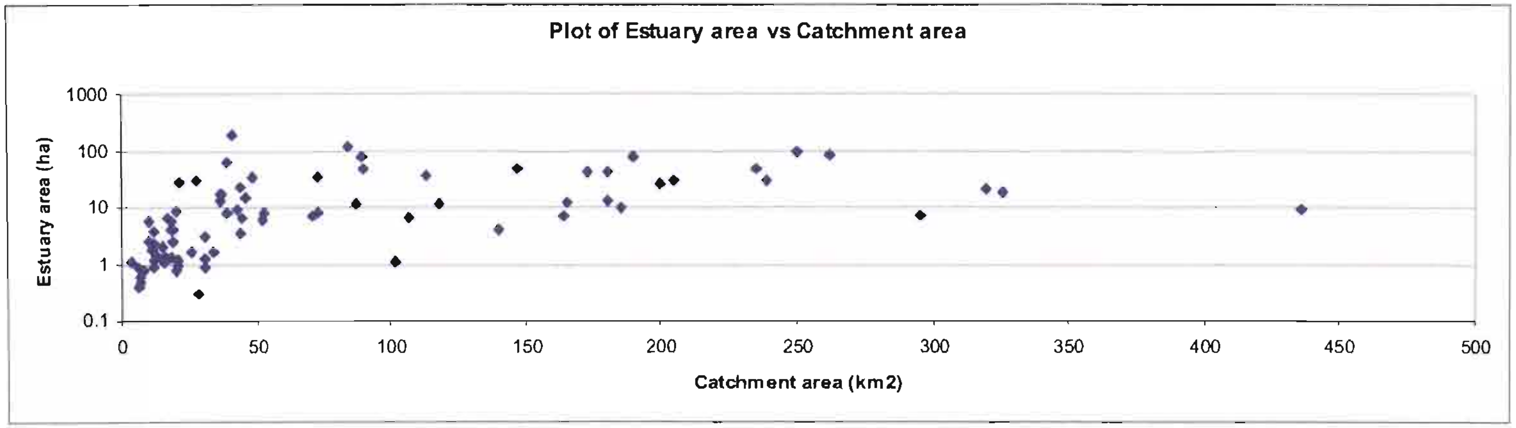



**Figure 2-10: Plot of the area of the estuary against the catchment area of the same estuary.**

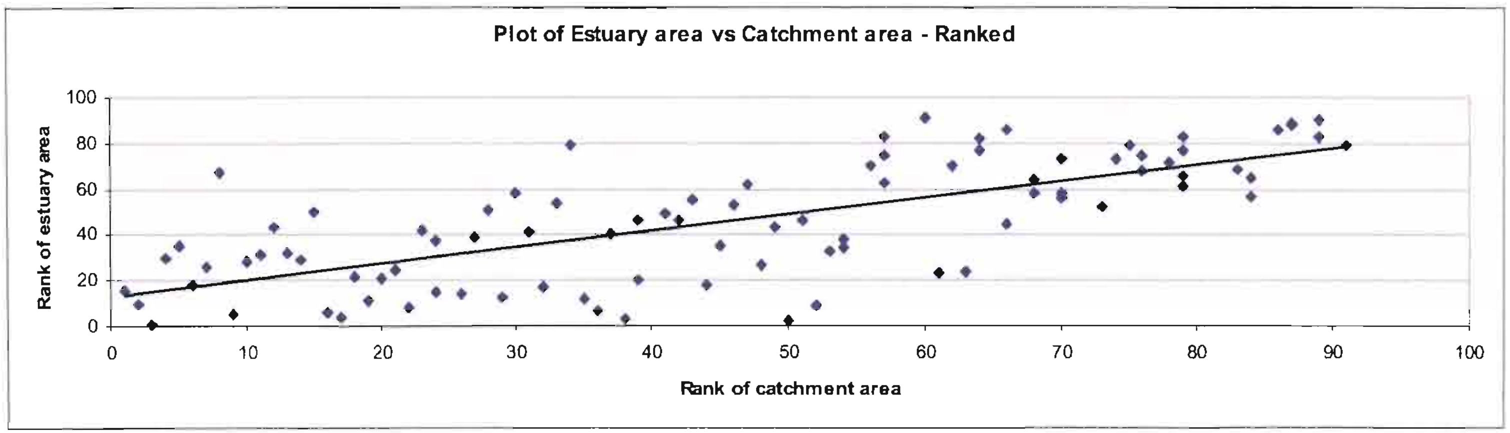



**Figure 2-11: The ranks of estuary area versus the respective ranks of catchment area.**

*(Where a rank of 1 is assigned to the largest number)

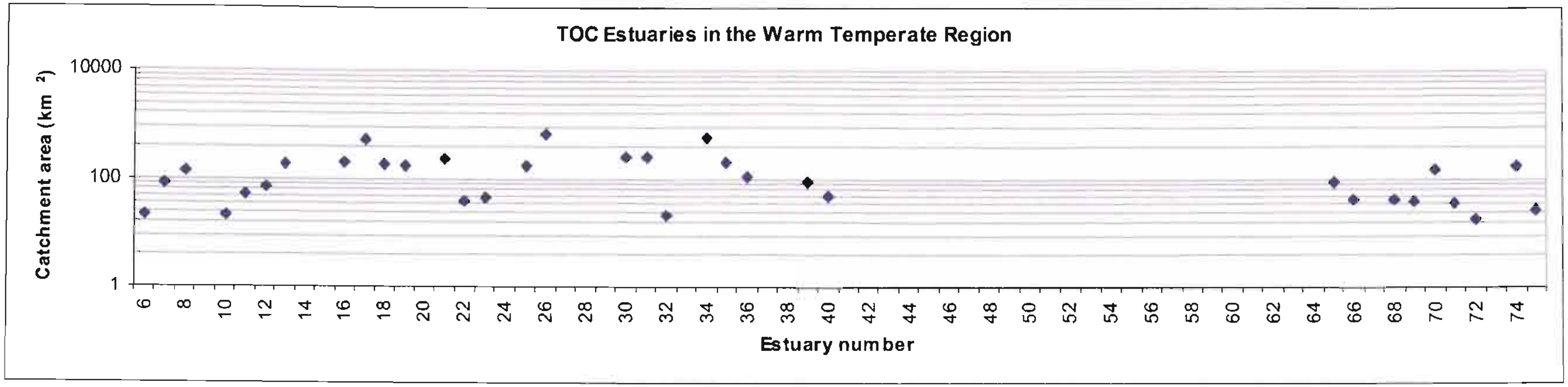



**Figure 2-12: Catchment areas of temporary open estuaries in the warm temperate zone. The estuary numbers correspond to those in figure 2-1.**

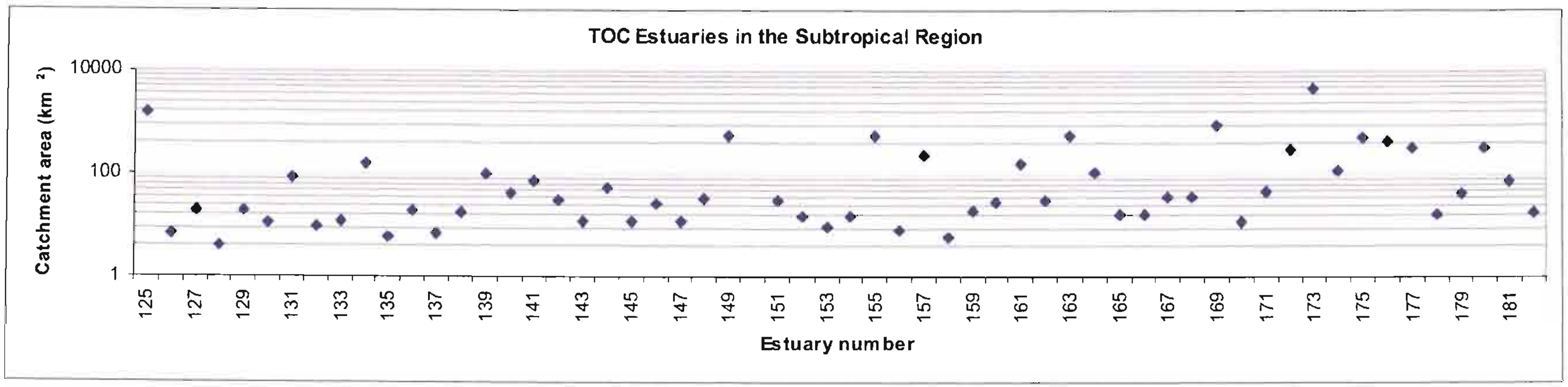



**Figure 2-13: Catchment areas of temporary open estuaries in the subtropical zone. The estuary numbers correspond to those in figure 2-1.**

### 2.9.1. Characteristics of the case study estuaries

Information specific to Mhlanga and Mdloti Estuaries was extracted from Jezewski, Pyke and Roberts (1984), Begg (1978, 1984), Ramm et al. (1985/6) and CSIR (1990) tables 2-4 and 2-5 were produced.

**Table 2-4: Characteristics of Mhlanga Estuary.**

| | Begg (1978 & 1984) | Jezewski, et al (1984) | Ramm, et al. (1986) | CSIR (1990) |
|---|---|---|---|---|
| Catchment area (km$^2$) | 85, 124, 196 | 118 | 118 | 118 |
| River length (km) | 28 | | 28 | 28 |
| Longest collector (km) | | 25 | | |
| MAR (10$^6$m$^3$) | 19.7 to 29.5 | 23 | 19.8* | |
| Min. flow m$^3$/s | 0.02 | | | |
| Max. flow m$^3$/s | 1.75 | | | |
| Av. Flow m$^3$/s | 0.28 | | | |
| Lagoon area m$^2$ | 114 000 | 114 000 | 114 000 | |
| Depth (m) | | | 1.7 | |
| % Closed | | | 96 | |
| Time of concentration (hr) | | 5.8 | | |
| Freshwater req. (10$^6$m$^3$/yr) | | 0.801 | | |
| Sediment yield (tonnes/yr) | | | | 47 200 |

*Reported as 0.0198million m$^3$, however this appears to be an error.

**Table 2-5: Characteristics of Mdloti Estuary.**

| | Begg (1978 & 1984) | Jezewski, et al. (1984) | Ramm, et al. (1985) | CSIR (1990) |
|---|---|---|---|---|
| Catchment area (km$^2$) | 481,497,550,704 | 527 | 527 | 527 |
| River length (km) | 74 to 88 | | 81 | 81 |
| Longest collector (km$^2$) | | 75 | | |
| MAR (10$^6$m$^3$/yr) | 97, 105, 134 | 102 | 89.0* | |
| Min. flow m$^3$/s | 0.34 | | | |
| Max. flow m$^3$/s | 5 | | | |
| Av. Flow m$^3$/s | 2 to 2.5 perrennial | | | |
| Lagoon area m$^2$ | 136 000 | 183 000 | 136 000 | |
| Depth (m) | | | 1.24 | |
| % Closed | | | 64 | |
| Time of concentration (hr) | | 12.5 | | |
| Freshwater req. (10$^6$m$^3$/yr) | | 5.210 | | |
| Sediment yield (tonnes/yr) | | | | 210 800 |

*Reported as 0.89million m$^3$, however this appears to be an error.

From tables 2-4 and 2-5 a wide range of values are given for data such as catchment area. The catchment for Mhlanga Estuary forms part of the U30B quaternary catchment defined in Midgely and Pitmann (1994), whilst Mdloti Estuary catchment area falls in quaternary catchment U30A and part of U30B. Midgely and Pitmann (1994) reports the catchment area of U30A and U30B to be 376 and 221km$^2$ respectively, giving a total possible catchment for Mhlanga and Mdloti Estuaries combined equal to 597km$^2$ which also includes a portion of catchment area which provides runoff directly into the sea. The sum of the two catchments reported by Jezewski, Pyke and Roberts (1984), Ramm, et al (1985/6) and CSIR (1990) equates to 645km$^2$, exceeding the possible 597km$^2$. Some of the values reported in Begg (1978, 1984) are too high to conform to values reported by Midgely and Pitmann (1994).

Chapter 4 further explores issues of catchment area and estuary area, whilst flows for Mdloti and Mhlanga Estuaries are further explored in chapter 6.

## 2.10. Studies relating flow and mouth state

To ensure the demands on South African water resources are satisfied, both in terms of quality and quantity, for human requirements and ecological sustainability the National Water Act (Act 36, 1998) was introduced. Jezewski, Pyke and Roberts (1984) reported one of the first attempts to quantify the freshwater requirements of estuaries in South Africa. Jezewski used the evaporative requirement and the flooding requirement of each estuary as a basis for predicting the freshwater required for the abiotic functioning of each estuary. The evaporative requirement was defined as the volume of water required to replace the water lost by the estuary through evaporation and thus prevents the occurrence of hypersaline conditions. The flooding requirement was defined as the volume of water required to periodically breach the estuary, flush accumulated sediments from the system, and flood the wetlands around the margins of the system. It was argued that this could be estimated using the 2-year return period flood hydrograph for the system. The calculated freshwater requirements were generally less than 6% of MAR, with details of individual estuaries given in appendix B. These estimates are significantly lower than the requirements inferred using RDM procedures, that take a holistic approach incorporating both the abiotic and biotic functions of estuaries. This recent approach is outlined in CSIR, (2002). The RDM approach views a reduction of freshwater inflow as a threat to the natural functioning of the estuarine system, ultimately affecting the biodiversity of an estuarine system.

During the past two years, the RDM methodology has been applied to Mdloti and Mhlanga Estuaries (CSIR, 2002,2003). Some of the data used in the RDM study of Mhlanga Estuary included data from this current study.

The purpose of the RDM methodology is to determine the impact of changes in flow on the estuarine ecosystem and provide an indication of the health of the estuary in its present state relative a natural (reference) state.

### 2.10.1. RDM process

There are four levels of RDM studies, namely desktop, rapid, intermediate and comprehensive. Table 2-6 presents the use of the various levels, with the different levels requiring different degrees of detail.

**Table 2-6: The potential uses of the various levels of RDM (DWAF, 2003)**

| Level | Use |
|---|---|
| Desktop estimate | For use in Water Situation Assessment Model (WSAM) as part of the planning process only |
| Rapid determination | Individual licensing for small impacts in unstressed catchments of low importance & sensitivity; compulsory licensing "holding action" |
| Intermediate determination | Individual licensing in relatively unstressed catchments |
| Comprehensive determination | All compulsory licensing. In individual licensing, for large impacts in any catchment. Small or large impacts in very important and/or sensitive catchments. |

In terms of flow and mouth state the RDM studies have defined four typical abiotic states. Each RDM study aims to provide flow ranges, for a particular estuary, for each state. Each state is then described in terms of the abiotic characteristics and processes and the occurrence of each state estimated using simulated monthly flows for the present state of the estuary. Table 2-7 defines the four abiotic states.

**Table 2-7: Definition of the different estuary states (after CSIR, 2002)**

| State | Name |
|---|---|
| 1 | Closed, where the estuary is cut-off from the sea with no water exchange. |
| 2 | Semi-closed, with a perched outlet channel but no seawater intrusion (except occasional over-wash), and with water still flowing out to sea |
| 3 | Open, with seawater intrusion |
| 4 | Open, with no seawater intrusion under high flow conditions (river dominated), i.e. completely fresh |

The RDM also determines the reference or natural condition of an estuary using simulated data. Comparing the present state of the estuary to the reference condition provides a method of determining health of the estuary relative to its natural state. This methodology is also used in the analysis of the effects changes in flow will have on the natural functioning of the estuary in question.

### 2.10.2. Mhlanga Estuary

The Mhlanga Estuary was reviewed using the rapid RDM process (CSIR, 2003). As part of this study the present and reference (or natural) conditions of the estuary were evaluated using flow duration curves from 75 years of simulated monthly flows. The occurrence of the four estuary states are tabulated in tables 2-8 and 2-9 for the present and reference conditions respectively, with the estimated threshold flows as presented in CSIR (2003). CSIR (2003) determined the percentage of time the estuary was in each state by combining the threshold flows and the flow duration curves. Note that data collected as part of this current study contributed towards the RDM study.

**Table 2-8: Mouth state proportions under present state conditions (after CSIR, 2003)**

| State | Threshold Flows ($m^3/s$) | Percentage |
|---|---|---|
| Closed | < 0.4 | 49 |
| Semi-closed | 0.4-0.5 | 26 |
| Open - estuarine | 0.5-5.0 | 25 |
| Open - fluvial | > 5.0 | < 1 |

**Table 2-9: Mouth state proportions under reference state conditions (after CSIR, 2003)**

| State | Threshold Flows ($m^3/s$) | Percentage |
|---|---|---|
| Closed | < 0.4 | 82 |
| Semi-closed | 0.4-0.5 | 3 |
| Open - estuarine | 0.5-5.0 | 15 |
| Open - fluvial | > 5.0 | < 1 |

The results from CSIR (2002) reproduced in tables 2-8 and 2-9 indicate that the Mhlanga Estuary was naturally closed for approximately 82% of the time however under present conditions it is only closed approximately 49% on average. The reduction in the percentage of time the estuary is closed on average can be attributed to the increase in flow due to the addition of treated effluent into the estuarine system.

### 2.10.3. Mdloti Estuary

The rapid RDM method was used to assess the Mdloti Estuary by CSIR, 2002. The estimated threshold flows used to define the four biotic states are tabulated for present conditions and reference conditions in tables 2-10 and 2-11 respectively. The percentages given for each state were determined by CSIR (2003) by combining the threshold flows and flow duration analysis based on 75 years of simulated monthly flows.

**Table 2-10: Mouth state proportions under present state conditions (after CSIR, 2002)**

| State | Threshold Flows ($m^3/s$) | Percentage |
|---|---|---|
| Closed | < 0.3 | 45 |
| Semi-closed | 0.3-2.0 | 28 |
| Open - estuarine | 2.0-5.0 | 13 |
| Open - fluvial | > 5.0 | 13 |

**Table 2-11: Mouth state proportions under reference state conditions (after CSIR, 2002)**

| State | Threshold Flows ($m^3/s$) | Percentage |
|---|---|---|
| Closed | < 0.3 | 2 |
| Semi-closed | 0.3-2.0 | 61 |
| Open - estuarine | 2.0-5.0 | 20 |
| Open - fluvial | > 5.0 | 17 |

CSIR (2003) indicate that the flows at Mdloti Estuary have been reduced between reference and present conditions from 98.7 to 72.3 million $m^3$ per year. This lowered flow rate is a combination of the effect of the construction of Hazelmere Dam and the abstractions for irrigation. From tables 2-10 and 2-11 it can be deduced that with the reduction in flow there was a large increase in percentage of time the estuary is closed.

### 2.10.4. The Great Brak

Another example of a study conducted on an estuary, was Huizinga (1995) on the Great Brak Estuary. The need to study and develop a management strategy for the Great Brak Estuary arose with the construction of the Wolwedans Dam 2km upstream of the estuary. Huizinga (1995) identified that the mouth state would be greatly impacted by the reduction of streamflow resulting from the dam. The Great Brak was expected to remain open during summer as the prevailing wave conditions in the area are low whilst in winter high waves close the estuary. Typical prolonged periods of open conditions were expected at the Great Brak Estuary during summer, therefore management of the flows in summer is important in order to imitate the natural behaviour of the estuary. Should the flows be greatly reduced the estuary will not open as regularly causing problems for fish migration, poor water quality and is unattractive for tourists.

## 2.11. Summary

The importance of a study relating flow rates and mouth state (e.g. Perissinotto, R, et al. 2003), is linked to the effects on the biotic component of the estuarine system. The breaching of an estuary has a large impact on the physio-chemical environment influencing the entire food chain, as well as providing connection to the sea for migration both into and out of the estuary.

Estuaries provide a unique environment where fluvial and marine elements compete. Temporary open estuaries exist where a berm forms between the river and the sea closing the lagoon off for periods of time. The mechanisms of breaching are closely related water balance, whilst the forces generally responsible for closure are marine in origin. The preceding sections provide background information on the elements linked to either the fluvial or marine environment including climate and wave dynamics.

General information on the physical characteristics are available from sources such as Begg (1984). From these characteristics a simplified residence time was determined, scaling out the size of the estuary and making them more comparable. There was a weak trend found between the calculated residence time and the percentage of time closed.

Some of the studies, which incorporate the effect of flow on mouth state, were discussed in section 2.10. From the studies on Mhlanga and Mdloti Estuaries, conducted using the rapid RDM process, there is evidence of changes in mouth dynamics linked to changes in streamflow. These studies indicate that Mdloti Estuary is receiving less flow than in its natural state and breaching less frequently while conversely Mhlanga Estuary receives more stream flow and breaches more regularly than it would have in its natural state.

# 3. CASE STUDIES

Mhlanga and Mdloti Estuaries are located along the east coast of South Africa, in KwaZulu Natal, approximately 19 and 25km north-east of Durban respectively. Both Mhlanga and Mdloti Estuaries are temporary open, perched estuaries, formed at the points where the Ohlanga and Mdloti Rivers reach the sea. A map showing the location of the case studies is presented in figure 3-1.


**Figure 3-1: Location map.**

## 3.1. Review of available data/Physical data

Summarized in table 3-1 are some of the physical characteristics of the two case studies. The methods used in obtaining this data are described in this section.

**Table 3-1: Characteristics of Mhlanga and Mdloti Estuaries.**

| Characteristic | Mhlanga Estuary | Mdloti Estuary | Source |
|---|---|---|---|
| CSIR no. | NN2 | NN3 | e.g. CSIR, 1990 |
| Quaternary catchment | U30B | U30 A&B | |
| Av. catchment slope | 0.0056 | 0.0070 | Jezewski, et al., 1984 |
| Longest collector (km) | 25 | 75 | Jezewski, et al., 1984 |
| Time of concentration (hrs) | 5.8 | 12.5 | Jezewski, et al., 1984 |
| River gradient (1: ) | 86 | 95 | CSIR, 1990 |
| River sediment yield (t/yr) | 47 200 | 210 800 | CSIR, 1990 |
| Highest water level (mm) | 2960 | 3200 | Section 3.1.3 |
| Lowest water level (mm) | 670 | 780 | Section 3.1.3 |
| Estuary area ($km^2$) | 0.7 | 0.8 | Section 3.1.2 |
| Dynamic estuary storage ($m^3$) | 800 000 | 970 000 | Section 3.1.4 |
| Catchment area ($km^2$) | 80 | 108 + 376* = 484 | Section 3.1.1 |
| MAR (million $m^3$/yr) | 12.7 | 83.1 | Section 3.1.5 |
| MAR ($m^3$/s) | 0.40 | 2.63 | |
| Release from Hazelmere Dam (million $m^3$/yr) | - | 62.6 | Section 3.1.5 |
| MAR for relevant potion of U30B (million $m^3$/yr) | 12.7 | 17.1 | |
| Discharges (million $m^3$/yr) | 7.4 | 2.7 | Section 3.1.5 |
| Abstractions (million $m^3$/yr) | - | 5.9 | Section 3.1.5 |
| MAS (million $m^3$/s) | 20.1 | 76.5 | Section 3.1.5 |
| Berm length (m) | 664 | 725 | Section 3.1.3 |
| Berm width (m) | 30-60 | ±70 | Section 3.1.3 |
| Berm height (m) | 2.88-5.85 | 4.22-4.9 | Section 3.1.3 |
| % closed (natural) | 82 | 2 | CSIR, 2003 and 2002 |
| % closed (present) | 49 | 45 | CSIR, 2003 and 2002 |
| Av. measured flow ($m^3$/s) | 0.70 | 2.08 | Section 5.2.3 |
| Maximum seepage ($m^3$/s) | 0.25 | 0.53 | Section 5.3.1 |
| Maximum evaporation ($m^3$/s) | 0.02 | 0.02 | Section 5.3.1 |
| Median wave height (m) | 1.8 | 1.8 | Rossouw, 2002 |
| Net longshore transport-Dbn ($m^3$/yr) | 500 000 | 500 000 | Schoonees, 2000 |
| Dominant wave direction-Dbn | southerly | southerly | Rossouw, 2002 |

* catchment area for U30A as stated in Midgley et al, 1994.

### 3.1.1. Catchment area

Orthophotos, dating from 1992, of the areas surrounding the Mhlanga and Mdloti Estuaries and the rivers contributing to the estuaries were used to determine the catchment areas of the two estuaries. The catchment areas were estimated by examination of the 5m contour lines. In the determination of the catchment area for Mdloti Estuary, only the catchment area downstream of Hazelmere dam was measured. The catchment area upstream of Hazelmere dam constitutes the catchment area as defined by Midgely et al, (1995), as quaternary catchment U30A, and has not been specifically measured for this project as the water falling in the catchment upstream is collected by the dam with only the flow released by the dam reaching the estuarine system. The orthophotos were also used to determine river morphology, land use and location of structures. Information and mapping data obtained from the Durban City Engineers was used to check the data from the orthophotos. The data provided was in Arcview GIS format, from which the map of the catchment areas, presented in figure 3-2, was generated.

Data obtained from the Water Research Commission in the form of the Midgely et al (1997, 2nd Ed.), included general information on the catchment areas for Mhlanga and Mdloti (downstream of Hazelmere) Estuaries within the quaternary catchment area U30B, and the rest of Mdloti Estuary catchment area (upstream of Hazelmere) U30A. The information obtained included mean annual precipitation, mean annual runoff, underlying geology, etc.

The quaternary catchment area U30B consists of the catchment area for Mhlanga Estuary, the downstream portion of Mdloti Estuary catchment area and some catchment area providing runoff directly into the sea. Therefore the sum of the portions of catchment area for the two estuaries falling within the U30B area should sum to less than 221km$^2$. The sum of the two measured areas is 188km$^2$, with the remaining 33km$^2$ draining towards the coast.

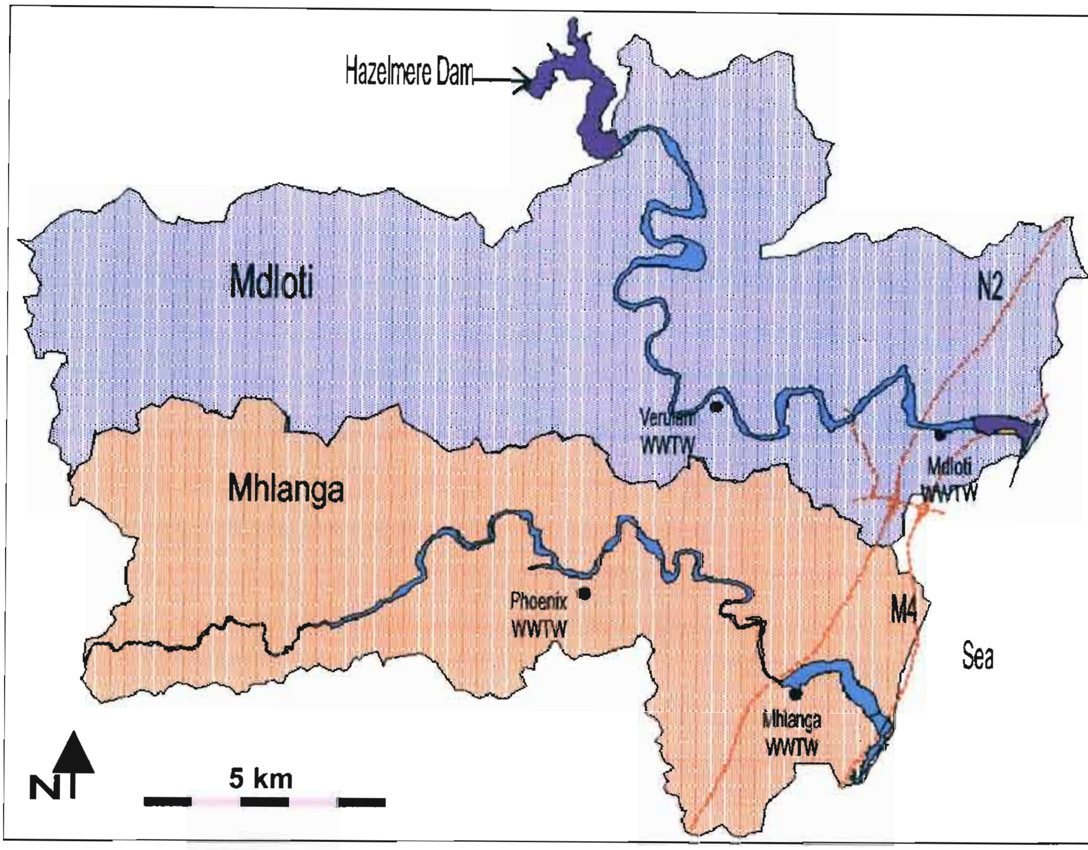



**Figure 3-2: The catchment areas for Mdloti and Mhlanga Estuaries. The area shown for Mdloti Estuary is the portion below Hazelmere Dam.**

### 3.1.2. Lagoon area

The area of the lagoon portion of each estuary was measured off a set of orthophotos dated 1992. Unfortunately the detail provided by the 5m contour interval on the orthophotos was not sufficient to determine the true head of the estuary. Therefore the head of the estuary was found by projecting the maximum water level, determined from fieldwork, upstream using the 2m contour data and mapping, dated 2003, supplied by the Durban City Engineers. Figures 3-3 and 3-4 show the Mhlanga and Mdloti lagoons as determined from the contours depicted. Not all of the contours are displayed in the figure as this would clutter the plot, therefore 2m contours are displayed up to 10m above MSL, and thereafter random contours are shown. Note that the values obtained for the surface areas of the estuaries are much larger than those defined by literature (e.g. Begg, 1984), this is probably linked to the definition of the estuary head.

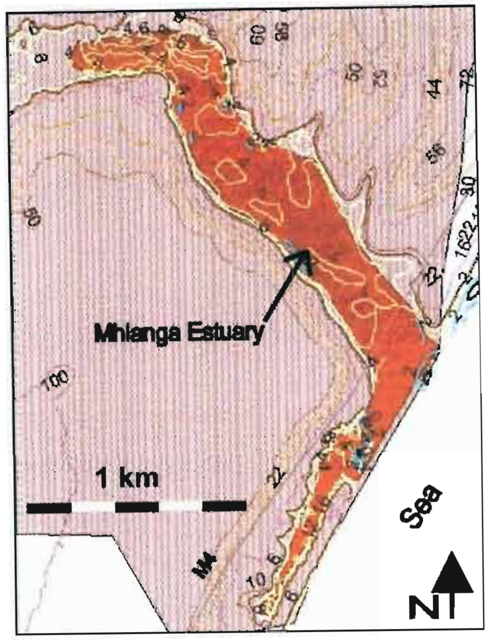



**Figure 3-3: Map showing the extent of Mhlanga Estuary.**

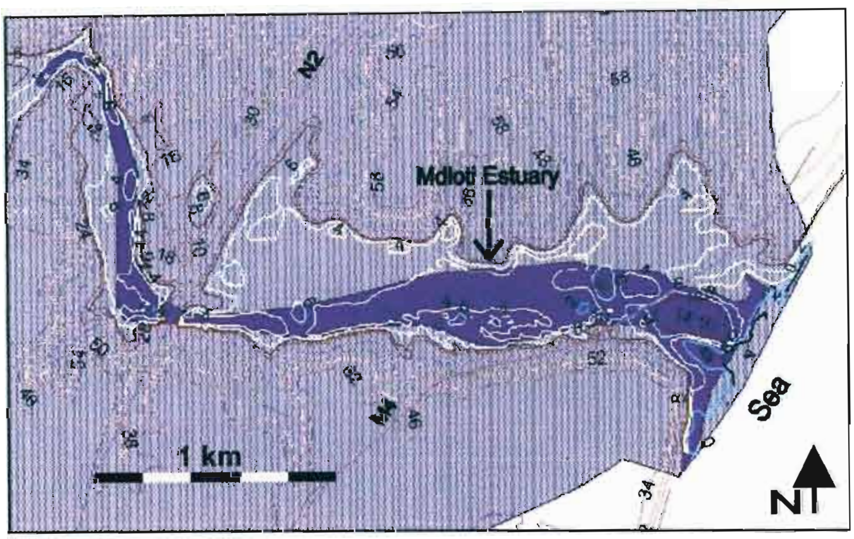



**Figure 3-4: Map showing the extent of Mdloti Estuary.**

### 3.1.3. Survey

All the water level data collected at Mhlanga and Mdloti Estuaries was referenced to the pile cap of the respective bridges. In order to report these measurements relative to MSL a GPS survey was conducted at both Mhlanga and Mdloti Estuaries. From this survey the heights of the pile caps at Mhlanga and Mdloti Estuaries were measured as 1274 and 962 mm above MSL respectively. The maximum and minimum water levels were then determined from the data collected relative to MSL (see section 5.2.4 for data collected on water levels).

The GPS survey was also used to measure the length, width and height of the sand berm.

### 3.1.4. Storage capacity

It is important to note that the estuarine environment is dynamic and therefore the volume can change depending on the water level of the estuary and the morphology of the lagoon.

The dynamic storage within the estuary is an important hydrological feature of temporary open estuaries. No hydro-graphic survey was conducted as part of this study, therefore a model has been used to estimate the storage capacity of the estuary. A possible model for storage of an estuary is a triangular prism, allowing for sedimentation and dead storage in the lower reaches, as seen in figure 3-5. The resulting cross-section representing the dynamic storage is trapezoidal.

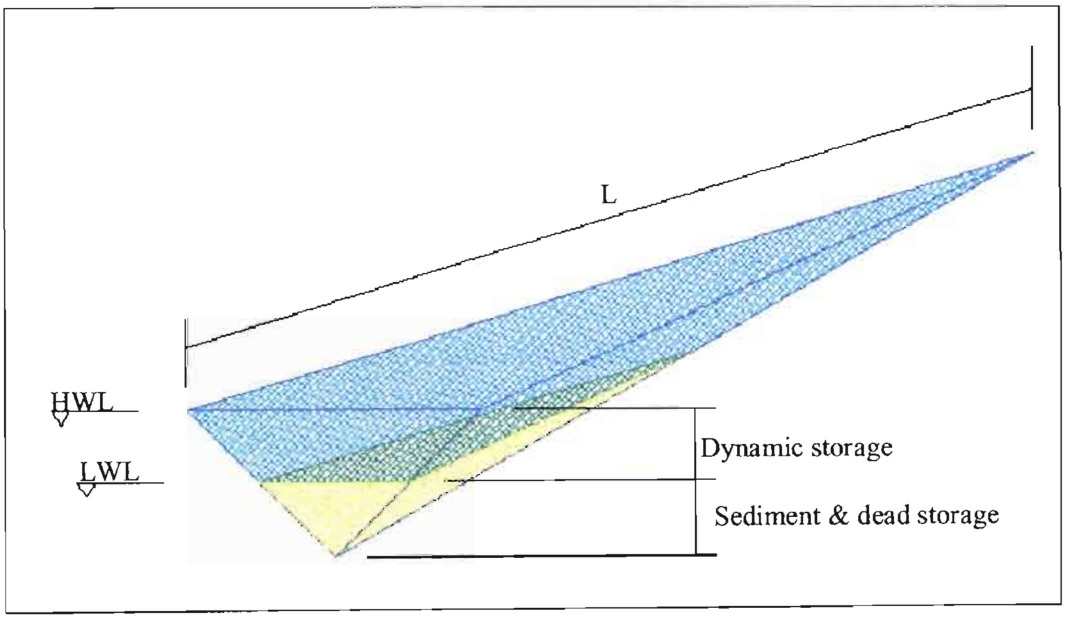



**Figure 3-5: Storage model used to represent the storage within an estuary. HWL and LWL refer to the high water level and low water level.**

Unfortunately there was insufficient data for this model therefore a rough estimate of storage was determined by:

$$V = \frac{1}{2} \cdot d \cdot A$$

In this equation V represents the volume of the estuary while d is the maximum change in water level and A is the surface area of the estuary when full. Table 3-2 contains the approximate storage for both Mhlanga and Mdloti Estuaries.

**Table 3-2: Determination of dynamic storage.**

| | Mhlanga | Mdloti |
|---|---|---|
| Max. change in water level (m) | 2.29 | 2.42 |
| Estuary area ($m^2$) | 700 000 | 800 000 |
| Storage ($m^3$) | 800 000 | 970 000 |

Observations during this study indicate that the actual morphology of the estuaries is far more complex. Several cross-sections of both Mhlanga and Mdloti Estuaries were measured for flow determination. Examples of cross-sections measured at Mdloti and Mhlanga Estuaries are presented in figures 3-6 and 3-7 respectively. A complete record of all the cross-sections and the location at which each of the cross-sections were measured are included in appendix C.

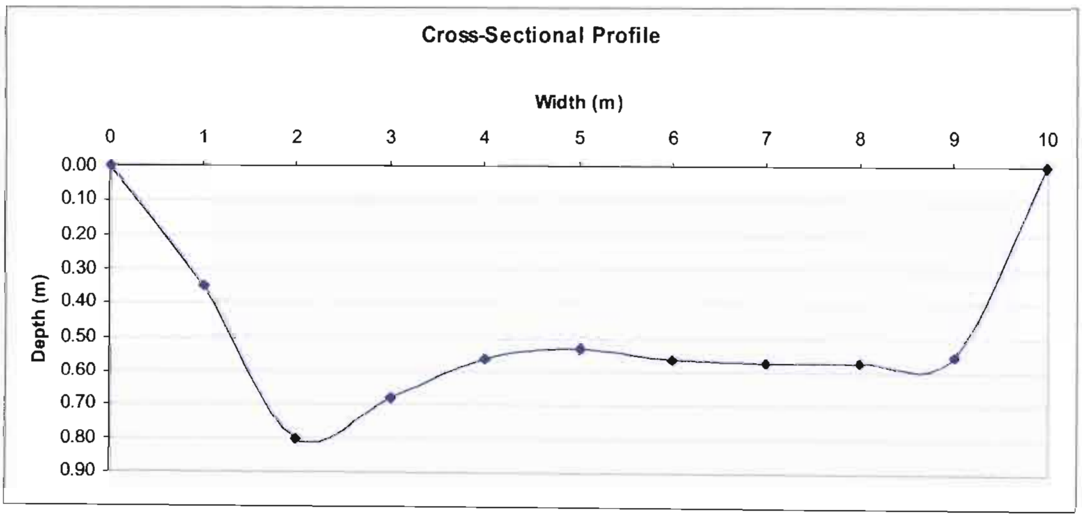



**Figure 3-6: The cross-sectional profile at Mhlanga Estuary measured on the 13 November 2002. The surface water level relative to MSL is 0.25m.**

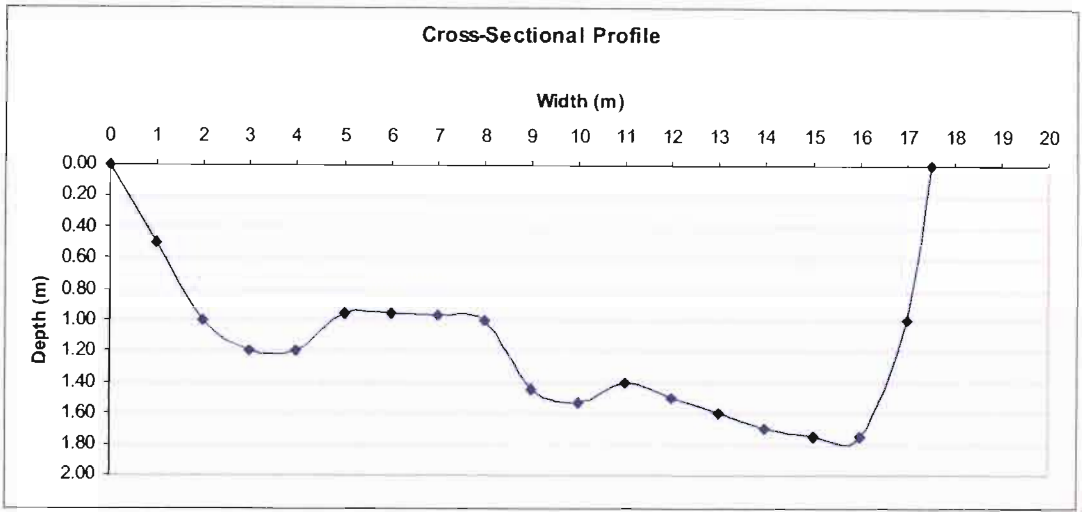



**Figure 3-7: The cross-sectional profile at Mdloti Estuary measured on the 22 January 2003. The surface water level relative to MSL is 2.25m.**

### 3.1.5. Abstractions and discharges

The Department of Water Affairs and Forestry (DWAF) provided information on the discharges from Hazelmere dam into the Mdloti River. The average discharge stated in table 3-1 was calculated from 20 years of complete data between 1977 and 2002, excluding the 1987 data. The 1987 data was excluded as the flood event occurring during this year was reported by Perry (1989) as probably the maximum experienced by Mdloti Estuary and therefore would bias the data. eThekweni Municipality Water and Sanitation (EMWS) provided information on the volumes of treated effluent discharged from the Mhlanga and the Phoenix Waste Water Treatment Works (WWTW) into the Ohlanga River upstream of Mhlanga Estuary (shown in figure 3-2). The current annual discharge or capping flow is approximately 7.2 x $10^6 m^3/yr$ ($0.23 m^3/s$). The effluent discharges from the Verulam and the Mdloti WWTW (see figure 3-2) have a current annual discharge of approximately 2.7 x $10^6 m^3/yr$ ($0.086 m^3/s$). These WWTWs are situated downstream of Hazelmere. Table 3-3 presents the discharges from the various WWTWs.

**Table 3-3: Summary of discharges.**

| WWTW | Discharge (million $m^3$/yr) | Discharge ($m^3$/s) |
|---|---|---|
| **Mhlanga** | 2.62 | 0.083 |
| **Phoenix** | 4.75 | 0.15 |
| **Mdloti** | 0.37 | 0.012 |
| **Verulam** | 2.33 | 0.074 |

Water is abstracted from Mdloti River by Tongaat-Hullet for irrigation and domestic use. The estimated abstraction is 5.9million cubic meters per year (0.19$m^3$/s). Water meters were recently installed; however this data is not yet available (Gurney, 2003).

The natural MAR reported in Midgely and Pitmann (1994) for the quaternary catchments was scaled by the catchment areas of Mhlanga and Mdloti Estuaries to obtain the natural MAR figures in table 3-1. For Mhlanga Estuary the present day Mean Annual Stream-flow (MAS) was determined by adding the discharges from WWTWs to the natural runoff. The present day MAR for Mdloti Estuary was calculated by adding the discharge from Hazelmere Dam and the WWTW to the natural runoff for Mdloti Estuary for the catchment area in U30B, and subtracting the abstractions. The discharge from Hazelmere Dam effectively replaces the runoff from quaternary catchment U30A, as it falls upstream of Hazelmere Dam, which would naturally enter Mdloti's estuarine system.

### 3.1.6. Weather data

Weather data, from the Mount Edgecombe station (reference number 0241072), was obtained from the weather bureau as it is the closest weather station to the two estuaries. The Mount Edgecombe station is situated approximately 11km south-west of Mdloti Estuary and 6km west of Mhlanga Estuary.

## 3.2. Mdloti Estuary

Mdloti Estuary has been transformed from its natural state through several human influences, both directly and indirectly. The largest direct influence on the hydrodynamics of the system is the Hazelmere Dam. Hazelmere Dam was constructed in 1975 and has a net capacity of 23.2 x $10^6 m^3$, with a surface area of approximately 223.9 ha. The effect of the dam on the hydrodynamics is to attenuate flood flows, release less flow under drought conditions and to change the seasonal stream flow pattern. The quaternary area U30A, is the portion of the Mdloti catchment area upstream of Hazelmere Dam. The average monthly stream-flow from the Hazelmere Dam is shown in figure 3-8 together with the simulated natural stream flow for the U30A catchment obtained from Midgley, et al. (1997). It was expected that the flow released form Hazelmere Dam would be lower than the simulated natural stream-flow, however this is not the case. Either the simulated data underestimates the natural stream-flow for the catchment or there is an overestimation of the flows released from Hazelmere Dam creating this inconsistency.

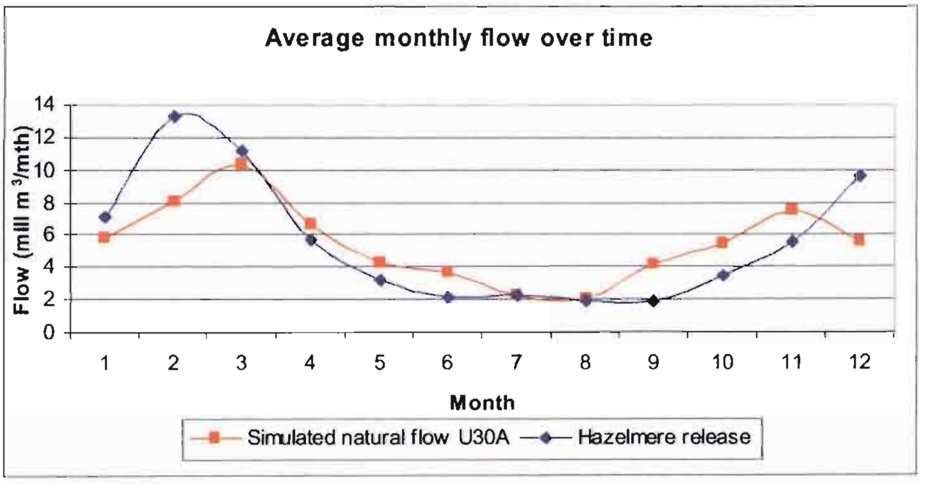



**Figure 3-8: Plot of seasonal variations in flow, both simulated natural stream-flow and actual flow released from Hazelmere Dam.**

Hazelmere Dam is not the only factor affecting the stream flow; water is also directly discharged and abstracted from the river. Discharges into the estuary are in the form of treated waste water released from two WWTWs, namely Verulam WWTW and Mdloti WWTW (see figure 3-2). These discharges add a capping flow to the existing flow throughout the year and increase the organic and nutrient loading in the estuary. Water is abstracted for both irrigation of sugarcane and domestic purposes, lowering the flow rate.

The sugarcane plantations which cover a large portion of the Mdloti catchment area, not only impact the estuarine system through abstraction of water, but also affect the available runoff from the catchment. CSIR (2002) reports that agricultural use of the floodplain and catchment area surrounding an estuary can result in increased nutrient and sediment loading. Along with the increase in sediment loading and therefore turbidity, fertilizers, pesticides and insecticides are also introduced into the system.

Human influence has also had an impact on the breaching position of the estuary. Plate 3-1 shows the different locations at which the estuary breaches.

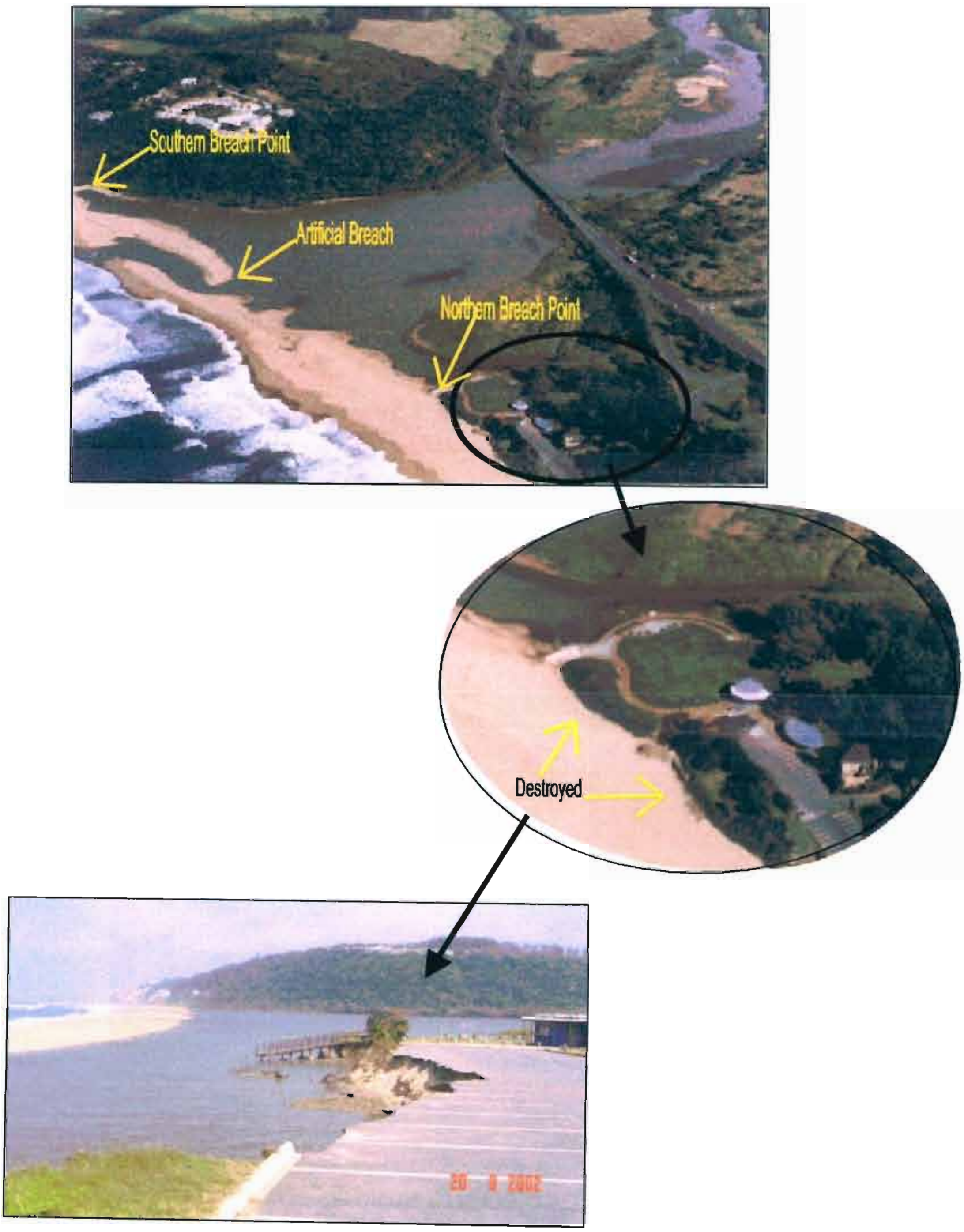



**Plate 3-1: The change in position of breaching at Mdloti Estuary and the destruction caused by the recreational centre.**

Historically Mdloti Estuary breached towards the south in a rocky region. This natural breaching point has a rock sill which prevents the estuary from emptying completely.

Previously Mdloti Estuary has been artificially breached in order to protect houses built on the fore dunes from being undermined and crops in the flood plains from being inundated. When the estuary is artificially breached, a channel is made in the centre of the berm, rather than at its natural location to the south. Artificially breaching the Mdloti Estuary, in the centre of the berm, results in the estuary emptying completely. (PPDC, 2002 Draft).

At the time the photograph was taken the estuary had been artificially breached at the location shown. Since the construction of the recreational centre on the northern bank of the estuary the vegetated dune north of the estuary has been undermined and eradicated as far back as the seaward facing parking bays. It appears that the developments have altered the natural flow path of the estuary, particularly in the northern region and have caused a reduction in berm width to the north, possibly aiding the occurrence of breaching in this region.

Other direct human impacts on the estuary include the construction of the M4 bridge across the estuary. In order to build this bridge, embankments were required and these embankments resulted in the loss of the old flood channel on both the northern and southern banks, as seen in plate 3-2. The bridge and embankments would therefore also have altered the flow and sedimentation patterns.

**Plate 3-2: The effect of the construction of the M4 bridge.**

The northern embankment of the bridge lies directly in the path of flood waters, and both embankments restrict the flood flow. To deflect the flood waters away from the northern embankment another embankment was constructed.

The flood of 1987 led to a much wider mouth eliminating the majority of the berm. Plate 3-3 was taken prior to the flood and the contrasting flood conditions are shown in plate 3-4. The flood also resulted in the failure of the bridge across the estuary.

**Plate 3-3: An aerial photograph taken in 1985, showing pre-flood conditions. (Perry, 1989)**


**Plate 3-4: The affect of the 1987 flood on the sand berm of Mdloti Estuary. (Perry, 1989)**

Sandwinning operations upstream of Mdloti Estuary have also had an impact on the environment (PPDC, 2002 Draft). During mining vegetation is destroyed or removed to create several access paths to the operation. Often the river is deviated during a sandwinning operation in order to provide storage areas, however after the operation ceases there is often little attempt at rehabilitating the area. Equipment required for the operation is generally serviced in close proximity to the river creating pollution. A further impact is the suspension of sediment leading to increased silt loading in the estuary.

## 3.3. Mhlanga Estuary

The sand bar separating Mhlanga Estuary from the sea was historically a vegetated sand dune, as shown in plate 3-5. Begg (1984) reported the loss of vegetation to the north due to trampling. As a result of the loss of vegetation, wind erosion affected this section of the berm lowering it and allowing for over-wash. This weakened this part of the berm and in 1980 a small flood broke through, altering the natural position of the mouth. It is possible that the combination of trampling of vegetation and a large flood resulted in the loss of the rest of the vegetation on the dune. The lack of vegetation means the berm has lost some of its protection as the plant coverage helps to keep the sand intact. The present state of the berm is shown in plate 3-6.

The mouth of the estuary is generally located to the south, as seen in the plates; this phenomenon has not changed despite the loss of vegetation of the dune, and possible reduction in berm height. The southern portion of the estuary has a reef within the onshore zone, which could influence the position of the breach.

**a)**

**b)**

**Plate 3-5: Plates a) & b) show the estuary in the open and closed state before the loss of the vegetated dune (Whitfield, Bate, Colloty and Taylor, www.upe.ac.za).**

**a)**

**b)**

**Plate 3-6: Plates a) & b) show the present state of the estuary in both the closed (a) and open (b) states.**

Human exploitation of Mhlanga Estuary and the surrounding catchment area, include the encroachment of sugarcane plantations, bridges and the discharge of treated waste water. The effect of the sugar plantations within the catchment is to increase the silt loading in the estuary, in turn affecting the turbidity and light attenuation in the estuary (CSIR 2003). The runoff from a catchment covered in sugarcane will have the same or lower runoff than if the catchment were covered by grasslands depending on the soil thickness (Schmidt, Smithers, Schulze and Mathews, 1998). Where sugarcane has been planted in the floodplains it has encroached on natural wetlands, which has particularly affected the northern bank of Mhlanga Estuary.

The embankments which form part of the bridge across the estuary encroach on the natural habitat of the estuary reducing the reed beds in the vicinity. Construction of such a structure places limitations on the estuary, particularly under flood conditions when the flow is restricted by the bridge.

There are two waste water treatment works which discharge treated effluent into the Mhlanga Estuary, namely the Phoenix and the Mhlanga WWTWs. The discharges have two major impacts on the estuary. Firstly the discharge contains nutrients which flow directly into the estuary and can lead to eutrophication. Secondly, and more relevant in terms of this study, the introduction of treated effluent increases the flow into the estuary by approximately 58% of the natural MAR.

Another factor which could affect both estuaries is urbanisation within the catchment. Urbanised areas generally have a higher runoff, which is usually collected in storm drains and can be discharged into the estuaries without screening. Runoff from the N3 and M4 also discharges into the estuaries, along with any pollutants washed from the road.

### 3.4. Summary

The two case studies presented are situated close to one another in similar climatic regions. However, in terms of the way that the changes in flow have impacted on the functioning of the estuaries, they provide examples of different scenarios. Mdloti Estuary experiences less flow than would naturally occur, whilst Mhlanga Estuary experiences an elevated flow. Furthermore the nature of the flow changes imposed on the estuaries are also different. A summary of the key characteristics is given in table 3-4.

**Table 3-4: Summary of key characteristics.**

| Characteristic | Mhlanga Estuary | Mdloti Estuary |
|---|---|---|
| Catchment area ($km^2$) | 80 | 484 |
| MAR (million $m^3$/yr) | 12.7 | 83.1 |
| ΔFlow/MAR (%) | +58 | -8 |
| % closed (natural) | 82 | <5 |
| % closed (present) | 55 | 69 |

The main change affecting Mdloti Estuary is the construction of the Hazelmere Dam, which severely attenuates flood flows, while also reducing flow during low flow periods. Abstractions also have a large impact on low flows. From table 3-4 it is shown that the reduction in flow has resulted in an increase in the percentage of time the estuary is closed.

In contrast at Mhlanga Estuary the addition of the treated effluent to the stream-flow has had a large effect in increasing the low flows, while having relatively little impact on flood flows. Table 3-4 shows that the increase in flow has resulted in a decrease in the percentage of time the estuary is closed.

# 4. FIELDWORK METHODOLOGY

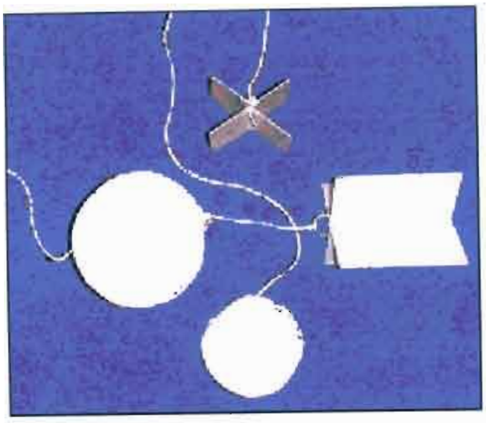
## 4.1. Introduction

During the project a range of data was collected in the field. Water levels and flow rates were a large portion of the fieldwork for this project. Surveying was also required and this ranged from the use of a GPS to link the water levels within the estuary to mean sea level, to a photographic survey of the beach to monitor the change in the beach profile. KZN Wildlife provided daily monitoring of the mouth state, and data on salinity concentrations were obtained by the UND biology department. The methodology and theory are discussed in this section to establish the nature and relevance of the fieldwork.

## 4.2. Flow measurements

Direct measurements of the inflows into the estuary were made at several stations upstream of the estuary. Initially flow measurements were made using a drogue comprising of a float and a drag vane shown in plate 4-1 a). The method involved timing the drogue, as it travelled a known distance at discrete intervals across the width of the river. Where possible the vane was set to approximately 0.6 times the river depth in order to obtain the average velocity of the vertical velocity profile. The method was limited as it required a uniform straight channel and wind and reeds sometimes interfered with the drogues. Depth was also a limiting factor, as only the surface velocity of shallow water could be measured. Cross-sections were obtained manually using a sounding rod while wading across the river as shown in plate 4-1 b). It is estimated that the error associated with the use of drogues varies from 10 to 40%.

Since February 2003 the Model 3000 Swoffer instrument, shown in plate 4-2, has been used to determine the velocities and the flow rates upstream of the estuaries. The instrument is a propeller type velocimeter which uses a 2 inch propeller and a photo-fibreoptic sensor to determine the velocity of the water from the rotation rate of the propeller. The velocity range of the instrument is from 0.03 to 7.5 meters per second, with an accuracy of approximately 1% (Swoffer Instruments, 2002). The velocimeter is fitted to a wading rod which is used to determine the river depth at discrete intervals across the river width. Both the depth and distance across the width of the estuary are manually entered into the portable micro-computer. The average velocity is measured at each position, with the propeller set at 0.6 of the river depth, and recorded in the portable micro-computer. The flow rate through the cross-section is computed by numerical integration.



**a)** **b)**

**Plate 4-1: The photographs show: a) the drogues and b) the determination of the cross-sectional area.**


**a)** **b)**

**Plate 4-2: The plates show: a) the Swoffer instrument and b) the Swoffer instrument in use upstream of Mdloti estuary.**

## 4.3. Water level monitoring

A key aspect of the study of estuarine dynamics is the monitoring of changes in water level. Initially the water level was monitored using photographs of the M4 bridges at Mhlanga and Mdloti Estuaries. The measured height of the top beam and the height of the column were used to scale the water height from digital photographs, relative to the pile cap. Figure 4-1 shows the dimensions of the bridges used to scale the water level from the photographs.

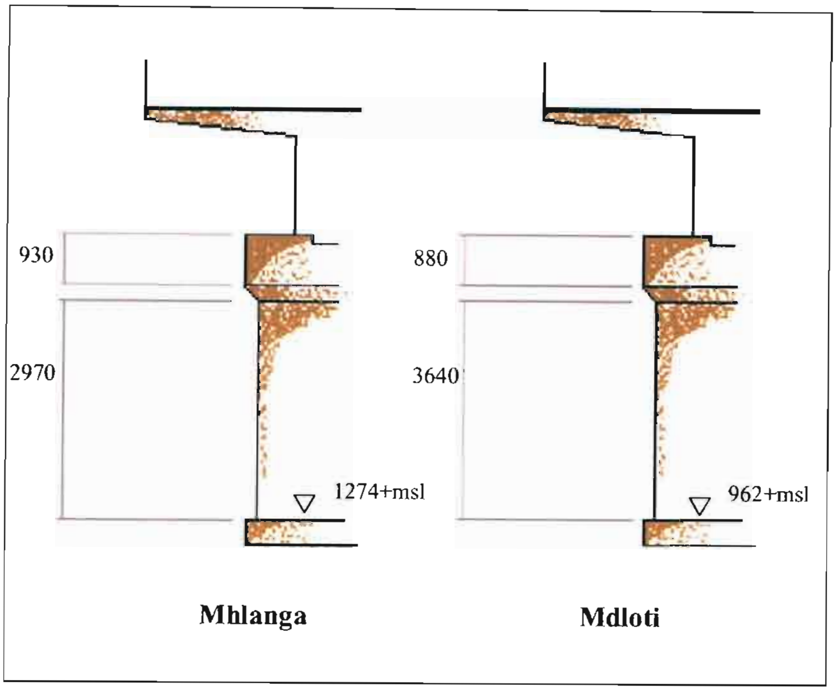



**Figure 4-1: The dimensions of the M4 bridges over Mhlanga and Mdloti Estuaries.**

The digital camera used to take the pictures to determine the water level has a resolution of 1600 by 1200 pixels. Depending on the position from which the photograph was taken relative to the bridge the data extracted from the photographs has an accuracy ranging from 10 to 300 mm. Lower accuracies occurred on days when there was poor visibility when photographs were taken from the beach. The quality of photographic data improved with the discovery of access to the bridges alongside the M4.

The need for continuous water level monitoring became apparent in 2002 as weekly water levels did not provide an adequate level of accuracy in terms of temporal resolution. High resolution records of water level fluctuations can be used to provide a record of when the estuary changes state, (i.e. whether it is open or closed) as well as giving an indication of the volume of water stored in the estuarine system. The data recorded could also show short term changes due to rain events, or when the water level remains constant it is indicative of the system losses, such as seepage, being equal to the inflows into the estuary. Any tidal influx into the estuary when in the open state, would also be visible from the data logged. It was therefore decided that an instrument would be developed to continuously monitor the water level in the estuaries.

The instrument was required to be small, compact and waterproof so that it could be placed below the low water level, out of sight. It was important to limit visibility and accessibility to the instrument in order to diminish the risk of vandalism and theft, particularly when the water level is low. Alternatively a big structure could have been used to protect the device, however this was less desirable as it would interfere with the estuary aesthetically, attract unwanted attention and it would be cumbersome to install.

Based on the above considerations it was decided to use a pressure sensor linked to a small data logger, housed in a sealed capsule. The capsule was placed in a perforated container which formed a permanent fixture during the monitoring period.

Figure 4-2 is a schematic diagram of the preliminary design of the water level monitor (WLM), incorporating the use of the Tinytalk TK0702 miniature data logger.

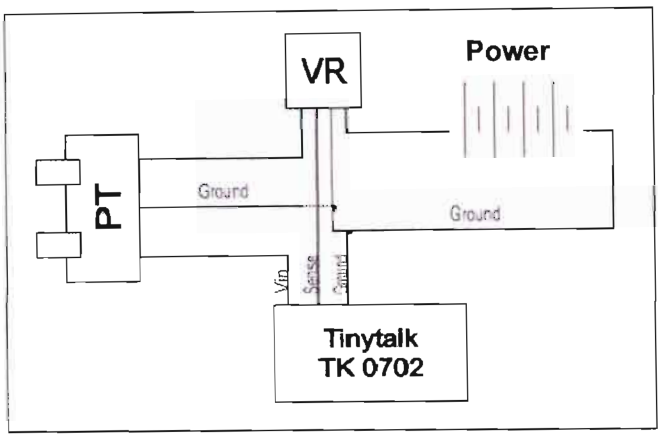



**Figure 4-2: A schematic diagram which was the basis of the WLM design. Where PT is the pressure transducer and VR the voltage regulator.**

In this application it was decided that logging was to be done at hourly intervals. This time span is more than adequate during the closed phase. However a higher resolution is preferable during breaching and the open phase which can display changes in water level of up to 1240 mm and 300mm in one hour respectively. A compromise between the requirements for the open and closed phases was required as the logger can only store in the region of 1800 data points, therefore the data logger can operate for 75 days set on the hourly interval. The tinytalk logger logs the voltages it receives from the pressure transducer after it outputs a sensing signal pulse to indicate a reading is imminent. The sensing signal was used to trigger the powered warm-up period for the pressure transducer prior to taking the reading, allowing it to stabilise.

The Motorola MPX 5050 pressure transducer was chosen based on availability, function and affordability. A differential pressure transducer vented to the atmosphere can provide a direct water level reading accounting automatically for barometric pressure variations. However a problem arises with visibility of the instrument, as a vent to the atmosphere would be visible above the water line and was therefore undesirable. It was therefore decided to simply determine the water pressure, relative to the pressure within the sealed capsule and to subsequently compensate for changes in barometric pressure during post processing. The pressure transducer has an error estimated to be 2.5% of the total range under all conditions.

A problem arose with the initial design of the water level monitor as the sensing signal generated by the logger only allows for a 150 millisecond warm up period, whilst the pressure transducer requires 15 seconds to warm up. To overcome this problem a PIC microcontroller was incorporated with the technical assistance of Mr R Van Zyl, from the University of Natal Pietermaritzburg (UNP). This microcontroller was programmed to continuously monitor the time between sensing signals and used this time to turn on the voltage regulator for the required 15 second warm up period prior to sampling. Plate 4-3 shows a Tinytalk data logger and the pressure transducer mounted on a printed circuit board designed and built by Mr R van Zyl of UNP and incorporating the PIC microcontroller. The circuitry for the board, the component list and costs are given in appendix D.

The Tinytalk TK0702 has an eight bit resolution; therefore it has 256 levels (from 0 to 255) to measure a 5 meter column of water giving an accuracy of approximately 20 millimetres. Compensation for changes in atmospheric pressure is required as variations of 200 mm can occur over extended time periods. The manufacturer's specifications are included in appendix E.


a) b)

**Plate 4-3: Different views of the Tinytalk data logger and the pressure transducer mounted on a circuit board along with the microprocessor, are shown in a) and b).**

The pressure transducer also required an external power source in the form of batteries. In determining the battery specifications a compromise between size and durability was required. The pressure transducer requires a 5 volt supply, and in order for the voltage regulator to supply a regulated 5 volts, an minimum input voltage of 5.5 volts was required, therefore 4 AAA alkaline batteries were used, supplying a 6 volt voltage.

**Plate 4-4: The materials for the capsule comprising of perspex tubing and HDPE end plugs.**

Electronic equipment requires a dry environment in which to function, therefore the water level meter needed to be housed in a water tight capsule. A clear Perspex tube was used with an inner diameter of 34mm and a 40mm outer diameter. The end plugs were constructed on a lathe from a 50mm diameter high density polyethylene (HDPE) rod. The casing and raw materials are shown in plate 4-4. O-Rings and silicone grease were used to create the seal between the plugs and the tube. One plug was drilled in order to accommodate the pressure sensor, the exposed surface was countersunk and recessed grooves were machined as a precaution to prevent false readings when using a bladder, described below. A bleed hole was created in the other cap by drilling and tapping a hole, with a screw as a bleed cap and a greased o-ring to ensure no leaks. Both the electronics and the casing were tested under laboratory conditions before placing the water level monitors in the field. The test cell shown in plate 4-5 was used to test the water level monitors.

According to the manufacturer's specifications for the pressure transducer, attached in appendix E, the optimum operating conditions are in air, therefore the water level monitor was sealed in a 150 µm, flexible, air filled plastic bladder, heat sealed by means of a soldering iron, as shown in plate 4-6(a). Initial trial installations showed that the bladders were, however easily punctured in the field causing errors in the data retrieved. As the bladders were proving unreliable in the field, they were discarded and the loggers were simply placed into the estuary with a porous geo-fabric cover over the end cap, as seen in plate 4-6(b). The geo-fabric allowed water to reach the pressure transducer but traps dirt from the water, preventing it from disturbing the pressure readings or blocking the pressure port.

**Plate 4-5: Test cell used for experiments conducted with the water level monitors.**


a)


b)

**Plate 4-6: The data logger a) enclosed in a bladder and b) with geo-fabric cover.**

In order to ensure the water level monitor was always placed in the same place and could not float away a perforated container was fixed in the estuary. The initial canister design was a section of steel pipe sealed on one end with a lid on the other attached to a steel stake about 1 meter in length. The idea behind the design was that the stake would be driven into the floor of the estuary near the M4 bridge, however this did not work in practice as it was not easy to drive the stake into the ground underwater. The second design consisted of PVC pipe with an end cap on one side and a lid on the other. This canister was attached to the piles underneath the bridge pile caps using stainless steel brackets, rope and stainless steel wire. Scuba divers, shown in plate 4-9, were used to place the containers under the pile caps. The position of the canisters at Mdloti and Mhlanga Estuaries are shown in plate 4-7 and 4-8 respectively.


**Plate 4-7: The canister was placed under the pile cap of the first column of the northern end of the M4 bridge at Mdloti Estuary.**

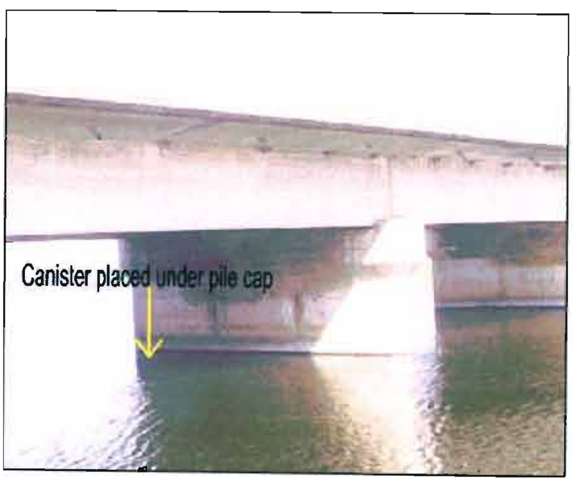



**Plate 4-8: At Mhlanga Estuary the canister was placed under the pile cap of the first column of the M4 bridge on the Northern side at the position shown.**

The water level monitors were retrieved on a regular basis, not exceeding 75 days as this was the limit set by the available memory of the logger when using one hour logging intervals. The water level monitors were placed in a test chamber under different pressures, both before and after being placed in the estuary, to calibrate the instrument.


**Plate 4-9: Installing the water level monitors using the boat and divers. The plate on the left shows the divers holding the canister before installation.**

## 4.4. Salinity

An estuary is defined as a junction between a river and the sea, therefore by analysing the salinity distribution it can be determined which parts of an estuary are influenced by the river flow and which by tidal flow. In the case of a temporary open, perched estuary the increased salinity near the mouth over a closed period is probably from either overtopping or saline water trapped during closure.

In the case of temporary open/closed (TOC) estuaries it is expected that under open conditions and at low tide the estuary will exhibit a salinity profile dominated by freshwater, particularly if the estuary is perched. Conversely the estuary could experience tidal domination during high tide as waves push into the estuary.

As part of the fieldwork undertaken by the UND biology department, salinity samples were taken at three stations, the mouth, middle and head of the estuary, on a monthly basis. The vertical profiles of salinity were recorded using a YSI 6920 Water Logger, with five to ten centimetre resolution (Perissinotto, 2003). The salinity concentration in freshwater is less than 0.5 ppt, while marine water has a salinity of approximately 35 ppt at this location.

The purpose of investigating the salinity profile of an estuary in the context of this research was to determine the existence of patterns in terms of stratification and differences between the open and closed phases. The interaction between saline and freshwater within an estuary makes the estuarine environment unique. It was expected that Mhlanga and Mdloti Estuaries would have very limited tidal exchange as they are perched.

The salinity profiles obtained have several limitations. Only three stations within the estuary were sampled, the head, middle and mouth, with only one sample at each station. Should one of the sampling points be unrepresentative of the conditions, large errors could be obtained in the analysis of the data. In some instances readings were not taken consecutively. For instance, there was a difference of up to two hours between some readings, if this occurs when the estuary is open, the change in tide over the time interval could be large enough to affect the salinity measurements.

## 4.5. Surveying of the berm

The sea facing slope of the berm is continuously moulded by the sea, therefore a daily survey spanning a tidal cycle of two weeks, to cover tidal conditions from spring to neap and back to spring, was carried out in order to determine how these changes affect the breaching of the estuary. The study was conducted at Mhlanga Estuary as at the time it was the most active estuary of the two. Two positions were chosen to measure the profile changes, the first at the approximate position of the mouth and the second slightly north of the mouth position to provide a means by which to gauge the effect of the ocean even when the mouth is open. The measurements were taken at low tide, when there was maximum exposure of the beach slope.

Poles, marked at 25 centimetre intervals, were placed at the edge of the estuary and edge of the sea, with a rope between the two. The rope had two meter markings on it and at each two meter point a stake was driven into the sand. Photographs of the beach were taken using a digital camera fixed to a levelled tripod. The poles were used to provide a vertical scale for the picture while the stakes provided a horizontal scale. Levelling the tripod on sand was not always very accurate as sand is not a stable surface on which to work, therefore the horizon was used during post processing to ensure the data obtained was level. Plate 4-10 is an example of the photographs used in determining the beach profiles.

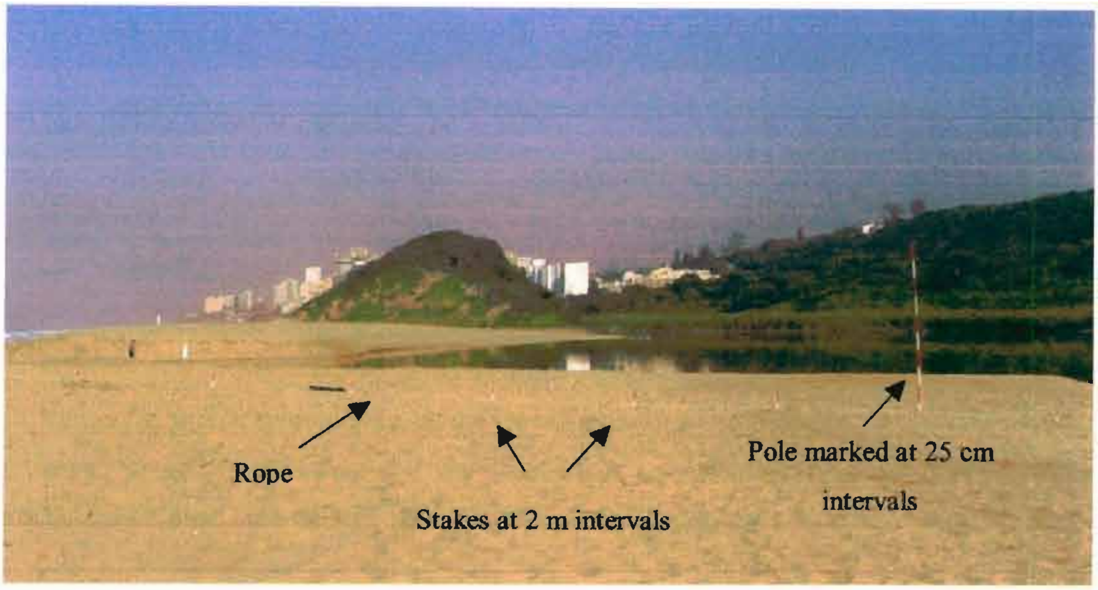



**Plate 4-10: Example of photographs used in the determination of beach profile.**

The method used to obtain the beach profiles had several flaws:

- Although the tripod was levelled, working on sand resulted in several photographs containing a tilt. Where possible the horizon was used to compensate for this.
- The position of the camera varied from day to day and in some instances was varied for specific cross-sections.
- Lighting was occasionally a factor distorting post analysis of photographs.

The digital camera used to take the pictures has a resolution of 1600 by 1200 pixels. The error associated with a half degree tilt of the camera over thirty metres is approximately 260 mm in the vertical and approximately 1 mm in the horizontal.

# 5. DISCUSSION OF FIELDWORK

## 5.1. Introduction

The main objective of the fieldwork was to determine the effects of flow on mouth state. Over the study period flow rates, water levels and mouth state were measured or observed, from which threshold flows for the various mouth states are discussed. The data collected also provides information on the losses associated with the system. As rainfall is an easier parameter to measure, and rainfall data is readily available this section also deals with the relationship between mouth state and rainfall. Mechanisms related to the mouth state such as failure and closure of the berm are discussed from observations made together with the data collected. The time scales associated with both the breaching and closure of the estuaries are also discussed.

## 5.2. Data collected

During the observation period from March 2002 to August 2003, field data was collected at both Mhlanga and Mdloti Estuaries. The data collected is presented in sections 5.2.1 to 5.2.5, and comprises of data on rainfall, mouth state, flow rates, water levels and beach profiles. This data provides the basis for the analysis which follows in sections 5.3 to 5.6.

### 5.2.1. Rainfall Data

Figures 5-1 and 5-2 present the daily rainfall events over the observation period from March 2002 to August 2003. This data was obtained from the South African Weather Bureau, and was collected at the Mount Edgecombe station (reference number 0241072)

The Mean Annual Precipitation (MAP) for Mhlanga and Mdloti Estuaries (quaternary catchment area U30B) is approximately 982 mm. The expected average rainfall for the Mt. Edgecombe weather station, near Mdloti and Mhlanga Estuary, between the months of January and August, is approximately 60% of the MAP, however the region received less than 30% of the MAP between January and August in 2003. Over the entire observation period (March 2002 to August 2003) the area received approximately 65% of the expected rainfall. A plot of the monthly rainfall over the observation period against the average monthly rainfall is shown in figure 5-3.

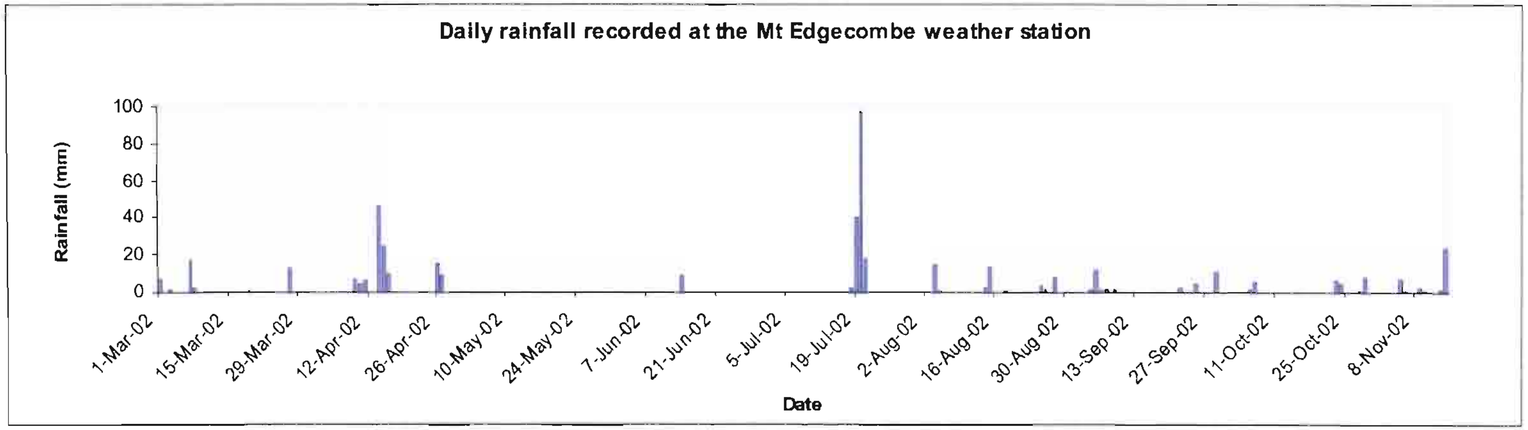



**Figure 5-1: Daily rainfall occurring between March 2002 and mid November 2002.**

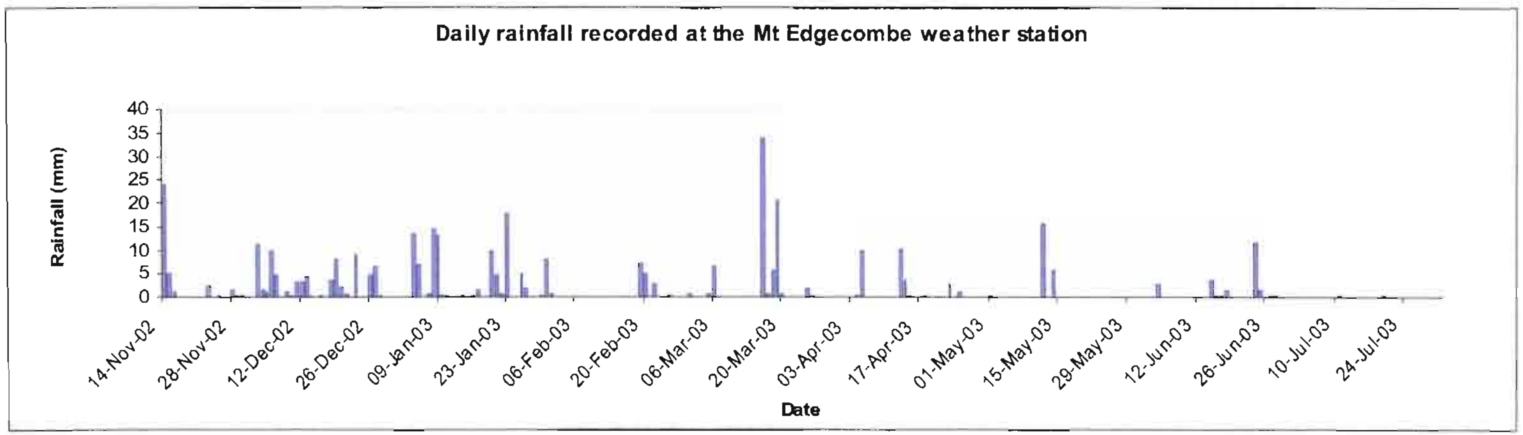



**Figure 5-2: Daily rainfall occurring between mid November 2002 and July 2003.**

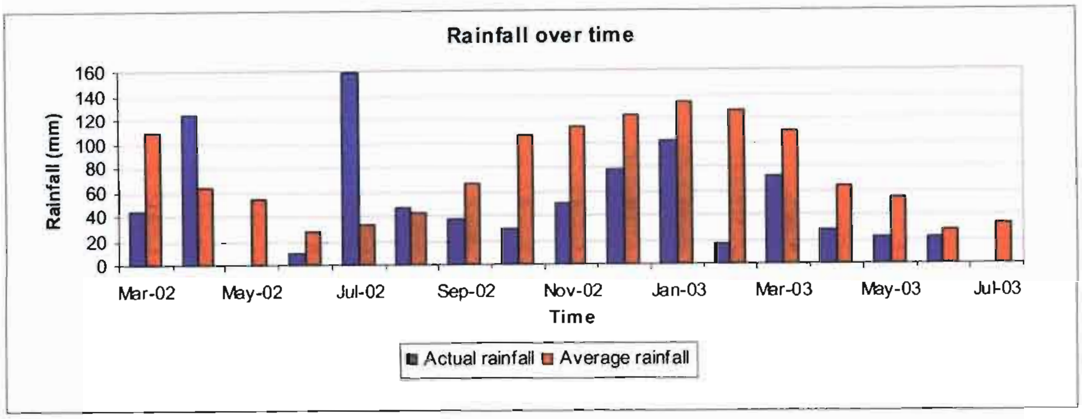



**Figure 5-3: Comparison of monthly rainfall over the observation period against expected average monthly rainfall.**

### 5.2.2. Mouth State

Data gathered on mouth state for Mdloti and Mhlanga Estuaries is presented in figures 5-4 and 5-5 respectively. The mouth states at Mdloti and Mhlanga Estuaries over the observation period are summarized in table 5-1. Appendix F contains all the data recorded relevant to mouth state.

**Table 5-1: Summary of the mouth state at Mhlanga and Mdloti Estuaries.**

| | Parameters | Quantity | Comment |
|---|---|---|---|
| Mdloti Estuary | No. of breaches | 9 | 6 within 3 days of neap tide, 2 on neap tide |
| | No. of partial breaches | 4 | 3 within 3 days of neap tide |
| | No. of days fully open | 103 | 21% |
| | No. of days partly open | 47 | 10% |
| | No. of days closed | 328 | 69% |
| | Total no. days with data | 478 | 100% |
| Mhlanga Estuary | No. of breaches | 18 | 9 within 3 days of neap tide, 3 on neap tide |
| | No. of partial breaches | 14 | 6 within 3 days of neap tide, 1 on neap tide, 1 on spring tide |
| | No. of days fully open | 146 | 27% |
| | No. of days partly open | 97 | 18% |
| | No. of days closed | 296 | 55% |
| | Total no. days with data | 539 | 100% |

Ramm et al. (1986) stated that Mhlanga Estuary is typically closed 96% of the time, while Mdloti Estuary is closed 64% of the time. CSIR, 2002 reports that Mhlanga and Mdloti Estuaries are closed/semi-closed 75% and 73% of the time respectively, under present conditions It was therefore expected that Mdloti Estuary would breach more frequently than

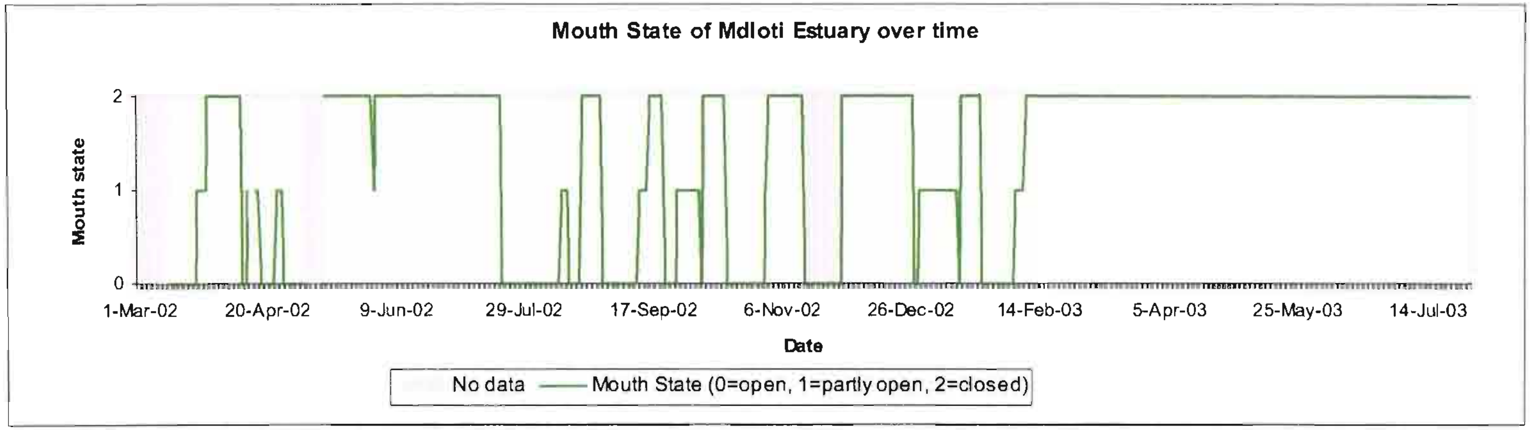



**Figure 5-4: The mouth state at Mdloti Estuary over the observation period.**

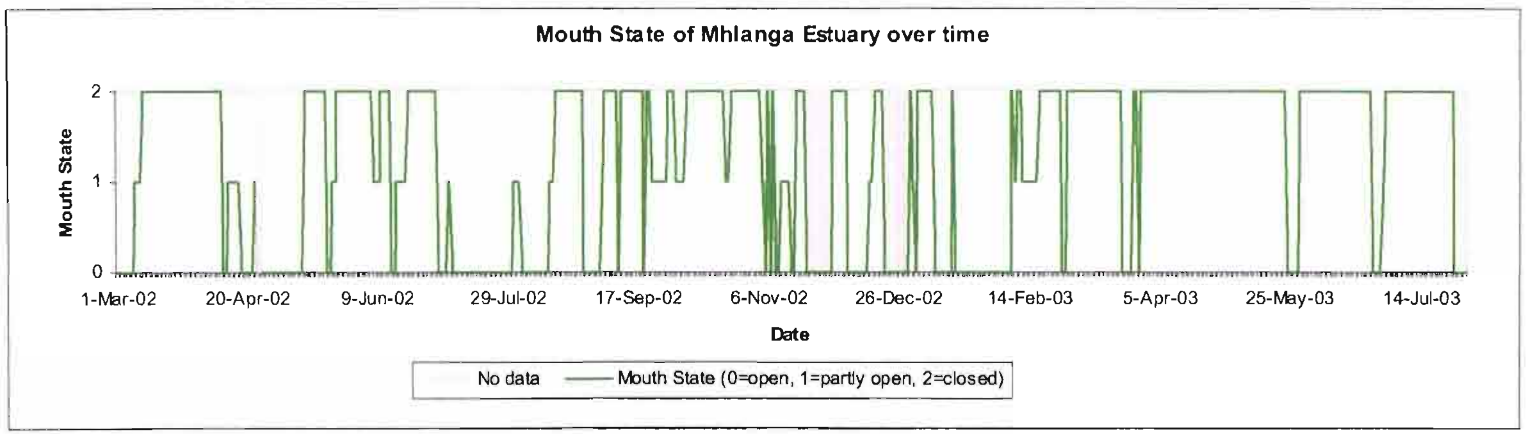



**Figure 5-5: The mouth state at Mhlanga Estuary over the observation period.**

Mhlanga Estuary. Even though Mhlanga and Mdloti Estuaries were open 27% and 21% respectively, Mhlanga Estuary breached double the number of times Mdloti Estuary breached. Since February 2003 Mdloti Estuary has remained closed, reflecting the lowered rainfall, however Mhlanga Estuary has continued to breach regularly.

### 5.2.3. Flow Data

Figures 5-6 and 5-7 show a plot of the flow rates measured at Mdloti and Mhlanga Estuaries respectively. Where flow measurements were made upstream of a WWTW discharge point, the estimated discharges, obtained from the EMWS, were added to the measurement. Appendix C contains the locations of the flow readings along with the cross-sectional data and velocity readings.

No flow measurements were made for Mdloti Estuary between February and June 2003, due to accessibility problems encountered upstream of the estuary, as seen in plate 5-1.

**Plate 5-1: Water hyacinth preventing flow measurements upstream of Mdloti estuary.**

The abundance of water hyacinth upstream of Mdloti Estuary made it very difficult to gain access to the head of the estuary by boat. After travelling as far as the hyacinth would permit attempts to measure the flow were unsuccessful as there was no measurable flow. While the estuary remained closed the water hyacinth remained a problem upstream. Eventually alternative access to Mdloti River via a small bridge near Mt. Moreland, upstream of the hyacinth problem, was found suitable for taking readings.

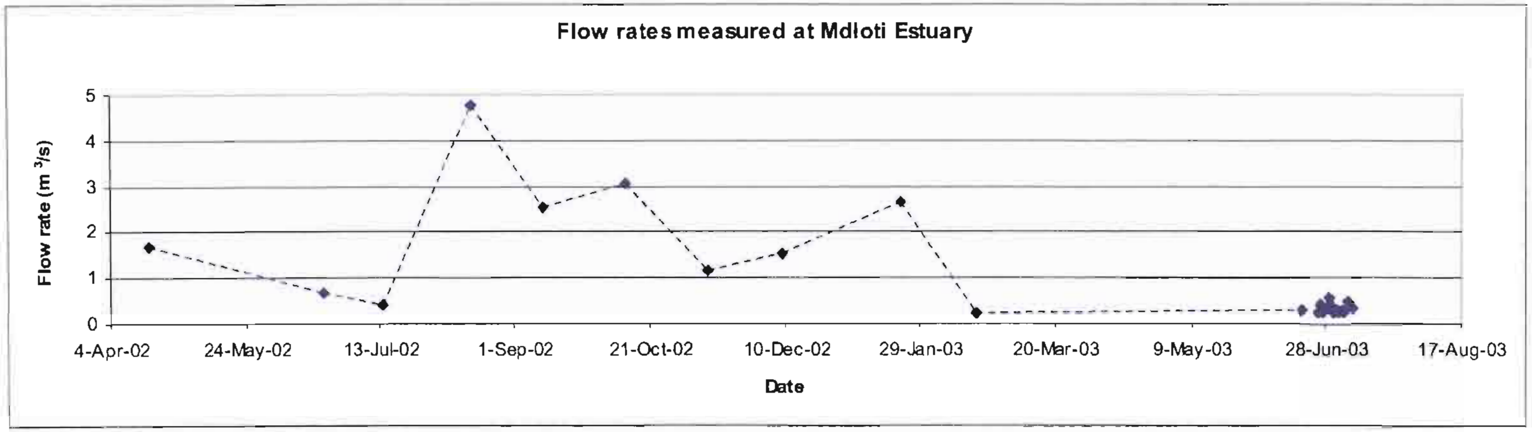



**Figure 5-6: Spot flow data measured at Mdloti Estuary over the observation period. (Points joined by dotted line for clarity).**

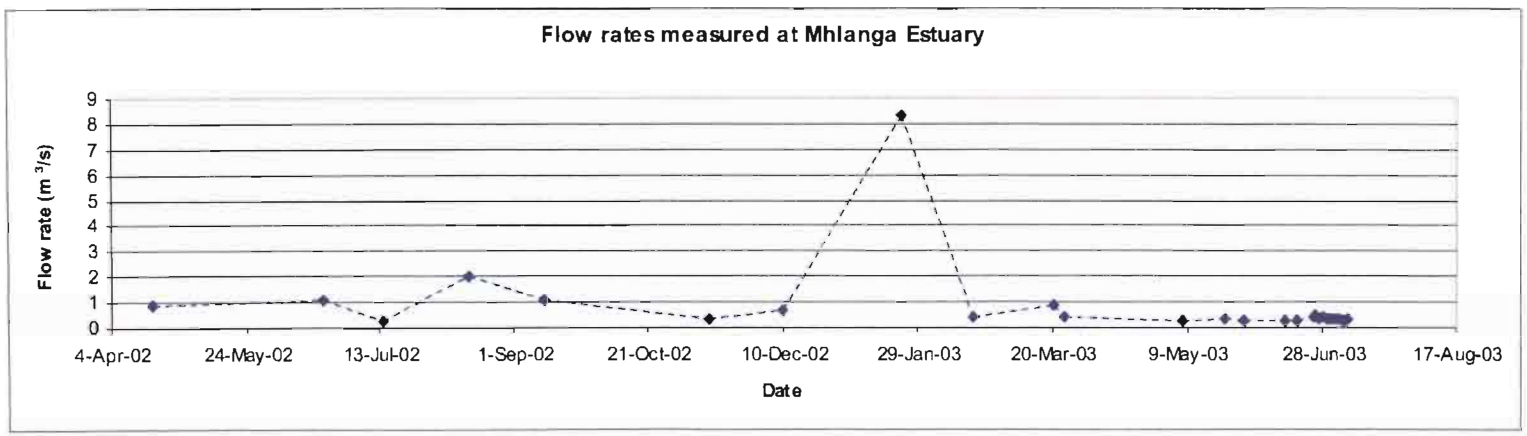



**Figure 5-7: Spot flow data measured at Mhlanga Estuary over the observation period. (Points joined by dotted line for clarity).**

Some of the other problems encountered in measuring flows at the estuaries included wind and reeds adversely influencing the drogues. The Swoffer instrument was only effective where wading was possible and required a minimum velocity of 0.03 m/s.

The average measured flow for each estuary, over the observation period, was determined using a simple arithmetic average of all the samples yields a value of $1.09m^3/s$ for Mdloti Estuary and $0.75m^3/s$ for Mhlanga Estuary. However these figures are biased as samples were taken more frequently in June and July of 2003 than in the other months. Therefore for each month an average of the flow readings was taken and one reading form each month averaged to obtain $2.08m^3/s$ and $1.40m^3/s$ for Mdloti and Mhlanga Estuaries respectively. A flow of $8.35m^3/s$ was measured at Mhlanga Estuary in January 2003 is included in the latter average even though it was a short lived flooding event that was not representative of the flows for that month. If the flooding event is excluded the average flow is $0.70m^3/s$.

The expected flow rate or MAS (inclusive of the effects of Hazelmere Dam, WWTW discharges and abstractions) was estimated, in chapter 3.1.5, to be 76.5 million $m^3/yr$ and 20.1 million $m^3/yr$ for Mdloti and Mhlanga Estuaries respectively. This is equivalent to $2.42m^3/s$ and $0.64m^3/s$. The average flow rate of $2.08m^3/s$ obtained for Mdloti Estuary is approximately 79% of the expected flow, which is reasonable as the estuary experienced only 65% of the expected precipitation. At Mhlanga Estuary the measured flow (excluding the flood event) was approximately 110% of the expected stream-flow. Mhlanga Estuary should have an average flow less than the expected stream-flow due to the low rainfall. This suggests that either the flow measurements were not representative of the actual average flows or that there were higher discharges into the estuary from the WWTW. Alternatively the MAR for Mhlanga Estuary could have been underestimated.

### 5.2.4. Water levels

The water level data was as expected lower when the estuary was open and shortly after closing than when it had been closed for a period of time. From the water level data for Mdloti Estuary figure 5-8 was produced. Figures 5-9, 5-10 and 5-11 represent the water level data for Mhlanga Estuary. Appendix G contains the water level data obtained from photographs of the bridges as well as an example of the data captured by the water level monitors.

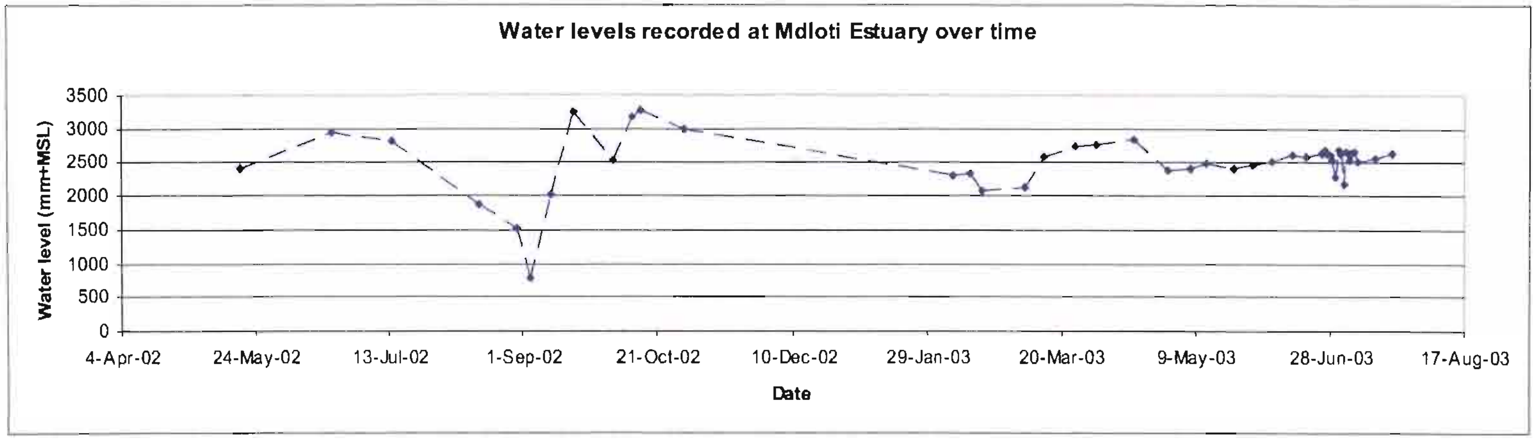



**Figure 5-8: Spot water level data measured at Mdloti Estuary over the observation period. (Points joined by dotted line for clarity).**

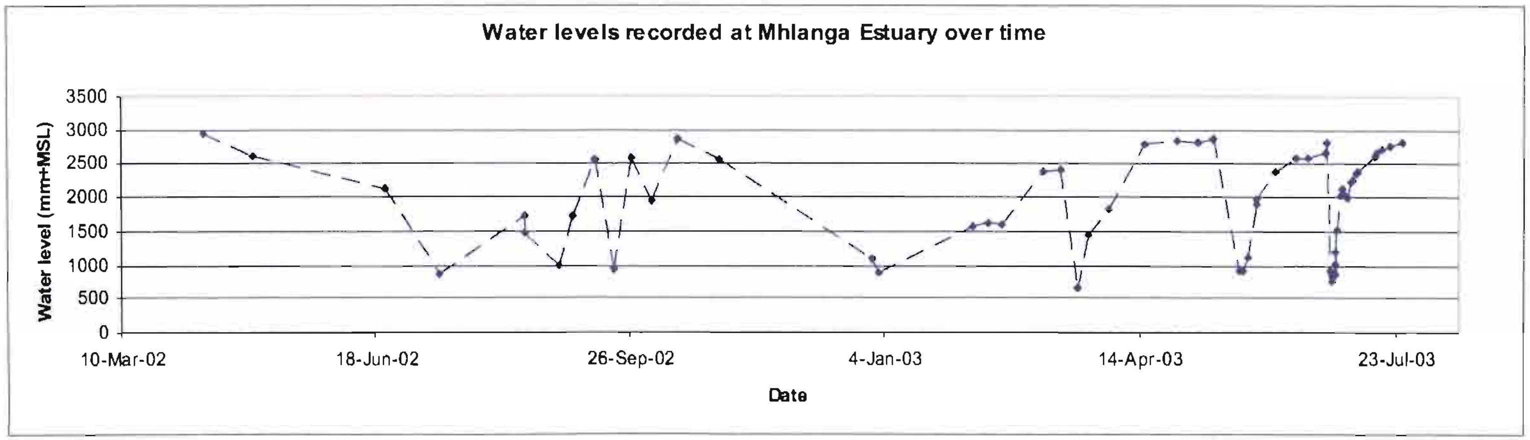



**Figure 5-9: Spot water level measurements at Mhlanga Estuary over the observation period. (Points joined by dotted line for clarity).**

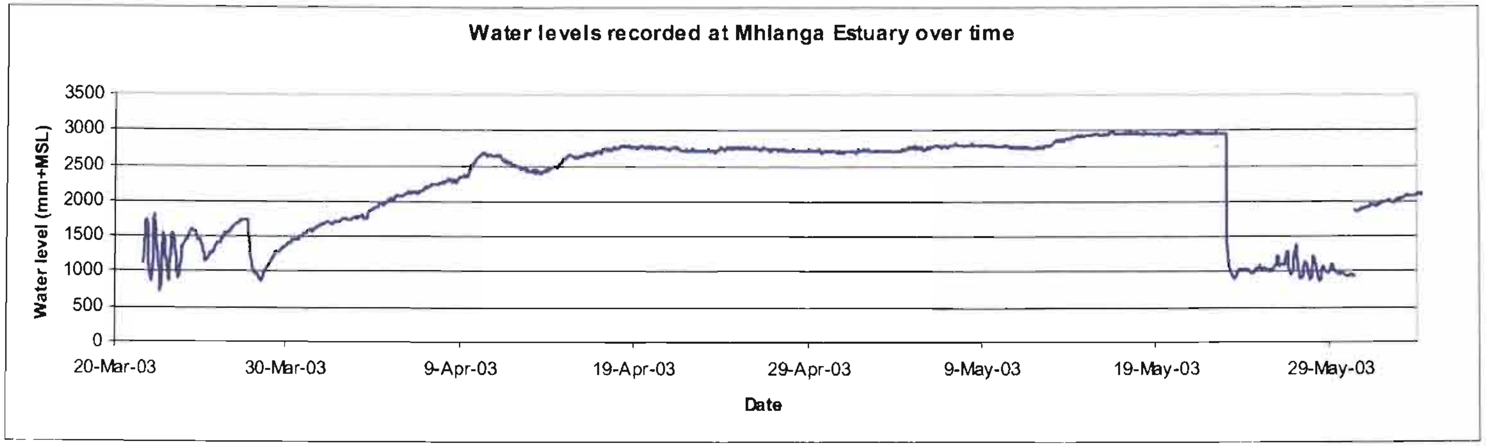



**Figure 5-10: Continuous water level data measured, using water level monitors, between March 2003 and August 2003.**

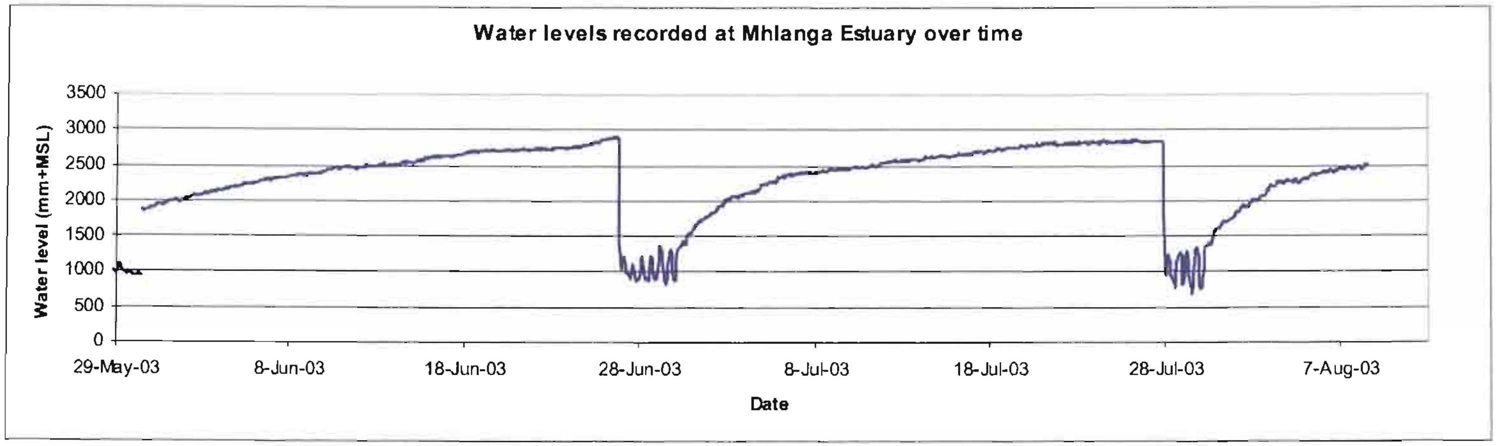



**Figure 5-11: Continuous water level data measured, using water level monitors, between March 2003 and August 2003.**

In figures 5-10 and 5-11 the continuous water level monitoring data over the period from the 23 May 2003 to the 30 May 2003 was erroneous due to instrument failure. From the water level data the maximum and minimum water levels for the estuaries was estimated. The maximum water level recorded at Mhlanga Estuary was 2960 mm above MSL, while the minimum water level recorded was 670 mm above MSL. At Mdloti Estuary the maximum water level recorded was approximately 3200 mm above MSL and the minimum water level was 780 mm above MSL.

From plate 5-2 and 5-3 of the M4 bridges over the two estuaries, distinct high water marks are visible. The various water marks indicate the different breaching levels attained by the estuaries.

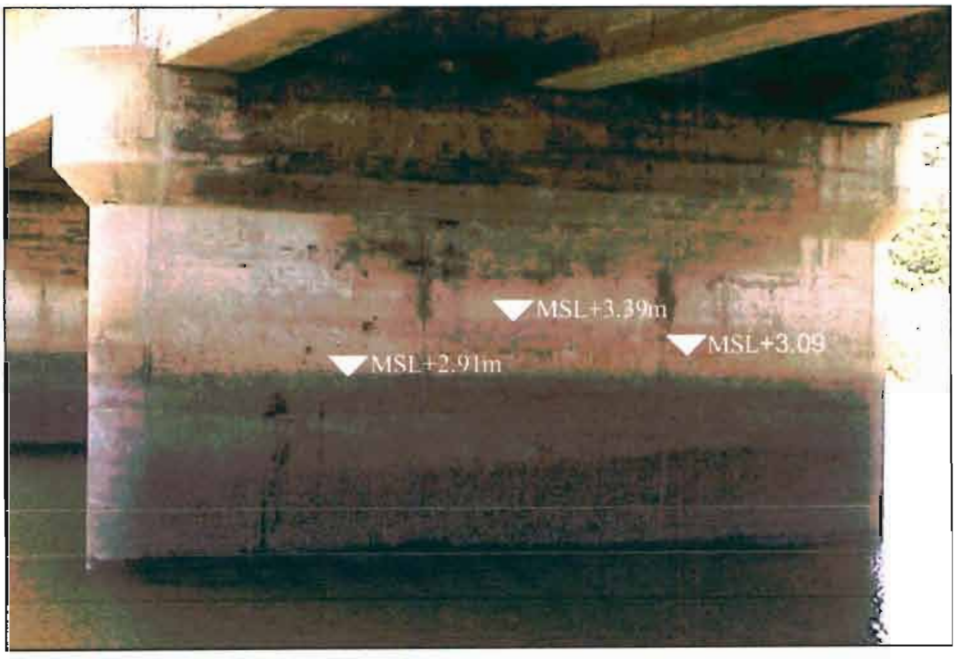



**Plate 5-2: The high water mark on the M4 bride over the Mhlanga Estuary.**


**Plate 5-3: The high water marks on the M4 bride over the Mdloti Estuary.**

The sand berm is a governing influence in determining the maximum water level of an estuary. The height of the sand berm is in turn a function of wave run-up. The relationship developed in Bagnold (1940) and discussed in section 2.9 estimated the berm height for the Durban area is in the region of 3 to 3.2 m, which concurs with the maximum water levels recorded at Mhlanga and Mdloti Estuaries.

### 5.2.5. Survey data

The beach profiles measured at Mhlanga Estuary over a two week period from the 25 June to the 8 July 2003, showed large changes. During the observation the tidal cycle shifted from spring through neap and back to spring. The profiles were taken at low tide when the beach was exposed, while some visual observations were made at high tide. Fortunately during the observation period the Mhlanga Estuary breached providing data on the mechanisms affecting the mouth of the estuary. This data can be used to estimate the volume of sand involved in closure as well as providing the opportunity to observe waves pushing water into the estuary and the process of closure of the estuary mouth. Examples of the data are shown in figures 5-12 and 5-13.

Daily profiles of the mouth area showed increases in sediment deposition in the mouth. This deposition was of the order of half a meter a day. During this breaching event the width of the berm was approximately 30m at the mouth, while the width of the mouth was approximately 26m. Therefore the wave action deposited approximately 400m$^3$ of sediment in the mouth of the estuary each day, that is $200m^3$ each high tide. This volume is far less than that of the longshore sediment transport for the Durban area, reported by Schoonees (2000) as $1400m^3$/day.

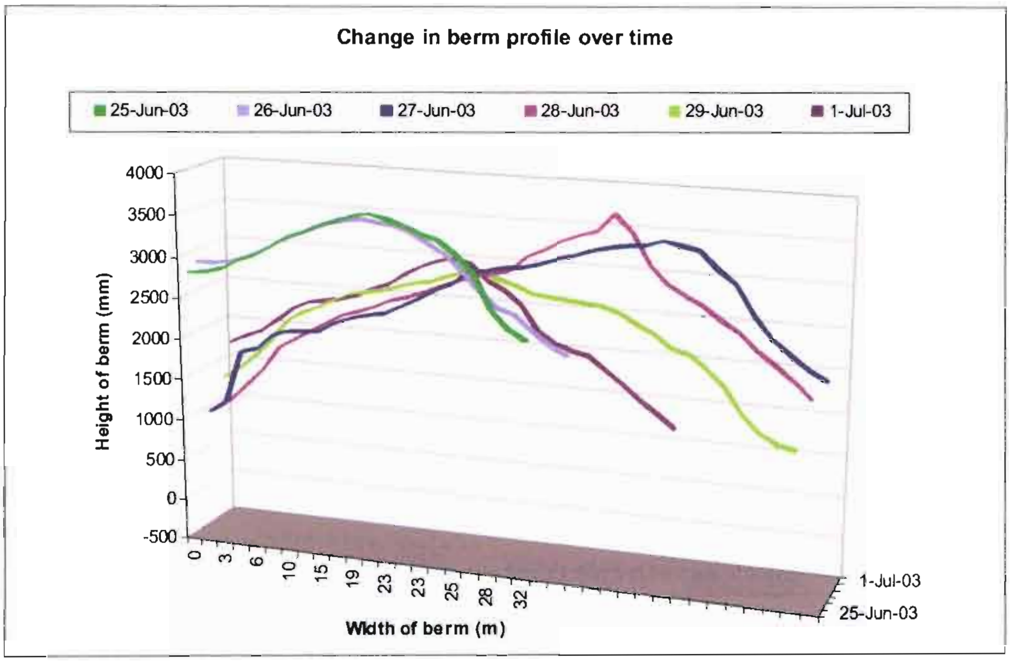



**Figure 5-12: Ribbon plots of selective beach profiles measured at Mhlanga Estuary.**

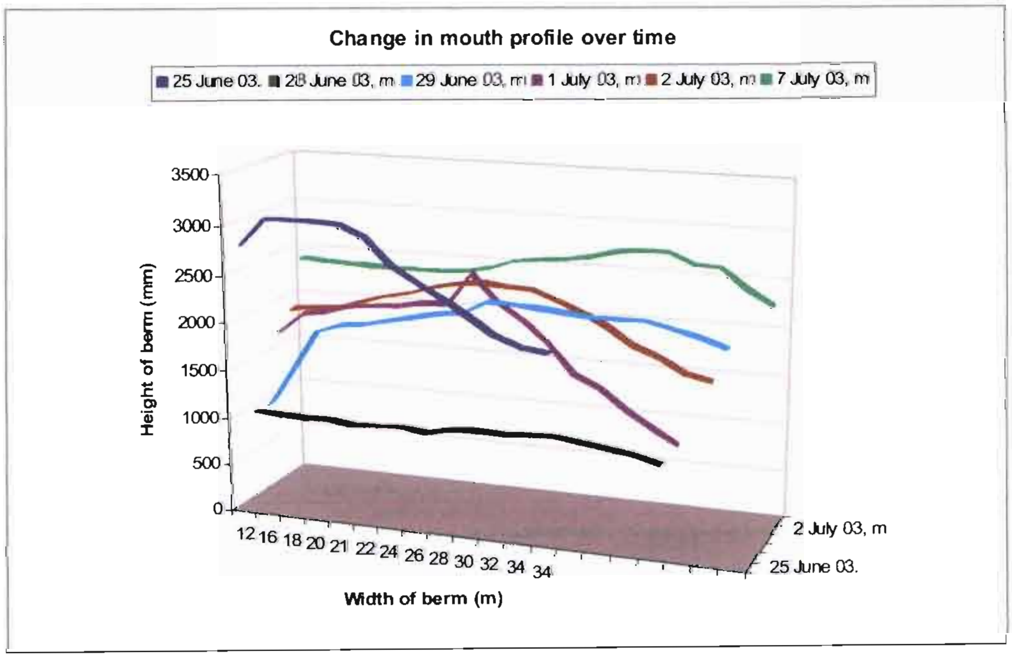



**Figure 5-13: Ribbon plots of selective mouth profiles measured at Mhlanga Estuary.**

## 5.3. The effects of flow on the mouth state

Flow and rainfall data for 2002 was separated from that for 2003 creating table 5-2. This was done to explore the change in mouth state and flow rates with the change in precipitation between 2002 and 2003.

**Table 5-2: Mouth state, rainfall and flow over the observation period.**

| | | Mar 02 – Dec 02 | Jan 03 – Aug 03 | Mar 02 – Aug 03 |
|---|---|---|---|---|
| Mdloti Estuary | Rainfall (%MAP) | 59 | 28 | 86 |
| | Expected rainfall (%MAP) | 74 | 60 | 133 |
| | % closed | 53 | 91 | 69 |
| | Av. flow ($m^3/s$) | 2.26 | 0.88 | 1.83 |
| | Av. flow (% MAS) | 86 | 33 | 69 |
| Mhlanga Estuary | Rainfall (%MAP) | 59 | 28 | 86 |
| | Expected rainfall (%MAP) | 74 | 60 | 133 |
| | % closed | 51 | 59 | 55 |
| | Av. flow ($m^3/s$) | 0.91 | 0.39 | 0.69 |
| | Av. flow (% MAS) | 144 | 62 | 110 |

As the precipitation during 2003 was considerably less than in 2002, it was expected that the estuaries would breach less frequently. This is true for Mdloti Estuary as both a decrease in average flow and an increase in the percentage of time the estuary was closed was observed. However Mhlanga Estuary experienced a decrease in the percentage of time the estuary was closed despite the reduction in average flow and precipitation. Another interesting observation is that during 2002, Mhlanga Estuary received more than the expected stream-flow, indicating a possible underestimate of the MAS as there was less than expected rainfall during the period in question. This underestimation could be attributed to the discharge estimates or the simulated figures for natural stream-flow.

Figure 5-14 and 5-15 are visual representations of the flow rates measured at Mdloti Estuary during different states. On two occasions the flow readings were obtained the day prior to breaching. These readings were incorporated with the open data as these flows may have resulted in breaching. The single value obtained when the estuary was in the partly open state was also incorporated with the data obtained for the open state. Superimposed on the figure are the values given by CSIR (2002) as threshold flows separating the different states. CSIR (2002) estimated that the Mdloti Estuary is closed when the flow rate is less than $0.3m^3/s$, whilst between 0.3 and $2m^3/s$ the estuary is partly open and when the flow rate exceeds $2m^3/s$ the estuary is open. Once the flow rate exceeds $5m^3/s$ the estuary was classified as river dominated.

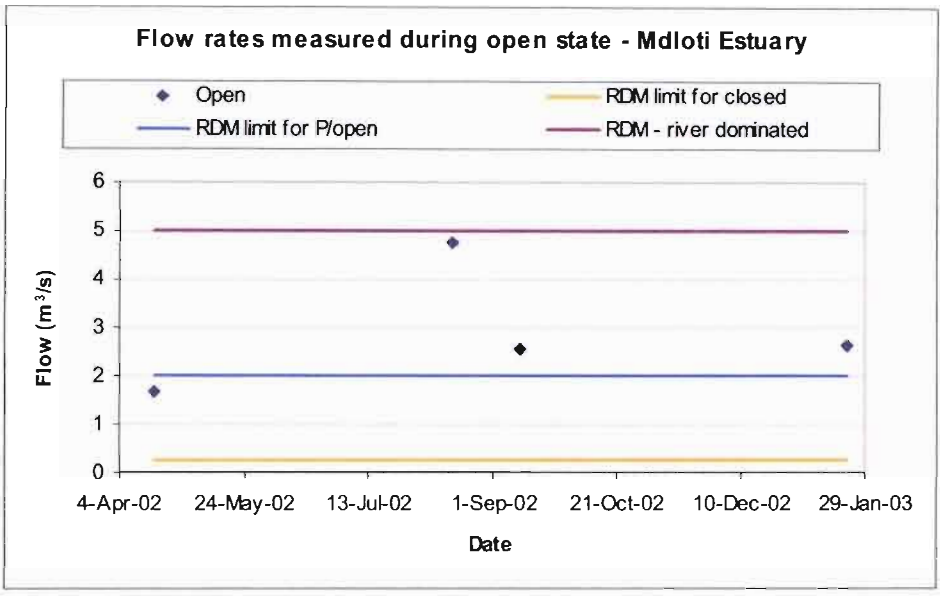



**Figure 5-14: Comparison of the flow rates obtained during the open and partly open states at Mdloti Estuary with RDM thresholds.**

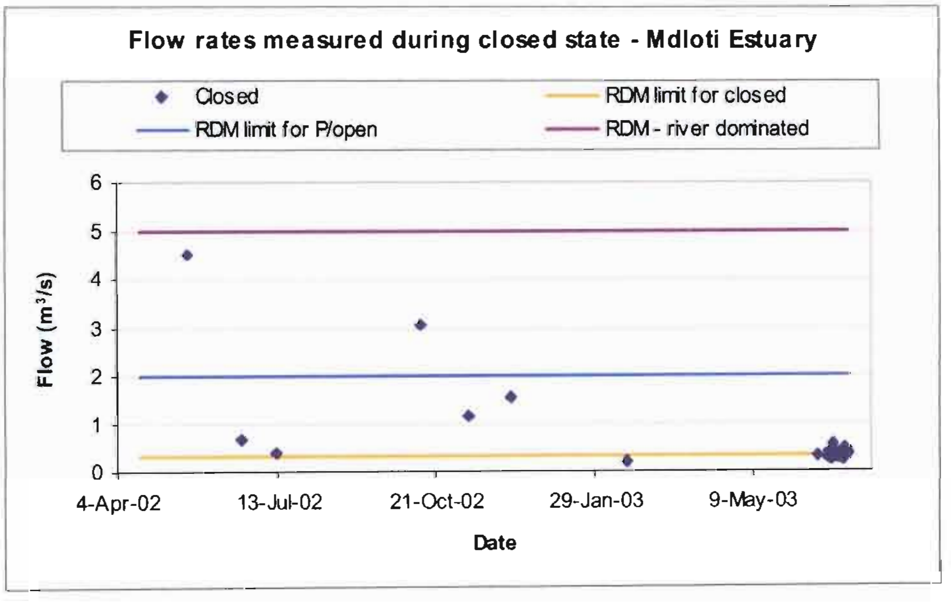



**Figure 5-15: Comparison of the flow rates obtained during the closed state at Mdloti Estuary with RDM thresholds.**

Approximately 70% of the flow rates, measured when Mdloti Estuary was closed exceed the $0.3m^3/s$ limit, given by CSIR (2002), above which the estuary was classified as partly open. The flow rate measured during the partly open state was $2.5m^3/s$, slightly above the maximum RDM limit of $2m^3/s$ for the partly open state. Two of the measured flow rates recorded, while the estuary was closed, were above $3m^3/s$ yet the estuary remained closed for several days thereafter even though similar flows were recorded when the estuary was open or about to open. A possible reason for this discrepancy is that the high flows recorded, when the estuary was closed, were shorter in duration than the time required for those flows to cause breaching. This indicates the importance of including water levels and residence time in determining the effect of flow on mouth state

At Mhlanga Estuary the threshold flows were estimated in the RDM report by CSIR (2003). Below a flow rate of $0.4m^3/s$ the estuary was classified as closed, while flows between 0.4 and $0.5m^3/s$ were given as the range corresponding to the partly open state. Between 0.5 and $5m^3/s$ the Mhlanga Estuary was classified as open with flows in excess of $5m^3/s$ classified as a river dominated state. Figures 5-16, 5-17 and 5-18 show the flow rates measured and the estimated thresholds flows.

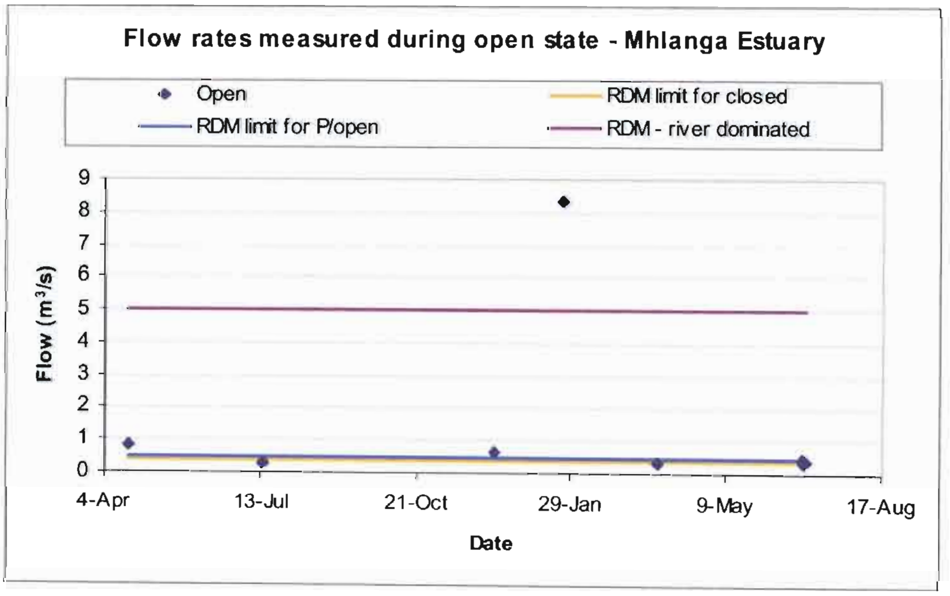



**Figure 5-16: Comparison of the flow rates obtained during the open state at Mhlanga Estuary with RDM thresholds.**

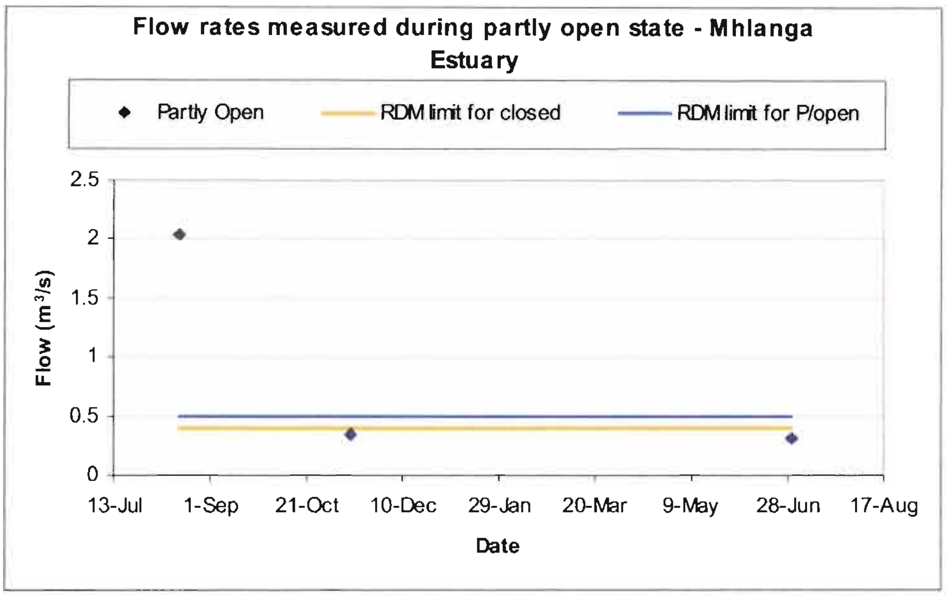



**Figure 5-17: Comparison of the flow rates obtained during the partly open state at Mhlanga Estuary with RDM thresholds.**

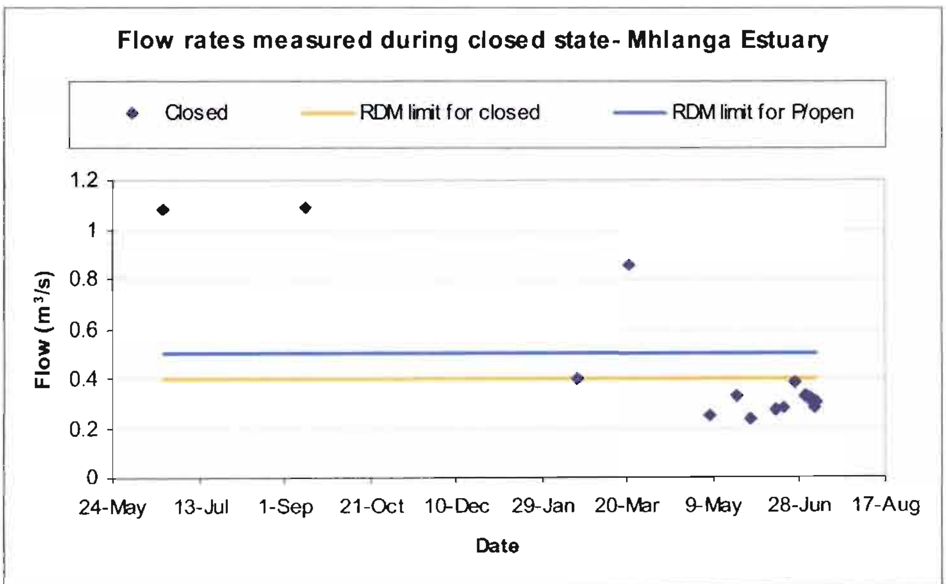



**Figure 5-18: Comparison of the flow rates obtained during the closed state at Mhlanga Estuary with RDM thresholds.**

Approximately 50% of the flows measured during the open phase were less than $0.4m^3/s$, however the measurements made once the estuary had been open for a while are not necessarily reflective of the flows which caused the estuary to open. One of the measurements was made during a small flood event during January 2003. The flow recorded was approximately $8.3m^3/s$. The salinity profile measured on the same day shows the estuary dominated by freshwater indicating a river dominated state as expected. The salinity measurements were made at low tide and it is not certain that the estuary continued to exhibit these characteristics under high tide conditions.

It seems that attempting to classify the state of the system based purely on the flow rate does not always achieve the required results as this approach does not account for the water level or the residence time of the estuary. A slightly different approach has therefore been used in determining the effect of flows on mouth state. The approach is based on the water balance, incorporating the residence time of the estuarine system as this is directly linked to the inflows and outflows. Initially the outflows are established after which the inflows are discussed in three categories: low flows, intermediate flows and high flows along with the effect of each flow regime on the mouth state.

### 5.3.1. Outflows

In the case of Mhlanga and Mdloti Estuaries the two main losses from the systems, when they are closed, are seepage and evaporation. This scenario is likely to be typical for perched estuaries with narrow sand bars. Both seepage and evaporation losses are storage dependant, with seepage increasing as the water level within the estuary rises and evaporation increasing as surface area increases.

Where estuaries are perched, the seepage losses can be substantial, and can dominate the evaporation losses. The seepage losses can be estimated by combining water level data and flow readings. When the water level remains constant in the estuary, there is an equilibrium as the inflows are equal to the outflows. Therefore flow readings taken at constant water levels are equal to the seepage losses at that water level. To determine the maximum seepage from the system, the relationship between flow rate and water level needs to be projected to the maximum water level.

During May 2003 the water level monitor at Mhlanga Estuary captured two different stages at which the water level remained constant for a period of time. Flow measurements were made during each of these two occasions. The water levels and flows recorded are tabulated in table 5-3.

Fortunately at Mhlanga Estuary a flow rate was captured the morning of a breach after the estuary had remained closed at the high water level for several days. This flow rate of $0.25m^3/s$

indicates the maximum seepage from the estuary. The average evaporation from the system was estimated by multiplying the MAE by the surface area. For Mhlanga Estuary the estimated evaporation from the system was calculated as $0.02m^3/s$, which is relatively small (<10%) compared to the estimated seepage and can therefore be ignored.

**Table 5-3: Constant water levels and the corresponding flow rates obtained at Mhlanga Estuary.**

| Date | Water level (m +MSL) | Flow rate ($m^3/s$) | Comment |
|---|---|---|---|
| 7 May 2003 | 2.79 | 0.19 | Constant approx. 20 days |
| 23 May 2003 | 2.96 | 0.25 | Morning of breach |

Two data points, shown in table 5-4, were obtained for Mdloti Estuary, neither of which corresponded to the high water level of the estuary.

**Table 5-4: Constant water levels and the corresponding flow rates obtained at Mdloti Estuary.**

| Date | Water level (m+MSL) | Flow rate ($m^3/s$) | Comment |
|---|---|---|---|
| 19 Feb 2003 | 2.09 | 0.20 | Constant > 10 days |
| 25 Jun – 8 Jul '03 | 2.57 | 0.34 | Averaged over 2 weeks |

There was not enough data available to determine an accurate relationship between water level and seepage. The rate of seepage increases with an increase in water level. From the information available figure 5-19 was produced, from which the maximum seepage was estimated. The maximum seepage was therefore estimated to be $0.53m^3/s$ at a water level of 3.2m above MSL. The maximum evaporation losses from the system, which occur when the estuary is full and the maximum surface area exposed, is approximately $0.02m^3/s$ or 5% of the maximum seepage. Table 5-5 contains a summary of the losses from Mhlanga and Mdloti Estuaries.

The residence time for any flow Q may be defined as $T_R = S/Q$ where S is the storage when the estuary is full. The residence time represents the time required for a specific flow to replace the storage volume. The residence time associated with the maximum seepage outflows therefore gives an indication of the time between successive breaching events when the flow is just large enough to overcome seepage losses.

**Table 5-5: Summary of losses and related information.**

| | Mhlanga Estuary | Mdloti Estuary |
|---|---|---|
| Seepage ($m^3/s$) | 0.25 | 0.53 |
| Evaporation ($m^3/s$) | 0.02 | 0.02 |
| Critical Tr (days) = $S/Q_{CR}$ | 34 | 20 |
| % of MAR | 68 | 21 |

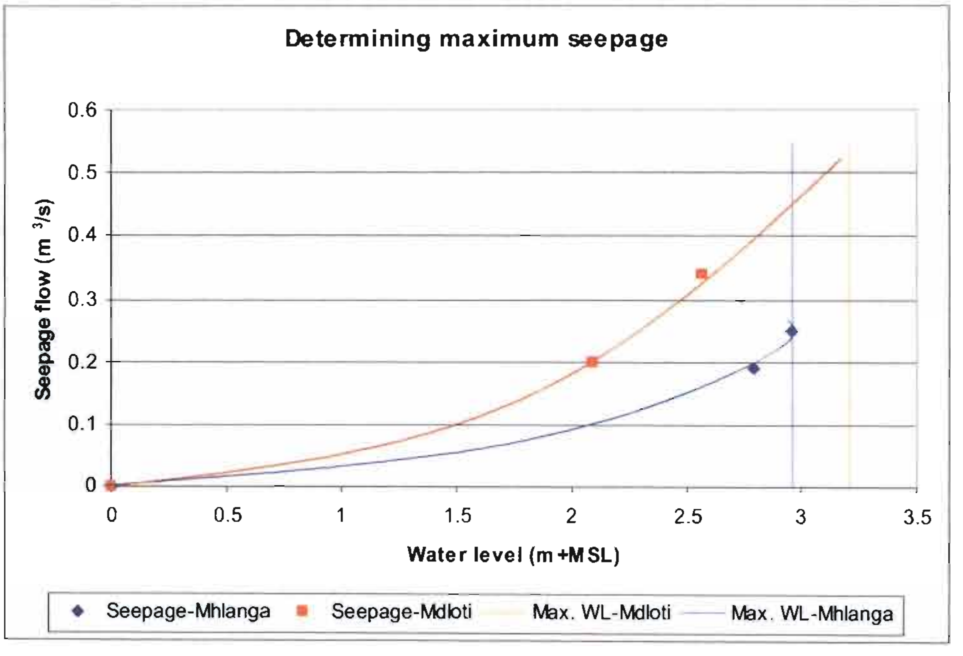



**Figure 5-19: Plot of seepage against water level used to determine maximum seepage.**

The seepage is also dependant on the characteristics of the berm and can therefore change depending on the morphology of the berm.

### 5.3.2. Low flows

Low flows are previously defined, in section 2.3, as the state under which outflows exceed the inflows and therefore the water level within the estuary does not rise. Both Mhlanga and Mdloti Estuaries are perched with low water levels at 670 and 780 mm above MSL respectively. The maximum losses, due to seepage and evaporation, from the system occur when the water level in the estuary is at a maximum. It can therefore be deduced that as long as the flows into the system are less than the maximum outflow from the system, the estuary will reach a equilibrium below the breaching water level, remaining closed until such time as the inflows increase above the maximum outflow. Therefore this state can be defined as:

$$\boxed{I - O_{max} < 0}$$

where I represents the inflows and $O_{max}$ represents the maximum possible outflow (approximately equal to the seepage in this case).

Under this condition should the inflows into the system be reduced to less than the outflows (eg. because of reduced rainfall or increased abstractions), the water level in the estuary will drop until an equilibrium is reached.

Mdloti Estuary has remained closed since February 2003 and therefore provides a good example of the low flow regime. The flow rates and water level between February and August 2003 are shown in figure 5-20. Superimposed on the figure are the maximum water level and the maximum outflow, estimated in section 5.3.1.

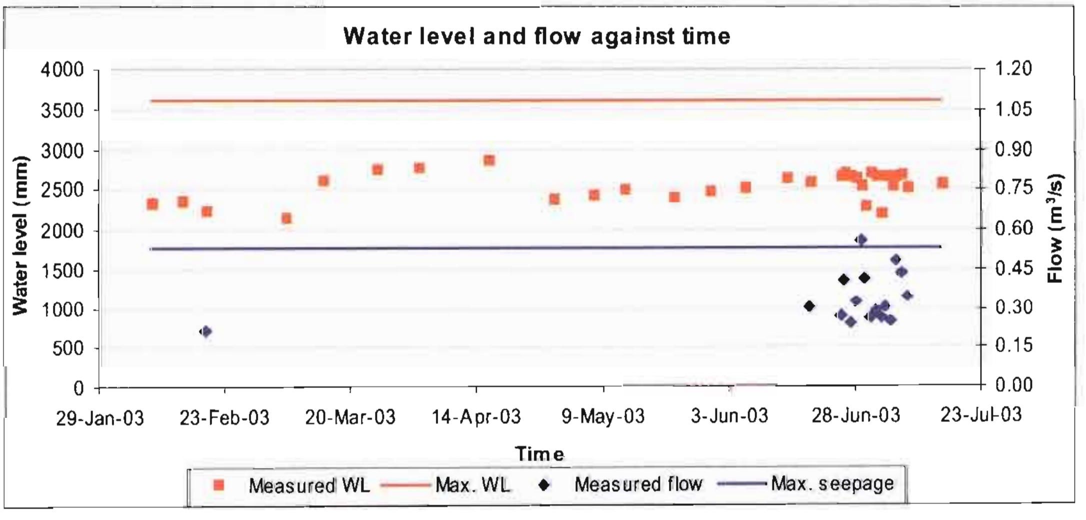



**Figure 5-20: Water levels and flow rates over time for Mdloti Estuary, with an indication of the maximum water level and maximum seepage.**

From the water levels it can be seen that although there were variations in the water level the maximum water level was not reached and the estuary did not breach.

During a two week survey conducted from the 25 June to the 8 July 2003 daily flow rates and water levels were recorded. Over this period the water level was fairly constant, with the flows generally below the maximum seepage. Although there is one defined instance in which the flow rate was above the estimated maximum seepage, the flow was not sustained for a sufficient period of time to cause the water level to rise to or above the maximum water level and cause failure of the berm.

### 5.3.3. Intermediate flows

The intermediate flow regime occurs when the inflows are adequate, such that given enough time the estuary can fill to the maximum water level, however there is insufficient flow to cause overtopping. It is possible to define this flow regime as:

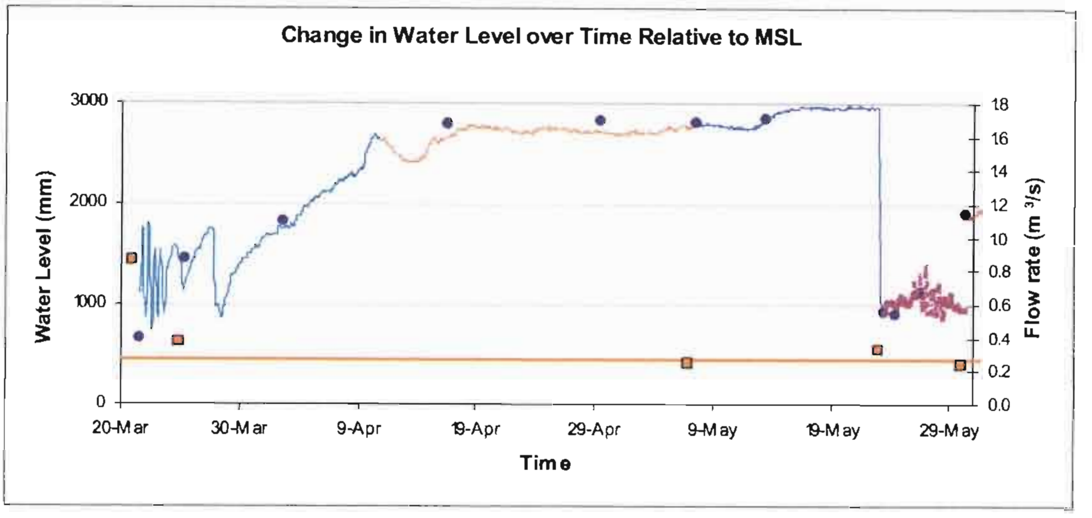
$$\boxed{I - O_{max} \approx 0}$$

This regime requires the inflow to be of similar magnitude to the maximum outflow. The intermediate flows lead to a rise in water level initially when the water level within the estuary is low. As the water level increases the seepage increases, therefore decreasing the rate at which the water level is rising. Should this flow rate be maintained for a sufficient time period, the water level will rise until the inflow equals the outflow at the maximum or natural breaching level. Stability is lost under this condition with the seepage eroding the seaward face, ultimately resulting in the estuary breaching.

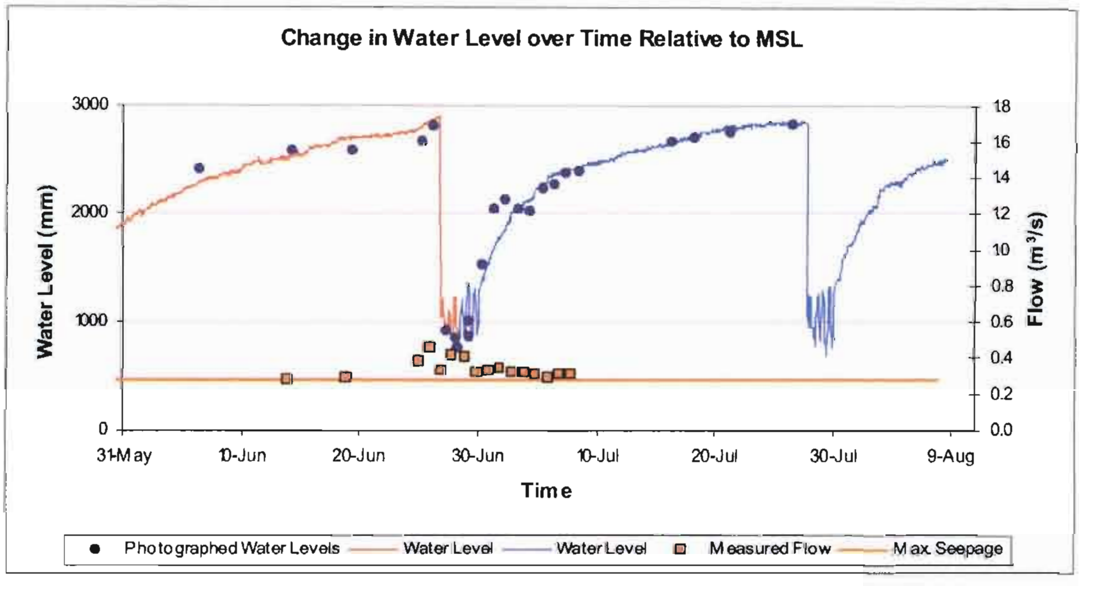
This flow state is very specific and can be seen as a critical flow. It is important to note that this critical flow may vary slightly depending on the characteristics of the berm.

Since there was a decrease in stream-flow due to the decrease in rainfall during 2003, the discharges from the WWTWs played a larger role in the flow. Between February and August the treated effluent discharge amounted to approximately 60% of the measured flow entering the Mhlanga Estuary. The outflows from the Mhlanga Estuary system were estimated as for Mdloti Estuary with seepage amounting to $0.25m^3/s$.

From the data recorded by the water level monitors installed in the Mhlanga Estuary a range of flow conditions can be identified. The continuous water level data relative to MSL is presented in figure 5-21. This data was checked by plotting the water levels obtained via digital photographs of the M4 bridge (shown as circles on the plot).




a)




b)

**Figure 5-21: Water levels and flow rates measured at Mhlanga Estuary between March and August 2003.**

Three separate breaching events are visible in figure 5-21 during the period from March 2003 to August 2003, despite the lower than average precipitation in the catchment. Figure 5-21 a) shows a range of flow states occurring between the closure in March and the breach in May of 2003. In April there was a phase at which the water level remains constant, indicating an equilibrium, in the low flow regime. Thereafter there is an increase in water level until the maximum water level was obtained, this level was maintained until neap tide when the estuary breached.

In figure 5-21 b) the change in water level occurring during the closed phase between the end of June and the end of July 2003 is typical of the curve expected in a system driven by intermediate flows. Over this period the system was driven mainly by base flows with negligible rainfall. The rate at which the water level rises slows down over time until the breaching level is reached.

Over the two week period starting 25 June 2003, daily observations were made at Mhlanga Estuary. On the 2nd day the estuary breached and higher flows were recorded when the mouth was open however they returned to average during closure. During July there was only 0.4 mm of rainfall yet the water level at Mhlanga Estuary continued to rise indicating the system was driven by baseflows at the time, constituting mainly of WWTW discharges.

### 5.3.4. High flows

When the inflows into the estuarine system exceed the maximum seepage, the water level will rise continuously. Initially the water level rises rapidly, slowing as the water level increases and seepage increases. The water level will continue to rise until the water level in the estuary exceeds the lowest point of the sand berm resulting in overtopping and scour. This flow regime is defined by:

$$\boxed{I - O_{max} > 0}$$

Jezewski (1984) states the one in two year flood at Mdloti Estuary has a peak discharge of approximately 76m$^3$/s. Under these flow conditions the outflows from the system are negligible in comparison to the inflows. The peak flow rate translates to a residence time of approximately 4 hours. Hazelmere Dam probably has little effect in attenuating floods of this magnitude.

During the 1987 floods Mdloti Estuary experienced an extreme flood flow of approximately 2000m$^3$/s (Perry, 1989). This flow was much larger than the maximum seepage which is of the order 0.53m$^3$/s. The flood flow translates to a residence time of approximately 10 minutes. Hazelmere Dam will not have been able to attenuate the flood as the volume of the dam was far exceeded by the volume of the flood.

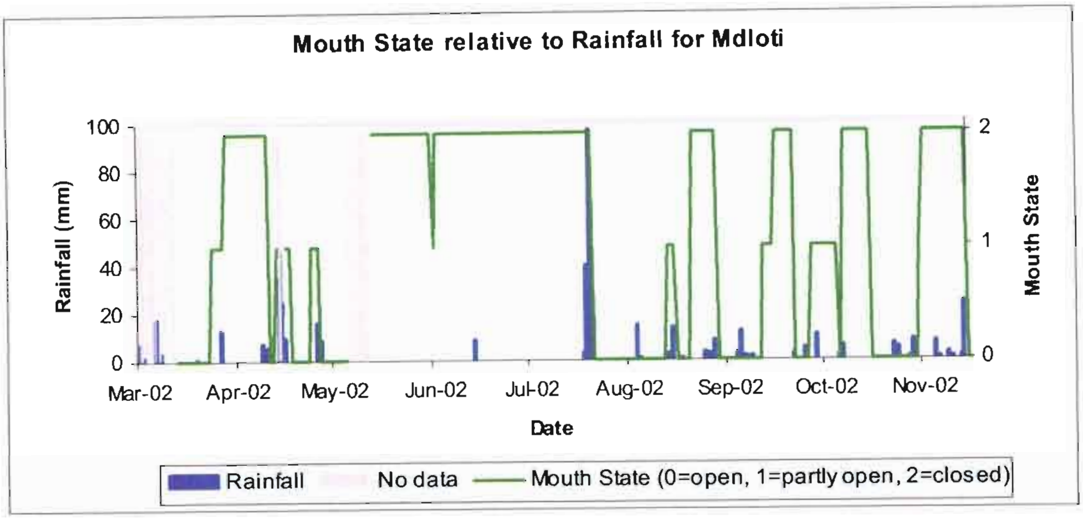
### 5.3.5. Summary

Mhlanga and Mdloti Estuaries appears to breach at a consistent high water level (approximately 3 and 3.2 m above MSL respectively). In determining how flows affect the mouth state a simple relationship was not found. The mouth state is easily determined for sustained high and low flow rates, with high flows leading to open mouth conditions and low flows causing the estuary to remain closed. The intermediate flows (flows of similar magnitude to the maximum seepage) are not as easily defined. This flow regime is likely to result in seepage failure, however the estuary may not breach immediately after reaching the maximum water level, but may remain in this unstable state. These scenarios only apply to sustained flows, for example should a high flow be attained for a short enough period of time the estuary probably will not breach unless it was almost full when the high flow occurred.

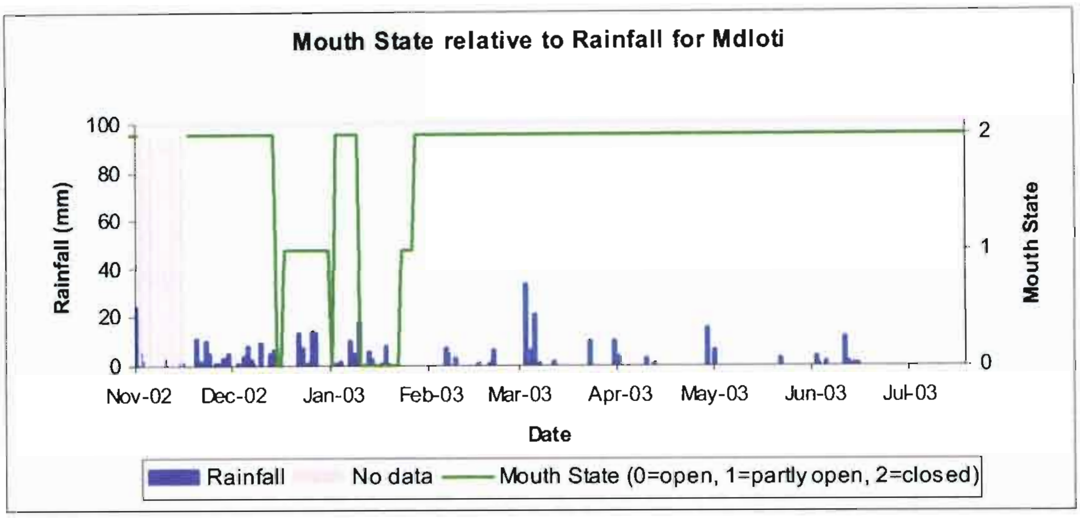
## 5.4. Effects of rainfall on mouth state

### 5.4.1. Mdloti Estuary

Figure 5-22 shows the plots of rainfall and mouth state over time. The rainfall experienced by the Mdloti Estuary during the various closed periods ranges from 0 to 70 mm over the catchment area. From the data there is no clear correlation evident between amounts of rainfall and breaching, with rainfall events of varying intensity coinciding with breaching events. A general trend exists as in 2003 the estuary breached less than in 2002, coinciding with a reduction in rainfall from 2002 to 2003.




a)




b)

**Figure 5-22: Plot of mouth state and rainfall over the observation period.**

Figure 5-23 was produced in order to further explore the effects of rainfall on the mouth state through plotting the rainfall accumulated in the month as well as the percentage of time the estuary was closed each month against time. There is a weak general trend between the amount of rainfall in a month and the percentage of time the estuary was closed within that month in that the rainfall decreased as the percentage closed increased. The computed Spearman's linear correlation coefficient of 0.37, was found insignificant at the 95% confidence level, but significant at the 85% confidence level.

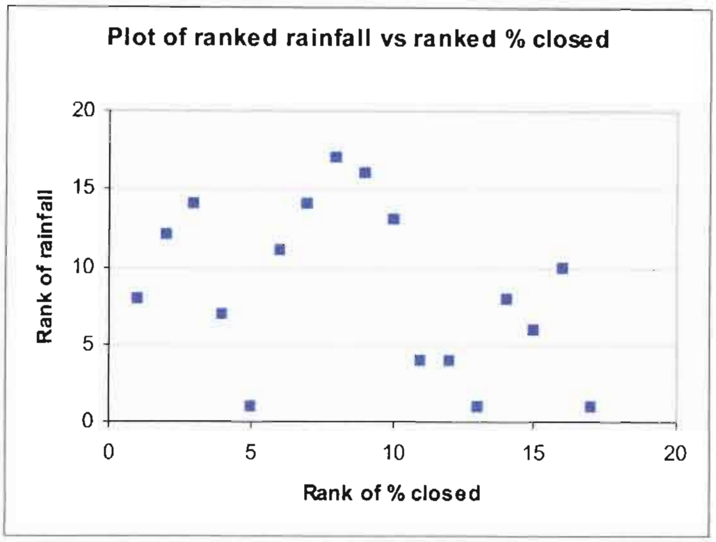
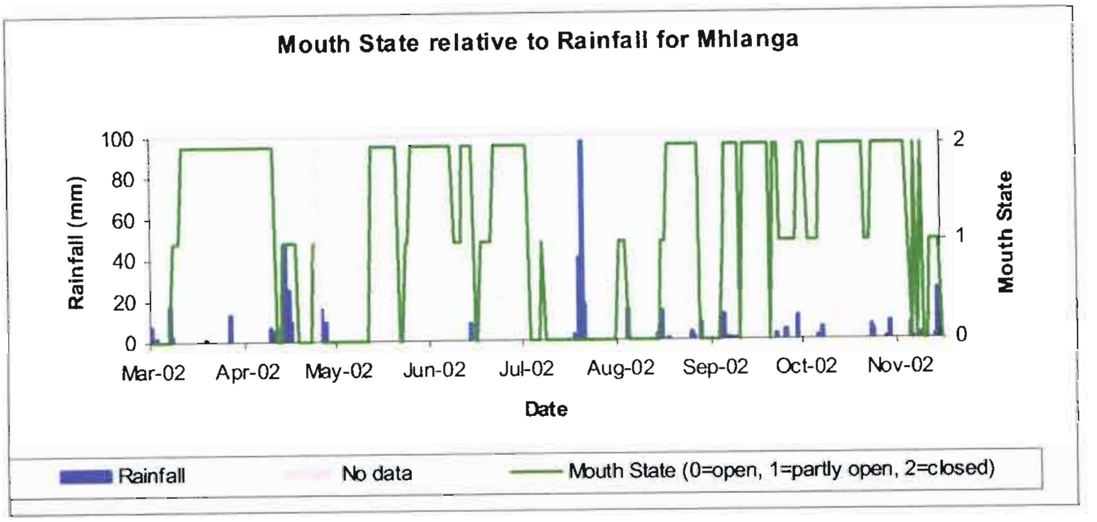



**Figure 5-23: Ranks of monthly rainfall and percentage of time in the corresponding month that the estuary mouth was closed.**

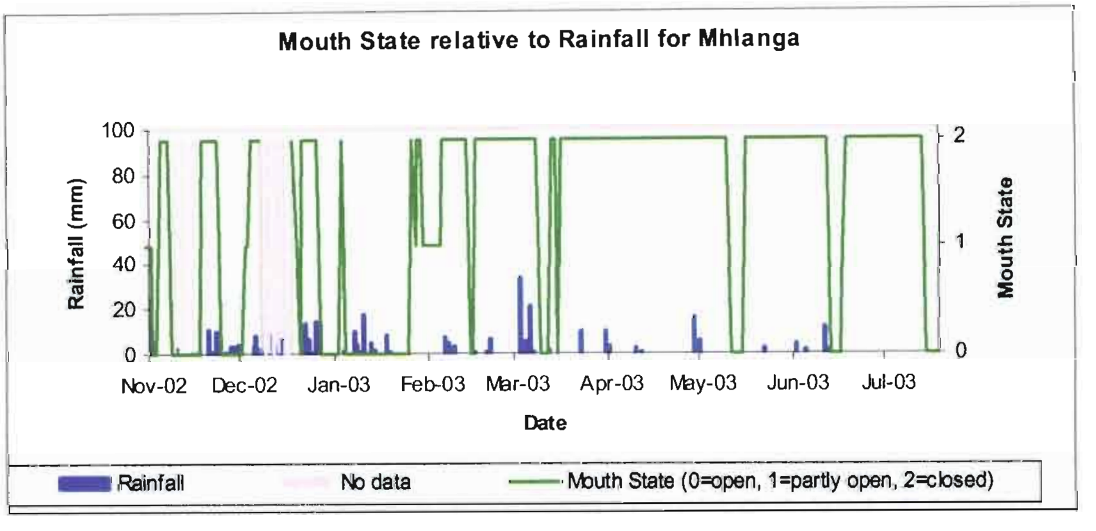
*(Where a rank of 1 is assigned to the largest number)

### 5.4.2. Mhlanga Estuary

Comparing the data collected in 2002 to the results in 2003 for the months March through to July Mhlanga Estuary was, as expected, open less frequently in 2003 than 2002 as the rainfall during the 5 months of 2002 amounted to 336 mm, while the same 5 months in 2003 only received 145 mm. Between March and December 2002 the estuary was closed approximately 57% of the time, whilst between March and December 2003 the estuary was closed 87% of the time. Between 1 August 2002 and 28 February 2003, Mhlanga Estuary was closed approximately 36% of the time, with a rainfall during this period of approximately 356 mm. In order to further explore the effects of rainfall on the mouth state figure 5-24 was produced. Again breaching coincided with varying intensities of rainfall and in some cases no rainfall was recorded over the closed period yet breaching still occurred.




a)




b)

**Figure 5-24: Plot of rainfall and mouth state over the observation period.**

As with Mdloti Estuary figure 5-25 was produced for Mhlanga Estuary in order to further explore the effects of rainfall on the mouth state by plotting the rainfall accumulated in the month as well as the percentage of time the estuary was closed each month. At Mhlanga Estuary there is a stronger general trend than at Mdloti Estuary between the amount of rainfall in a month and the percentage of time the estuary was closed within that month in that as the rainfall decreased the percentage closed increased. The Spearman's linear correlation coefficient of 0.61, is significant at the 95% confidence level.

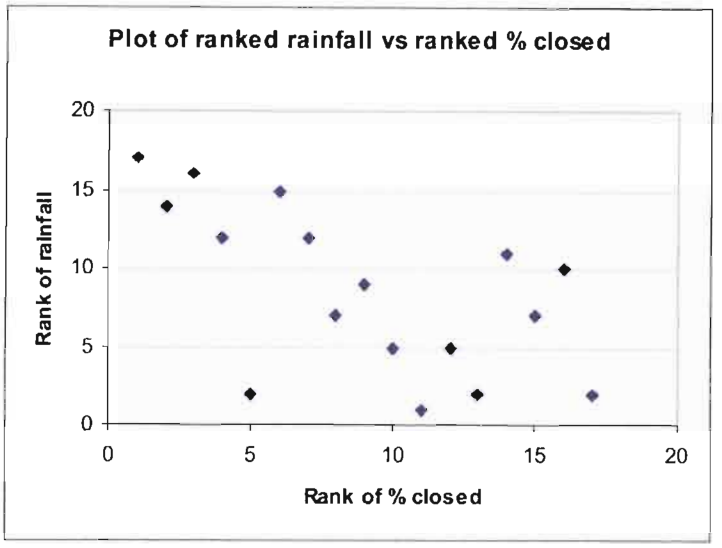



**Figure 5-25: Ranks* of monthly rainfall and percentage of time in the corresponding month that the estuary mouth was closed against time.**

*(Where a rank of 1 is assigned to the largest number)

### 5.4.3. Summary

The effect of rainfall on mouth state was sought as a long term rainfall data is more readily available than flow data. It could be expected that the conclusions obtained for determining mouth state from stream flow would be applicable when determining the effect of rainfall on mouth state. Therefore estuaries should open after receiving large amounts of rainfall and remain closed under drought conditions. However this cannot be looked at in isolation. For instance both Mhlanga and Mdloti Estuaries experienced drought conditions in 2003, and while Mdloti Estuary remain closed as expected Mhlanga Estuary continued to breach regularly, in large, due to the addition of treated effluent.

Although Mhlanga Estuary shows a correlation between rainfall and the percentage of time the estuary is closed, this method of determining mouth state may not work on all estuaries or under all conditions. The weak correlation between rainfall and mouth state found for Mdloti Estuary confirms that rainfall is not a reliable method of determining mouth state.

## 5.5. Tidal exchange

Initially the tidal exchange flows were expected to be insignificant in the cases of Mhlanga and Mdloti Estuaries as the estuaries are perched well above MSL. However the water level monitor recordings at Mhlanga Estuary indicated cyclical fluctuations in water level when the mouth of the estuary was open.

The first examples of tidally driven water level fluctuations within the Mhlanga Estuary were captured in March 2003 (shortly after the installation of the continuous water level monitor). The continuous water levels recorded are plotted in figure 5-26 on the same scale as the corresponding tide. The tidal water levels were predicted for Durban using a harmonic model, Hopper (2003).

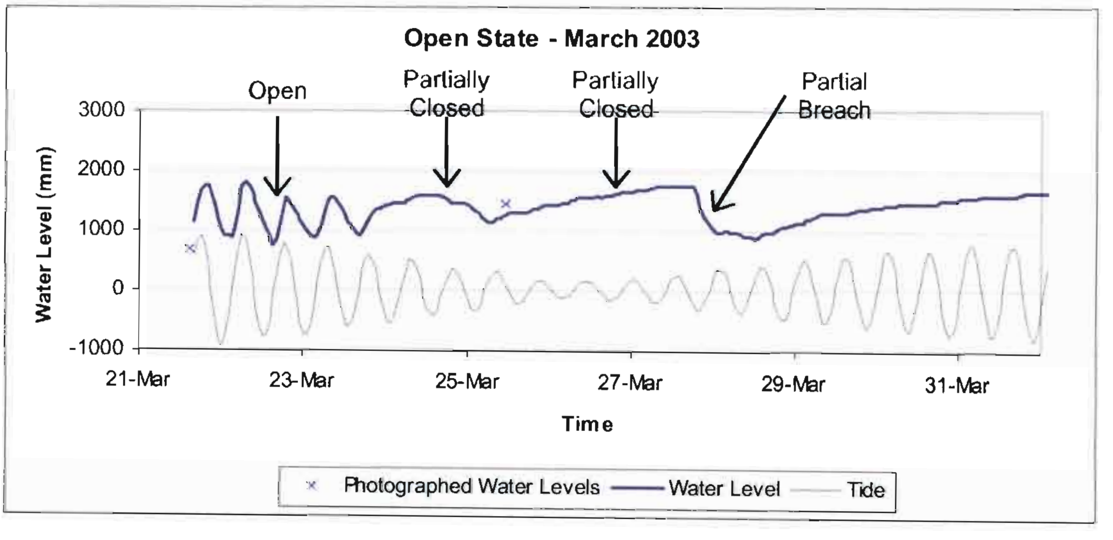



**Figure 5-26: The Mhlanga Estuary in the open state during March 2003**

The data shows initial periodic fluctuations followed by partial closures and breaches. The main point of interest was to establish whether the fluctuations are linked to the tide. During high tide the water level in the estuary reached up to 1800 mm above MSL, with the lowest recorded water level in the estuary, at low tide, approximately 740 mm above MSL. This fluctuation represents half the water level range occurring in the estuary and a volume exchange between 12.5% and 50% of the estuary's dynamic storage capacity depending on the relationship between depth and storage. During the open state the spring tide variations at sea were 2 m in range corresponding to a change in estuary water level of 1.06 m.

The fluctuations measured in the estuary are a result of the wave runup accentuated by the steep beach slope that is characteristic of the KwaZulu Natal coast. The fluctuation could be further enhanced within the estuary by the narrow, shallow mouth. (Huizinga, 2003)

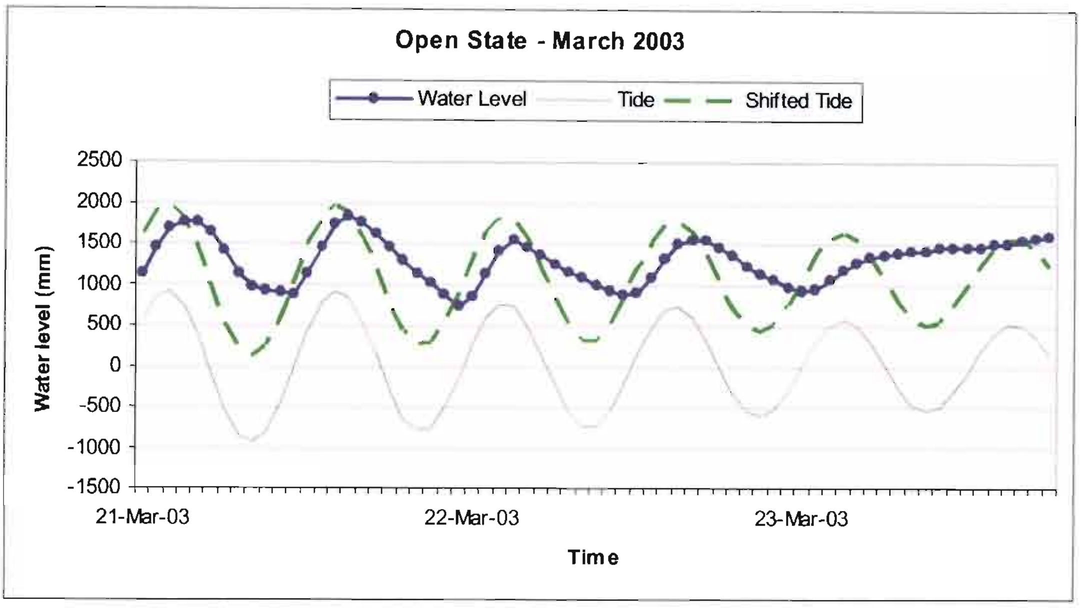



**Figure 5-27: Exploded view of the open phase presented in figure 5-26.**

Figure 5-27 is an exploded view of the water level fluctuations in the Mhlanga Estuary. The tidal level has been projected upwards, by 1 m (approximately 0.55 times the median $H_s$ for Durban, see table 2-2) to represent the effects of wave run-up.

The water level fluctuations seen in figure 5-27 do not follow the same sinusoidal path as the tide, but rather exhibit asymmetry, with the increase in water level occurring more rapidly than the decrease. Constriction of the mouth results in tidal asymmetry and in this case the estuary is flood dominated as the flood tide is more intense than the ebb tide. The constriction of the mouth also results in the water level in the estuary lagging behind the tidal fluctuation (e.g. Schumann, Largier and Slinger, 1999).

From the plots of water level against time it can be seen that the change in estuary water level is not as dramatic as the change in sea level. The change in water level in the estuary is inhibited by the perched nature of the estuary, with the difference between the estuary water level and sea level far greater at low tide than at high tide.

Figure 5-28 is a magnified plot of the tidal fluctuations which occurred in the estuary. Beginning at point A, where the tidal level (increased to account for wave run-up) exceeds the water level within the estuary causing a rise in the water level within the estuary. The rise in tidal level is larger than the water level rise within the estuary. The water level continues to rise until point C is reached despite the fact that the tidal level began to drop at point B some time before point C. Point C represents the point at which the tidal level and estuary water level have the same head and are once again equal, thereafter as the tidal level continues to drop, the water level in the estuary drops, however not as quickly. The estuary water level continues to drop after point D, despite the tide having turned, until the estuary water level matches that of the tidal level, restarting the cycle.

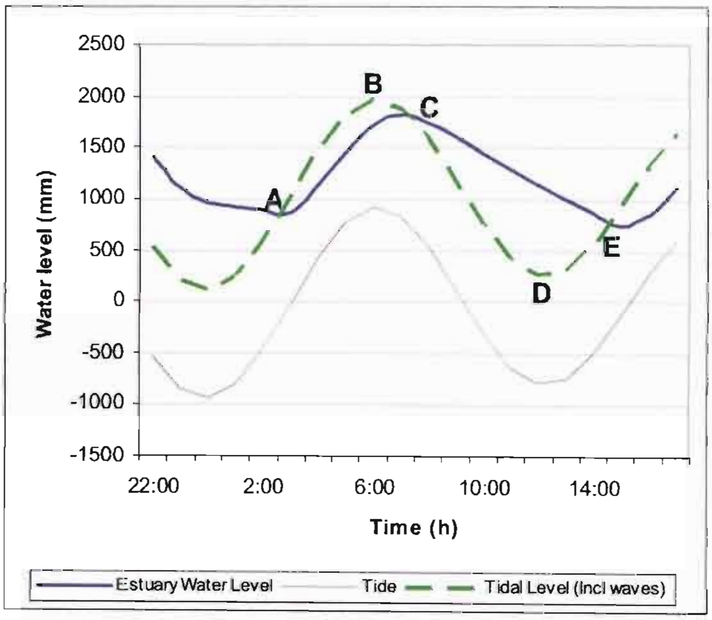



**Figure 5-28: Demonstrating the correspondence between the fluctuations in estuary water level and tidal fluctuations.**

Visual observations provided an explanation for the flood dominated tidal exchanges at Mhlanga Estuary. At high tide, water washing into the estuary uses the entire width of the mouth, as seen in plate 5-4, however when the water leaves the estuary, it flows out of a small channel in the middle of the mouth as shown in plate 5-5, thus causing the estuary to fill quicker than it empties.

**Plate 5-4: High tide pushing in through the entire width of the mouth.**

**Plate 5-5: A channel within the mouth of Mhlanga Estuary.**

Mhlanga Estuary breached during the early hours of the morning of the 23 May 2003, later that morning the water level logger was replaced, unfortunately the new logger had not sealed correctly, making the data unreliable. Data from the malfunctioning water level monitor is shown in figure 5-29. Although the data points were not quantitatively correct, from a qualitative perspective the estuary again shows the effects of the tidal variations.

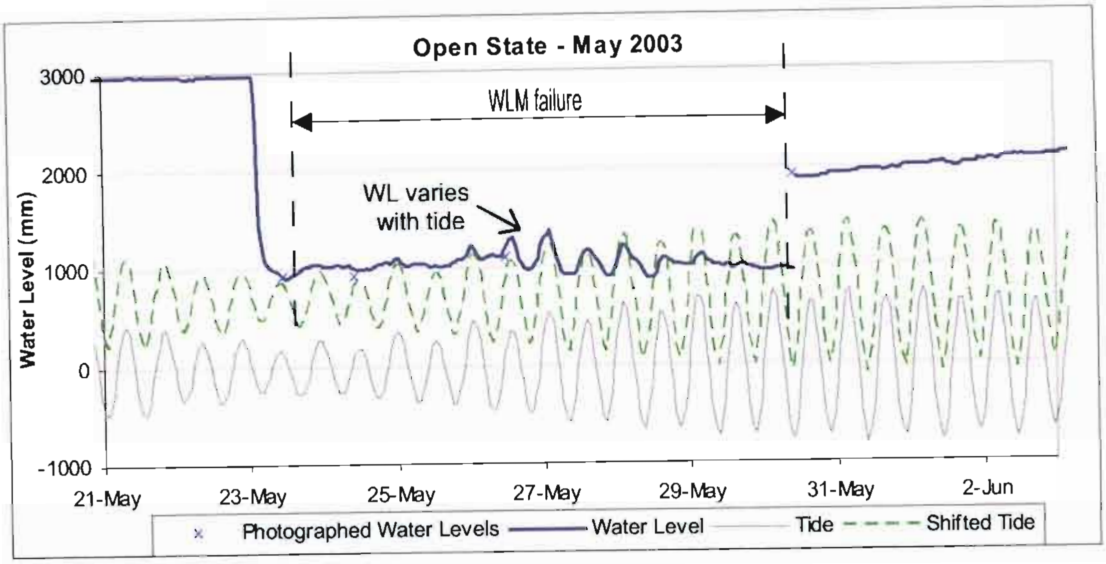



**Figure 5-29: The data collected over the open phase during May 2003.**

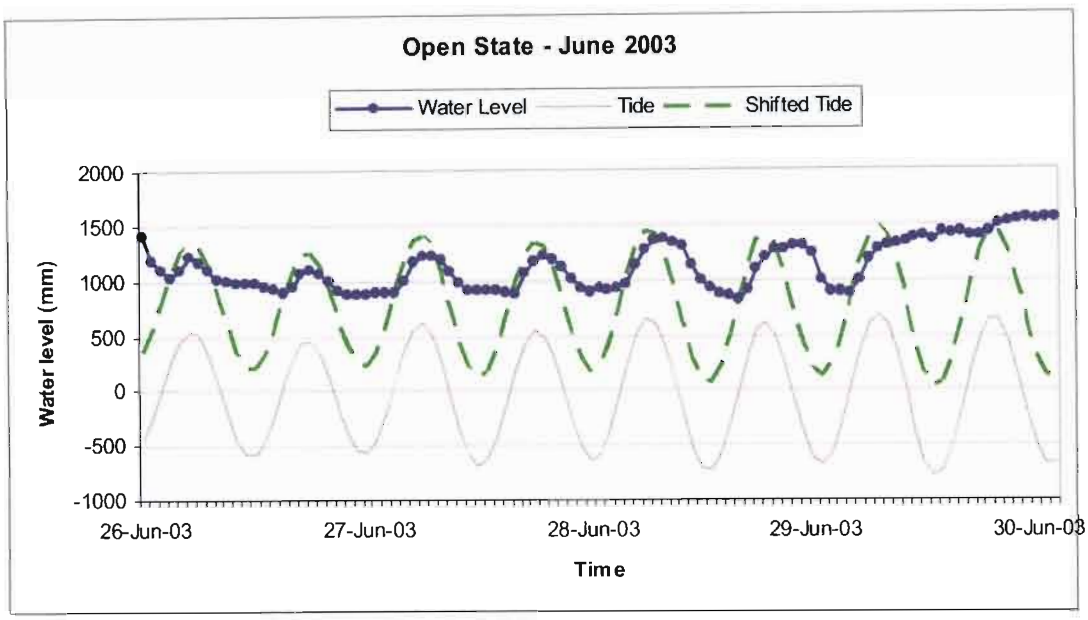



**Figure 5-30: The open state captured by the water level monitor during June 2003.**

Figure 5-30 shows the Mhlanga Estuary under open conditions during June 2003. The tidal level in this case has been projected upwards, by 0.8 m (approximately 0.44 times the median $H_s$ for Durban, see table 2-2) to represent the effects of wave run-up. An interesting feature of this data is that the water level data does not follow the same pattern as for the case shown in figure 5-26. As the tide shifts towards low tide the water level stops dropping indicating there is sediment forming a bar at the mouth preventing the estuary from emptying any further.

The tidal fluctuations in the sea during the open phase were between 850 and 1350 mm, causing a 200 to 500 mm change in the water level within the estuary. The tidal influence seen here is less than that for the first recorded open state during March 2003; this may be attributed to the difference in tidal range or wave conditions between the two cases as well as the mouth not having scoured as deeply.

Six high tide cycles are visible before the estuary closed on the 30 June, that is the estuary was open for approximately three and a half days. At present it is not possible to determine whether the estuary is fully or only partially closed from the data obtained from the water level monitors. It is also not clear when the berm became fully restored from the water level data. The best method for obtaining this information is from direct visual observations of the mouth.

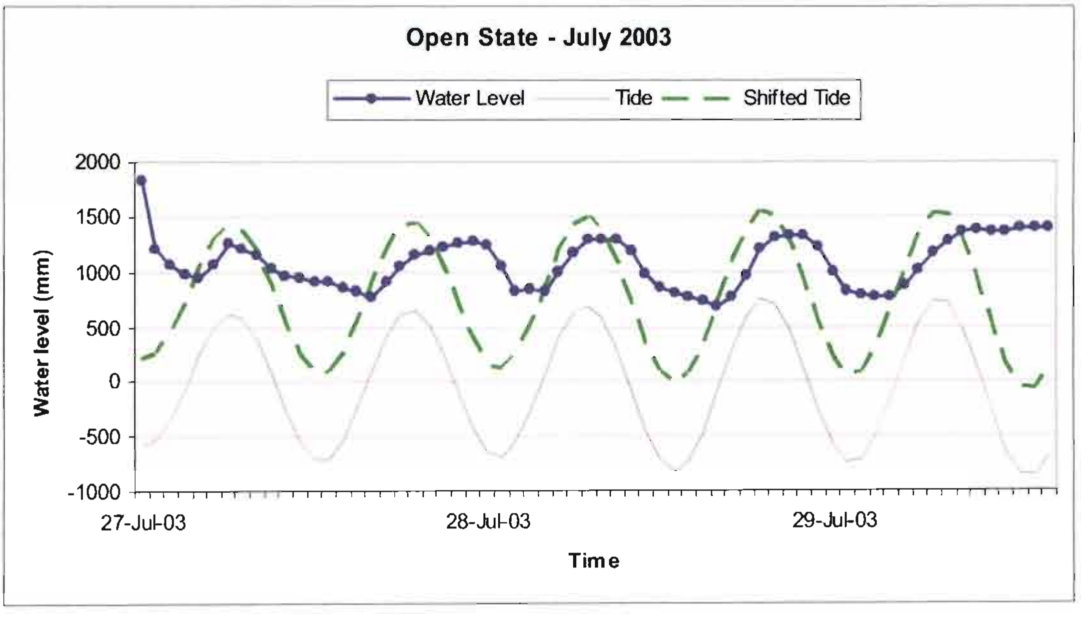



**Figure 5-31: The open state at Mhlanga Estuary during July 2003.**

During July the estuary was open for two and a half days, closing on the fifth high tide. As with the previous cases, figure 5-31 shows a strong correlation between the tide and the water level within the estuary under open conditions. The tidal level has been projected upwards, by 0.8 m (approximately 0.44 times the median $H_s$ for Durban, see table 2-2) to represent the effects of wave run-up. The tidal range at the time varied between 1350 and 1500 mm, while the water level within the estuary varied between 470 and 580 mm.

As the estuary closed at high tide saline water was trapped within the estuary. During the mouth closure that occurred towards the end of July 2003, the water level upon closure was approximately 1400 mm above MSL. The storage volume of the estuary this saline water trapped in the estuary was estimated to be 3.2% to 32% of the Mhlanga Estuary's dynamic storage capacity (depending on the relationship between depth and volume).

Since the installation of the water level monitors, the Mdloti Estuary has not breached, therefore an alternative approach was sought to determine whether or not the Mdloti Estuary experiences a tidal influence under open mouth conditions. As it has already been established that Mhlanga Estuary has a tidal influence, salinity changes were examined to see if a trend existed which could be used to determine tidal influence at Mdloti Estuary. There are two main sources of saline water in a perched estuary, namely over-wash and tidal inflow during the open phase. From observations at the estuary over-wash generally occurs at spring high tide, however it is likely to be small in comparison to the saline intrusion into the estuary that occurs during the open phase. Salinity measurements made at Mhlanga Estuary are consistent with higher salinities during high tide when the estuary is open and shortly after closure, with salinities lowering after prolonged periods of closure. Similar trends were sought for Mdloti Estuary and again there was an indication of higher salinities associated with the open phase and lower salinities to fresh water conditions after prolonged closure. Figure 5-32 is a plot of the salinity profile measured on the 12 September 2002, when the estuary was in the partially open state. While figure 5-33 shows the affect of prolonged closure, approximately 15 days, prior to sampling on 9 December 2002 as the salinity in the system has been reduced and the estuary is dominated by freshwater. It can therefore be deduced that Mdloti Estuary experiences tidal inflows when the mouth is open. A summary of the salinities measured over the study period are included in appendix H.

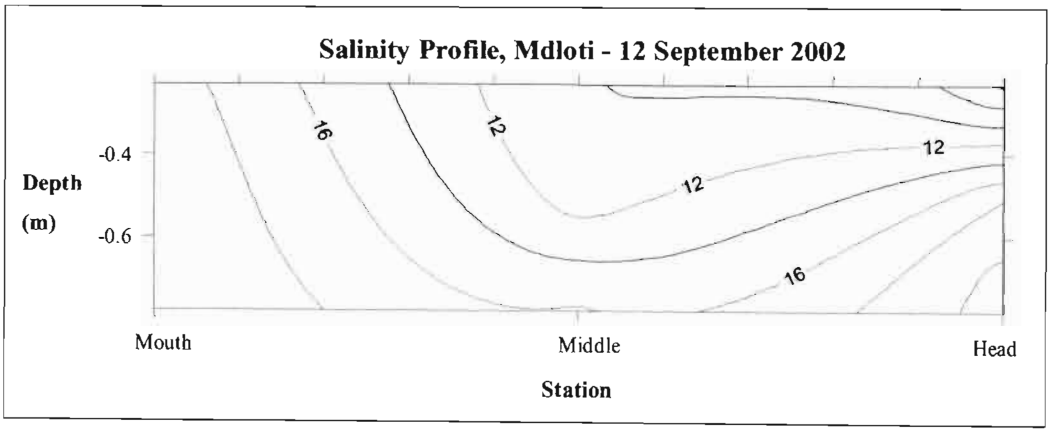



**Figure 5-32: Salinity profile at Mdloti Estuary under partly open conditions.**

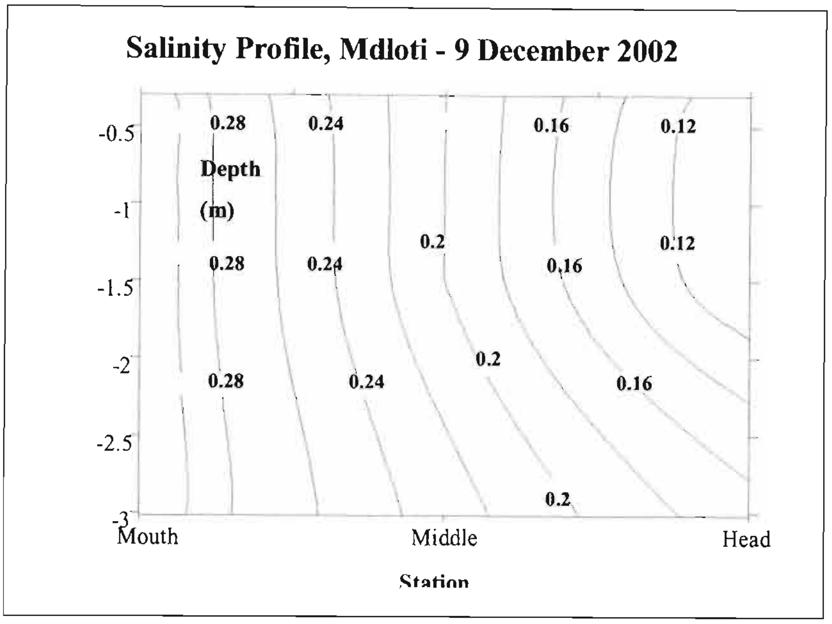



**Figure 5-33: Salinity profile at Mdloti Estuary after it had been closed for 15 days.**

### 5.5.1. Summary

From the data collected it was determined that both Mhlanga and Mdloti Estuaries experience tidal influence despite being perched above MSL. The tidal influence was initially observed from continuous water level data obtained during the open phase. The data showed distinct fluctuations of water level within the estuary during the open phase corresponding to changes in sea level due to tide. As there were no breaching events captured at Mdloti Estuary by the continuous water level monitor, salinity was used to determine whether tidal influence exists. However from the salinity alone it was not possible to determine the magnitude of the tidal intrusion.

The asymmetrical fluctuations in the estuary varied in magnitude for the different breaching events. These fluctuations are dependant on both the magnitude of the tide and the magnitude of the wave run-up responsible for the fluctuations. The volume of tidal influence at Mhlanga Estuary was determined to be of the order 20 to 35%.

### 5.6. Mechanisms affecting the sand berm

Even though there has been reduced runoff in the catchment area, Mhlanga Estuary has been breaching regularly. The data captured and observations made were used to explore the mechanisms involved in breaching and closure.

#### 5.6.1. Breaching

With respect to breaching at Mhlanga Estuary, three events were captured by the water level monitor. The first breach depicted in figure 5-34, occurred on the 23 May 2003.

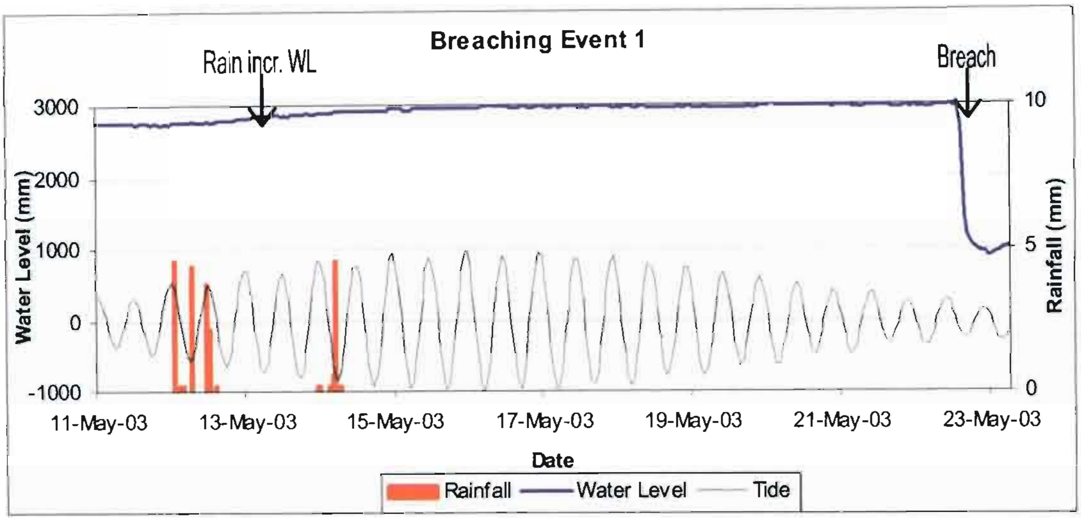



**Figure 5-34: Breaching event on 23 May 2003.**

Prior to breaching the estuary had been closed for approximately seven and a half weeks, during which time rainfall recorded for the area was about 50 mm (approximately half the average rainfall for this period). Each rainfall event was responsible for an increase in the water level within the estuary, as expected, with the rainfall occurring on the 14 May 2003 pushing the water level in the estuary to a high of approximately 2960 mm above MSL. This is the height at which breaching appears to occur. However breaching only occurred during neap tide, nine days after the estuary reached the high water level. Inputs into the estuary must have been similar to the outputs from the estuary during the nine days as the estuary maintained the high water level to within 60 mm, bearing in mind the accuracy of the logger is ± 20 mm.

The estuary breached at a water level of 2955 mm between one and two o'clock in the morning at low tide on the 23rd and by eleven o'clock the water level in the estuary had dropped to 906 mm above MSL. The largest drop in water level occurred during the second hour of breaching, between two and three o'clock, where the water level was reduced by approximately 1240 mm. At eleven o'clock on the morning of the breach the water level monitor was replaced. Unfortunately the logger introduced into the estuary failed, providing unreliable data after 11 am.

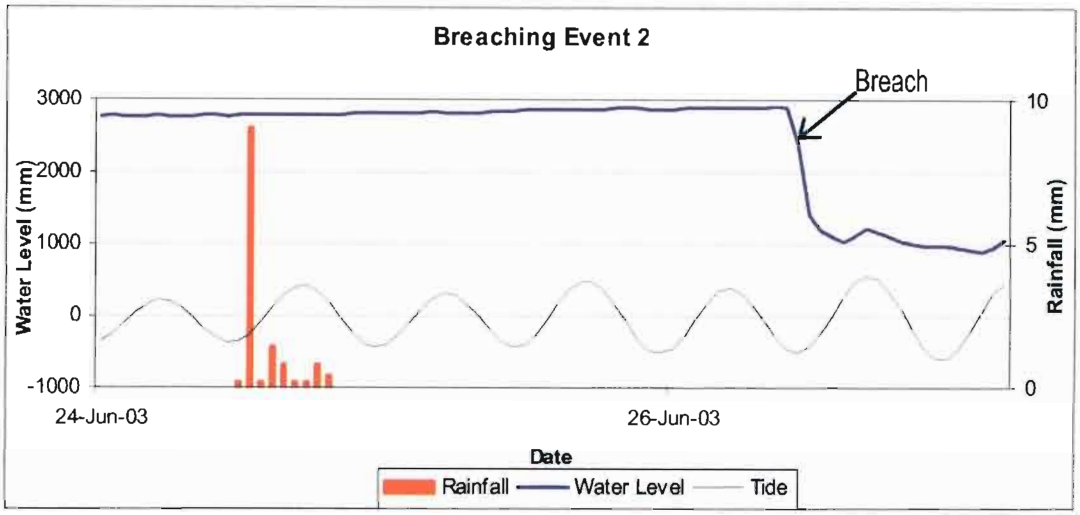



**Figure 5-35: Breaching event on 26 June 2003.**

The second breach captured on the data logger was on the 26 June 2003 and is shown in figure 5-35. The water level in the estuary was approximately 2915 mm above MSL, with the tidal situation shifting from neap to spring. During the preceding closed phase of approximately four weeks the area received a total rainfall of about 21.8 mm, 60% of which fell the day before breaching. In this instance the water level was raised and breaching occurred, there was no waiting period before breaching as observed in the previous event.

The estuary breached between eight and nine o'clock in the evening, again at low tide, on the 26 June, and took five hours to lower the water level to 1055 mm above MSL, after which the estuary experienced a rise in water level. At this point it would appear that the estuary had not completely emptied but the force of the tide pushing into the estuary was greater than that of the water trying to leave the estuary. During the following low tide the water level in the estuary reached a low of 920 mm above MSL. The most substantial drop in the water level occurred during the first two hours after breaching started, with a reduction of 515 mm in the first hour and 980 mm in the second hour.

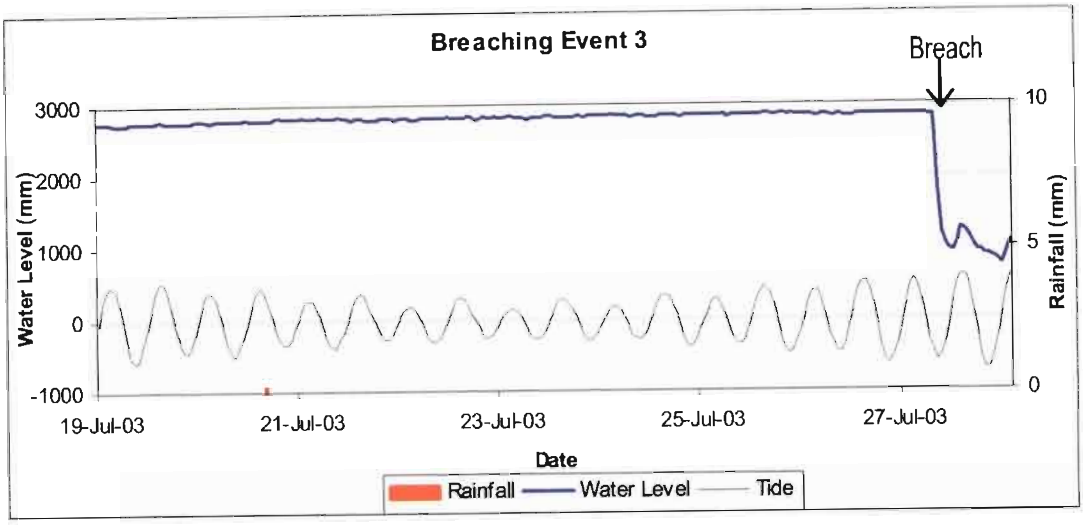



**Figure 5-36: On the 27 July 2003 the Mhlanga Estuary breached for the third time since the installation of the water level monitor.**

On the 27 July 2003 the estuary breached for the third time since the water level monitors had been installed. The water level prior to breaching was approximately 2810 mm above MSL as seen in figure 5-36. In the four weeks since the estuary closed on the 30 June 2003, the rainfall recorded in the area was very low at 0.4 mm. Mhlanga Estuary reached its peak water level on the 21 July with the water level fluctuating slightly (approximately 80 mm of fluctuation was recorded, however the accuracy of the logger is ± 20 mm) for 6 days before breaching. At the time of breaching the tide was shifting from neap to spring.

This breach began between eight and nine o'clock in the evening, again at low tide, with the water level dropping to 935 mm above MSL by one o'clock the following morning. The estuary then experienced the effects of high tide increasing the water level before it dropped to a low of 732 mm during the following low tide. As with the previous breaching event it appears the estuary had not completely emptied before the tide began to drive into the estuary mouth. The majority of the storage volume of the estuary was released within the first two hours of breaching with a water level decrease of 1000 mm in the first hour and 620 mm in the second hour.

Information on the three breaching events is summarized in table 5-6. In each scenario the estuary breached at low tide, with the last two cases emptying for five hours before tidally driven flow began to enter the estuary, increasing the volume of water in the estuary. The first breaching event recorded showed a reduction in water level even during the first high tide, probably as the tide at the time was neap and the waves were unable to push into the estuary. Once open the estuary appears to be influenced by the tide, this is further discussed below.

**Table 5-6: Comparing the three breaching events captured by the water level monitor.**

<table>
<tr><th colspan="2"></th><th>May</th><th>June</th><th>July</th></tr>
<tr><td colspan="2">Tidal Situation</td><td>Neap</td><td>4 days after neap</td><td>4 days after neap</td></tr>
<tr><td colspan="2">Tide</td><td>Low</td><td>Low</td><td>Low</td></tr>
<tr><td colspan="2">Water Level before breach</td><td>2955</td><td>2915</td><td>2810</td></tr>
<tr><td colspan="2">Lowest water level when open</td><td>875</td><td>826</td><td>690</td></tr>
<tr><td colspan="2">Rainfall during closed period (mm)</td><td>50</td><td>21.8</td><td>0.4</td></tr>
<tr><td rowspan="6">Reduction in water level during the hours following breaching</td><td>Hour 1</td><td>285</td><td>516</td><td>998</td></tr>
<tr><td>Hour 2</td><td>1240</td><td>980</td><td>622</td></tr>
<tr><td>Hour 3</td><td>255</td><td>219</td><td>131</td></tr>
<tr><td>Hour 4</td><td>106</td><td>85</td><td>86</td></tr>
<tr><td>Hour 5</td><td>43</td><td>61</td><td>38</td></tr>
<tr><td>Hour 5-10</td><td>123</td><td>n/a</td><td>n/a</td></tr>
</table>

The average change in water level occurring in the first 5 hrs of a breach is approximately 1.9 m. Using the storage determined in section 3.1.4, the volume of water flushed from the estuary in the 5 hrs is approximately 800 000m$^3$. This translates to a flow rate of 44m$^3$/s, which is greater than the peak discharge of 36m$^3$/s associated with the 1 in 2yr flood (Jezewski, et al., 1984).

Seepage appears to be an important factor in breaching at Mhlanga Estuary under the flow conditions observed in 2003. On two occasions seepage was observed at the base of the sand berm on the seaward side, within hours of a breaching event. Plate 5-6 was taken on the morning of the 26 June 2003.

**Plate 5-6: Seepage at the southern end of Mhlanga Estuary on the 26 June 2003.**

On the 15 September 2003 the scour due to seepage observed at Mhlanga Estuary was greater than that observed in June. Plate 5-7 gives an overall impression of the seepage event around midday. The exact time of the breach is unknown, however the estuary had breached by the following day and as the estuary had not breached before the tide turned it is assumed that it breached at the following low tide. The water level observed during this event was higher than previously recorded, approximately 3.2m.

**Plate 5-7: Seepage observed at Mhlanga Estuary on the 15 September 2003.**

Dramatic erosion of Mhlanga Estuary beach face was observed over several hours on the 15 September 2003. The increased depth of erosion from 11:19am to 12:32pm is shown in plate 5-8.

a)

b)

**Plate 5-8: Depth of scour observed at a) 11:19 and b) 12:32.**

### 5.6.2. Closure

From the data obtained from the water level monitors it has been established that Mhlanga Estuary appears to close at high tide. In June and July 2003 the estuary took 3.5 and 2.5 days to close respectively, which is equivalent to 7 and 5 tidal cycles. During a two week daily observation of the Mhlanga Estuary the process of closure at Mhlanga Estuary was observed.

The approximate volume of sediment lost from the sand berm when the mouth opened on the 26 June 2003, was estimated as $1400m^3$. Over the 3.5 days it took for the estuary to close the sand berm within the channel built up with a smaller channel releasing water through the middle. Plate 5-9 shows the mouth of the estuary with a channel in the middle, while plate 5-10 shows the build up of sediment.

The estuary took 7 high tides to close, therefore approximately $200m^3$ of sediment was deposited in the mouth each high tide, amounting to $400m^3$ per day. The Durban area has an average longshore sediment transport rate of $1400m^3$ per day (Schoonees, 2000), therefore the estuary required a sediment supply of approximately 30% of the longshore supply. It is also possible that some of the sediment originally scoured from the mouth was deposited in the surf zone and pushed back on shore. A daily berm survey carried out during this period indicated a rise in the sand berm around the channel of approximately half a meter a day, which is equivalent to approximately 400$m^3$/day, corroborating with the estimate calculated above by dividing the total volume of sediment removed by number of days to closure.

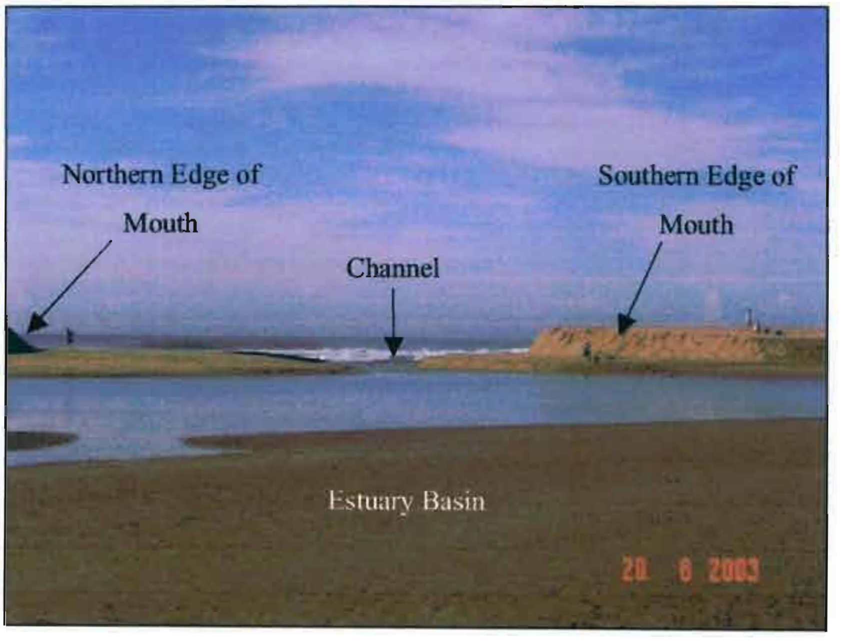



**Plate 5-9: The characteristics of the mouth.**

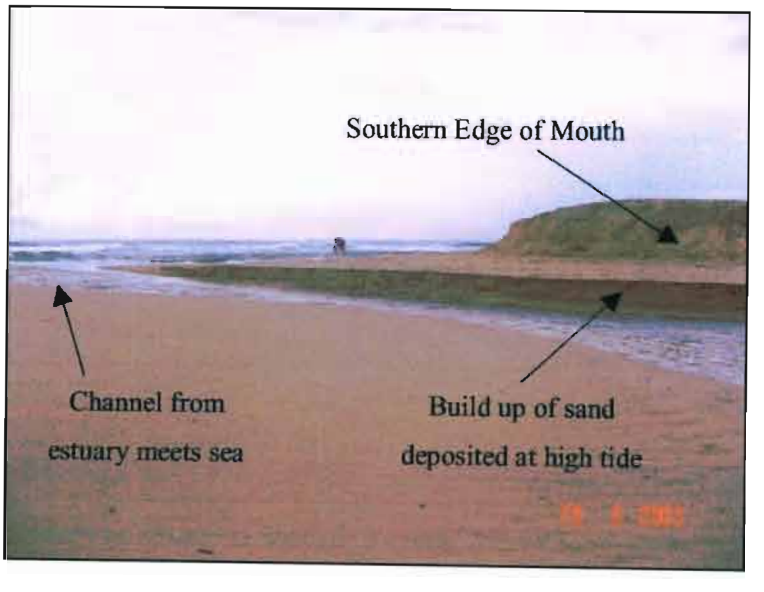



**Plate 5-10: Build up of sand, deposited during high tide.**

On the third day of the study observations were made at high tide to study the behaviour of the mouth. As the waves pushed into the mouth at an angle, sand was deposited into the channel which had formed down the centre of the mouth. Plate 5-11 shows the substantial channel connected to the sea, while plate 5-12 taken 6.5 hours later shows the channel narrowing on the seaward side. By low tide the following morning the estuary had partially closed with only a small trickle connecting the estuary to the sea.

An interesting aspect of the mouth closure is that it occurs at high tide trapping a large volume of saline water in the estuary. The water depth at the time of closure is approximately 1400 millimetres above MSL, as opposed to the level of 690 millimetres above MSL when open at low tide.

**Plate 5-11: Defined central channel on the morning of closure.**

**Plate 5-12: Channel becoming narrow on the seaward side, as the estuary closes.**

### 5.6.3. Summary

Each of the events captured by the water level monitors show that Mhlanga Estuary breached at low tide, while closure tended to occur at high tide, trapping saline water in the estuary. Once breaching commenced the estuary took approximately 5 hours to empty, which indicates a flow rate of the order $44m^3/s$.

Mhlanga Estuary continued to breach regardless of the lack of rainfall in the region. On two occasions seepage has been observed prior to breaching, and is possibly the cause of failure under the low flows experienced by Mhlanga Estuary.

Closure of the estuary is due to wave action depositing sediment in the estuary mouth. Cross-shore waves deposit layers of sediment in the mouth on a daily basis and unless the river flow is sufficient to remove this sediment the estuary is likely to close within a few days.

## 5.7. Modelling the relationship between flow and mouth state

Mhlanga and Mdloti Estuaries provided a platform, from which two different flow regimes could be explored. The main human influence impacting on the hydrodynamics of Mdloti Estuary is the Hazelmere Dam. The construction of a dam upstream alters the seasonal stream-flow pattern as well as having an attenuating effect on the flood flows. Under drought conditions, a higher percentage of the water entering the reservoir is retained by the dam. A second problem which arises during a low rainfall year is that more water is required for irrigation of the sugar cane and therefore more water is likely to be abstracted. As there is less flow in the river the required abstraction forms a higher percentage of the flow.

Mhlanga Estuary is subject to an increased flow due to WWTW discharge equivalent to approximately 60% of the natural MAR. This capping flow is not significant in terms of flood flows, however under low flow conditions this capping flow largely increases the baseflow resulting in regular breaching when the closed state is expected.

To compare the effects of changes in stream-flow on the behaviour of the mouth, flow duration curves (FDC's) have been calculated for the case studies and are discussed in section 5.7.1.

The RDM studies used flow thresholds to determine the mouth state from flow rate. However from this current study it has been shown that flows are only useful in determining mouth state in the high and low flow regimes and do not reflect the intermediate state. A simplified model for determining the percentage closed from flow data is presented in section 5.7.2.

### 5.7.1. Flow duration curves

FDCs provide a simple and informative manner of presenting the distribution of river flows from drought to flood conditions. The FDCs are usually presented as log-normal plots of discharge versus percentage of time that the discharge is either equalled or exceeded. This frequency distribution of flows does not account for the order in which the flows occur. 1-month annual and 1-day annual flow duration curves can be calculated from monthly or daily data sets, respectively over a recorded period or data sets can be grouped either seasonally or into similar months. (Smakhtin, 2000).

Monthly annual FDCs were plotted for both the present and natural or reference states at Mhlanga and Mdloti Estuaries. Comparing the FDCs for the reference and present state, the effects of human influences, such as discharge of treated effluent and the construction of Hazelmere Dam, are visible. The addition of treated effluent into the stream-flow entering Mhlanga Estuary causes an increase in the flow throughout the data, as seen in figure 5-37. An additional state was included in the FDC for Mhlanga Estuary, namely the future state. Provision was made for the future as it is foreseen that the WWTWs discharging into the Ohlanga River are likely to increase the amount of discharge form 20Ml/day to 35Ml/day, for which permits have been granted, within the next 4 years (CSIR, 2003).

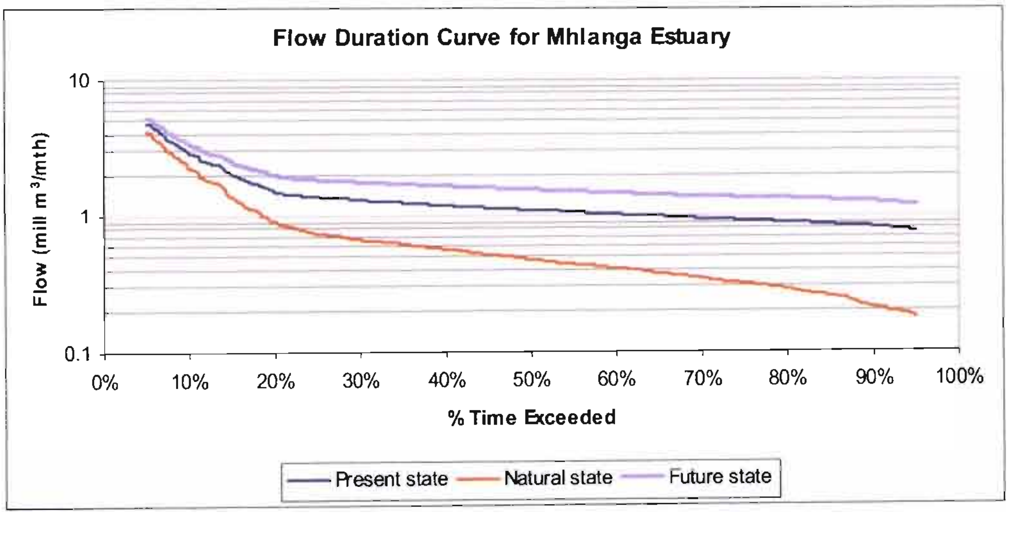



**Figure 5-37: A 1-month annual flow duration curve of both the natural state and the present day conditions at Mhlanga estuary.**

Although the elevation in flow is fairly uniform throughout the range, the effect on the low flows is more dramatic than on the higher flows. That is under flood conditions the additional treated effluent entering the system has negligible effect, whilst under low flow conditions the additional flow can be responsible for driving the system as witnessed at Mhlanga Estuary during 2003, when there was little rainfall yet the estuary continued to breach at fairly regular intervals.

At Mdloti Estuary the effect of the abstraction and discharge of treated effluent is merely to shift the flow rates down or up, however the construction of the dam alters the natural pattern of stream-flow. It is expected that Hazelmere Dam will attenuate the flood flows, the effects of which can be seen in figure 5-38.

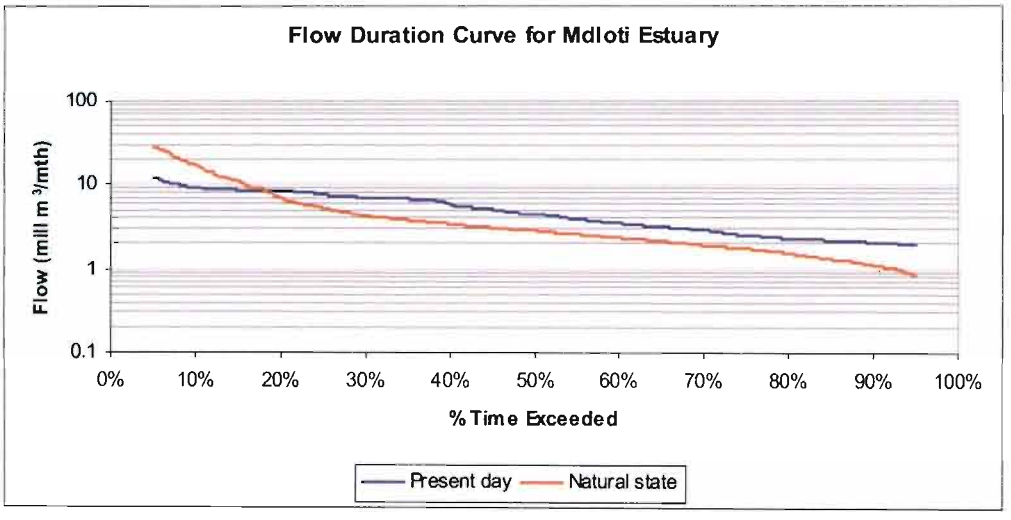



**Figure 5-38: A 1-month annual flow duration curve of both the natural state and the present day conditions at Mdloti Estuary.**

The data presented in figure 5-38 is problematic, with the present state data showing higher flows than the reference state. An overall decrease in the flows should be evident for the present state as the release from Hazelmere Dam should be less than the stream-flow for the U30A catchment and the abstractions from the Mdloti River downstream of the Hazelmere dam exceed the discharges into the river. Possible reasons for the inaccuracies could be that the simulated stream-flow data is underestimated or the Hazelmere Dam data overestimated. Other sources of error could include underestimation of the abstractions, as there was no gauged data available.

### 5.7.2. The model

It has been established that a temporary open estuary can be classified into three flow regimes.

1. The open regime which occurs under high flow conditions where the residence time of the inflow is less than the time required for closure to occur, thereby forcing the mouth to remain open.

2. The closed regime which occurs under low flow conditions, where the inflow is less than the maximum seepage losses, the estuary remains closed.

3. Inbetween the open regime and the closed regime is the open/closed regime which is dependant on both flow and residence time. For example high flows (significantly greater than seepage losses) may only be sustained long enough to increase the water level and not result in breaching, while relatively low flows (slightly greater than the maximum seepage loss), occurring when the estuary water level is high, can cause breaching in a short period of time. Note this open/closed regime is not the same as the partly open state but is better defined as intermittently open/closed.

Schematic representations of the conceptual model for the relationship between flow and mouth state developed for Mhlanga and Mdloti Estuaries are given in figures 5-39 and 5-40 respectively. These figures were produced using the data tabulated in table 5-7.

**Table 5-7: Relevant characteristics of Mhlanga and Mdloti Estuaries.**

| | Mhlanga | Mdloti |
|---|---|---|
| **$Q_c$ ($m^3$/s)** | 0.27 | 0.55 |
| **Storage=S ($m^3$)** | 800 000 | 970 000 |
| **$T_R$ at $Q_c$ = $T_{cr}$=S/$Q_c$ (days)** | ±34 | 20 |
| **Time to closure = $T_{cl}$ (days)** | ±5 | ±5 |
| **$T_{cr}/T_{cl}$** | 7 | 4 |

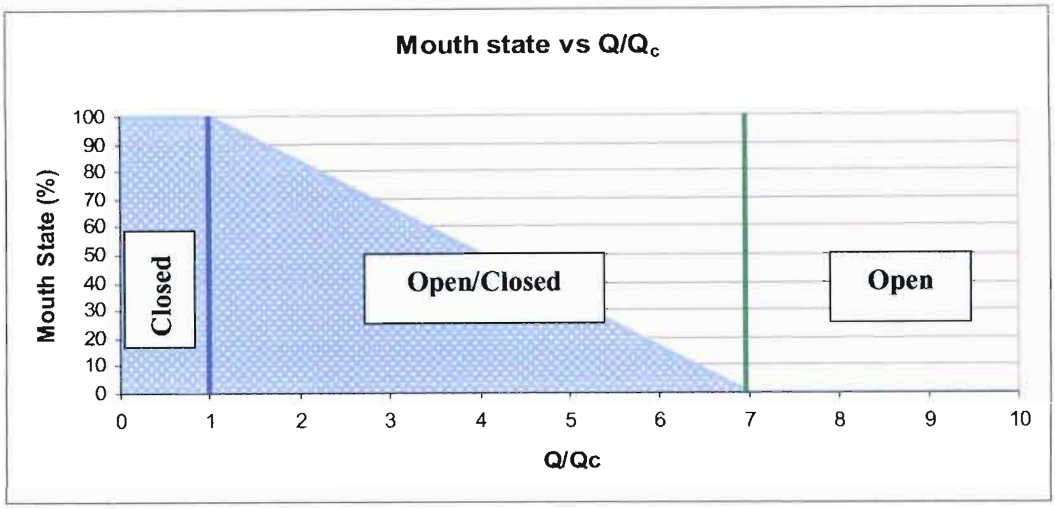



**Figure 5-39: Visual interpretation of the model for Mhlanga Estuary, where Q is flow and $Q_c$ critical flow.**

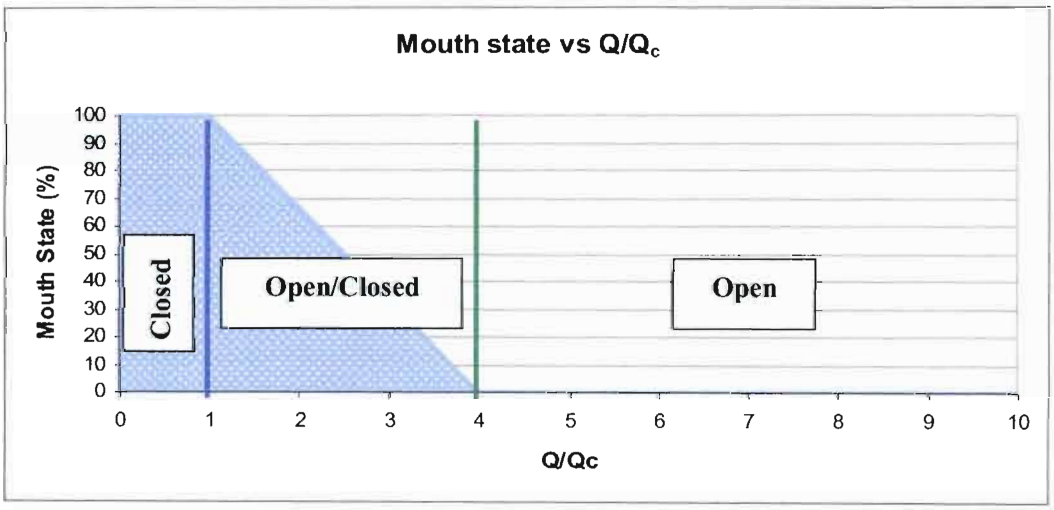



**Figure 5-40: Visual interpretation of the model for Mdloti Estuary, where Q is flow and $Q_c$ critical flow.**

Combining the model with the FDC for Mhlanga Estuary figure 5-41 was produced. By combining the data the percentage of time the estuary is likely to be in each regime, on average, can be estimated. These estimates are presented in table 5-8.

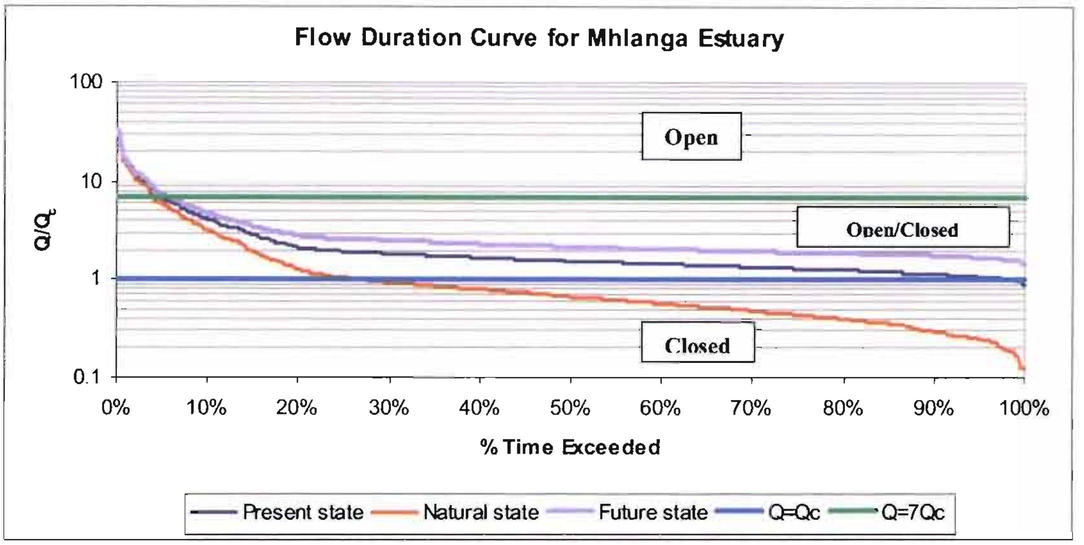



**Figure 5-41: Plot of flow normalized by the critical flow against the percentage of time exceeded. The three flow regimes are superimposed on the plot.**

**Table 5-8: Information extracted for Mhlanga Estuary from figure 5-41.**

| Regime | Present State (% of time) | Reference State (% of time) | Future State (% of time) |
|---|---|---|---|
| Closed | 1 | 73 | 0 |
| Open/Closed | 94 | 23 | 95 |
| Open | 5 | 4 | 5 |

To make this information comparable with the RDM data it has been assumed that in the open/closed regime, half the time the estuary is closed and the other half the estuary is open. The partly open state is difficult to determine, and in generally partly open states observed were during a transitional phase between open and closed. The data is tabulated in table 5-9.

**Table 5-9: Comparison of percentage closed for reference and present state obtained from various sources.**

| | State | Percentage closed | | |
|---|---|---|---|---|
| | | RDM | Model | Observed |
| **Mhlanga** | Reference | 82 | 85 | - |
| | Present | 49 | 48 | 55 |

The results obtained from the model for Mhlanga Estuary correlate well with the RDM results. The values obtained for % closed from observations are expected to be higher than the averages from the RDM data and the Model due to low rainfall during the observation period. Perhaps a larger proportion of the open/closed regime should be allocated to the closed state to improve the model.

## 5.8. Summary of results

- The three flow regimes:

  The flows were categorised in relation to the maximum seepage from the estuary.

| | | |
|---|---|---|
| Low flows | $I-O_{max} < 0$ | Estuary remains closed if the flows remain in this regime. |
| Intermediate flows | $I-O_{max} \approx 0$ | Water level reaches breaching level, becoming unstable |
| High flows | $I-O_{max} > 0$ | Very short residence time ($T_R$), if flow continues longer than $T_R$ overtopping occurs. |

- Open state:

  Both estuaries experience tidal influence under open conditions. From the water level data it can be seen that Mhlanga Estuary is flood dominated as the water level rises faster than it subsides.

| | March '03 | June '03 | July '03 |
|---|---|---|---|
| **Tidal Range (open) - mm** | 1000-2000 | 850-1350 | 1350-1500 |
| **Water Level range - mm** | 740-1800 | 200-500 | 470-580 |
| **No. High tides leading to closure** | * | 7 | 5 |
| **Days open** | 4* | 3.5 | 2.5 |

* The water level monitors were first introduced into the estuary during the open phase in March 2003, therefore this data is not available from the data logger

- Breaching:

  Upon breaching the estuary has an average flow rate of 44$m^3$/s over the first five hours of the breaching event. An interesting feature noted in all three breaching events captured is the occurrence of breaching at low tide.

| | | May | June | July |
|---|---|---|---|---|
| **Tidal Situation** | | Neap | 4 days after neap | 4 days after neap |
| **Tide** | | Low | Low | Low |
| **Water Level before breach** | | 2955 | 2915 | 2810 |
| **Rainfall during closed period (mm)** | | 50 | 21.8 | 0.4 |
| **Reduction in water level during the hours following breaching** | **Hour 1** | 285 | 516 | 998 |
| | **Hour 2** | 1240 | 980 | 622 |
| | **Hour 3** | 255 | 219 | 131 |
| | **Hour 4** | 106 | 85 | 86 |
| | **Hour 5** | 43 | 61 | 38 |
| | **Hour 5-10** | 123 | n/a | n/a |

- Closure:

  Closure took 2.5 to 4 days in the three full breaches recorded; however this was under low flow conditions. If higher flows existed the mouth could be maintained in the open state for longer.

| | |
|---|---|
| Volume of sediment removed from berm | 1400$m^3$ |
| Sediment deposited in estuary mouth daily | 400$m^3$ |
| Sediment available from longshore transport | 1400$m^3$/d |

- Modelling:

  A basic model can be used in the determination of percentage closed. This model incorporates the use of the critical flows and the timescales involved in mechanisms influencing the mouth state.

# 6. CONCLUSION

## 6.1. Introduction

Four questions were proposed at the outset of this dissertation, with the aim of determining the effects of flow on mouth state. It has been established that the hydrodynamic component of the estuarine system, in particular mouth state, has a large impact on the welfare of estuaries with respect to aspects such as water quality and the biological component. Estuaries are important not only from a biological aspect but also play a role in tourism and in subsistence farming.

## 6.2. Question 1: Flow and mouth state

*Is there a definite relationship between flow entering an estuary and the mouth state of an estuary?*

From the research conducted it was found that flow can be used to predict mouth state only under certain circumstances. For instance where high flows are sustained for a sufficient period of time the estuary is likely to breach. Conversely should low flows be sustained the estuary will remain closed. However for flows existing between these two regimes, or where flows are short in duration, the mouth state is not directly related. The best indicator of mouth state is water level, which governs the behaviour of an estuary.

## 6.3. Question 2: Rainfall and mouth state

*Can rainfall be used to determine the mouth state of an estuary?*

Rainfall is an easily measurable component of stream-flow, therefore a correlation between rainfall and mouth state was sought. There was a weak correlation between monthly rainfall and the percentage of time the estuary was open during that month. However the case study estuaries occasionally breached when there had been no rainfall during the closed period, while remaining closed for some time after a rainfall event.

## 6.4. Question 3: Tidal influence

*What, if any, tidal influence exists in perched, temporary open estuaries such as Mhlanga and Mdloti Estuaries?*

While the estuaries are open tidal influence exists despite the perched nature of the estuary. This phenomenon is as a result of wave runup superimposed on the natural tidal fluctuations. At Mhlanga Estuary data captured on the water level monitor showed asymmetrical fluctuations, exhibiting signs of flood domination, corresponding with the tidal fluctuations.

Salinity readings were used to confirm the existence of tidal influence at Mdloti Estuary, as no breaching events occurred after the installation of the continuous water level monitors.

## 6.5. Question 4: Mechanisms affecting the mouth

*What are the mechanisms involved in breaching and closure of an estuary mouth, and what are the timescales implicated?*

Breaching mechanisms were also explored in this dissertation. The mechanism by which an estuary breaches is dependant on the relationship between the inflows and outflows from the system. Where the inflows are of the same order of magnitude as the maximum outflows, the water level rises until the maximum breaching level is reached and seepage failure is likely to occur. However should the inflows be far greater than the outflows, failure through overtopping should occur. In the breaching events captured by the continuous water level monitors the water level tended to drop for 5 hours after commencement of breaching, until a low water level was reached.

Tidal influence is instrumental in the closure of Mhlanga Estuary, by progressively building up the mouth with each high tide. In the events captured on the water level monitors the closure took between 3 and 5 days. Length of time required for closure to occur could be prolonged if the freshwater inflow to the estuary is strong enough to scour the deposited sediment form the mouth. The estuary closed at high tide trapping a large volume of saline water in the estuary.

## 6.6. Summation

From the research conducted it was discovered that the mouth state of Mhlanga and Mdloti Estuaries is dependant on the water level within the estuary. There is a correlation between sustained high flows and an open estuary mouth and between sustained low flows which maintain the estuary in the closed state. However for the intermediate flow regimes, as well as high and low flows with short residence times, it is not as easy to determine the mouth state of the estuary. An estuary is a complex system and determination of the mouth state requires an understanding of the water levels, losses, residence times and flows.

## 6.7. Suggestions for further research

In order to further this research the continuous water level recordings need to be coupled with continuous flow measurements. Combining these two data sets will provide more accurate information on the relationship between flow and water level as well as providing more precise details on the water balance and hence the losses from the system. The flow records during open phases can also be used to indicate the magnitudes of flow required to keep the estuary open. It would also be valuable to obtain further data for these case study estuaries under different climatic conditions, for instance the affects of a wet year and average year on flows and mouth state.

Surveys of the estuary are valuable in determining the storage of the estuary. Sediment build up in the estuary affects the morphology of the lagoon. Sediment within an estuary provides habitat to several organisms. The creation and destruction of this habitat could greatly influence the food chain. During the closed phase a sediment yield analysis (e.g. Modified Universal Soil Loss Equation) could be used to determine the sediment entering the estuary, which can be confirmed with surveys. The effect of estuary breaching is to scour sediment from the estuary. The water levels, flow rates and mouth size affects the amount of sediment scoured from the estuary and in turn the health of the estuary, therefore particularly for artificially breached estuaries an understanding of the water levels and mouth size is required for adequate scouring to occur.

The water level at which breaching occurs is dependant on the characteristics of the berm. A study focussed on the affect of berm characteristics on the breaching of an estuary could provide an explanation as to how and when an estuary is likely to breach. For instance, as Mdloti

Estuary has remained closed for a large portion of 2003 and the berm has gradually become wider over this period, does this affect the flows required for the estuary to breach.

When the estuary is in the open phase, tidal influence is evident. A long term study could be used to determine the relationship between the tide level, significant wave height and the volume exchange within the estuary. A secondary affect would be to see how these characteristics affect the transport of sediment in and out of the estuary.

There are several other abiotic characteristics influencing the estuarine environment, for instance turbidity and salinity, both of which are linked to mouth state. The relationship between flows, mouth state and abiotic characteristics could be further explored to obtain an understating of the estuary.

# REFERENCES


Bagnold, RA, 1940. Beach formation by waves; some model-experiments in a wave tank. Institution of civil engineering journal, vol. 15, pp 27-53.

Barnhart, C L and Barnhart, R K (Eds.), 1992. The World Book Dictionary, World Book Inc., USA.

Begg, G W, 1978. The Estuaries of Natal, *Natal Town and Regional Planning Report* 41, pp 657. The Natal Town and Regional Planning Commission, Pietermaritzburg.

Begg, G W, 1984. The Estuaries of Natal Part 2 – Supplement to NTRP Report 41, *Natal Town and Regional Planning Main Series Report* 55, pp 182. The Natal Town and Regional Planning Commission, Pietermaritzburg.

Breen, C & McKensie, M (eds), 2002. Managing Estuaries in South Africa: An Introduction, Institute of National Resources, Pietermaritzburg.

CSIR, 1982. Report 13, On the Silwermine Estuary CSW3. In: Estuaries of the Cape, Part II, Synopses of Available Information on Individual Systems. (Eds: Heydorn, A.E.F and Grindley, J.R.). CSIR Report no. 412.

CSIR, 1990. Hydro Factors Affecting Siltation in the Lower Reaches of Natal/KwaZulu Rivers, CSIR Report EMA-D 9006

CSIR, 2002. Rapid Determination of Resource Directed Measures of the Mdloti Estuary. Draft Specialist Report for DWAF.

CSIR, 2003. Rapid Determination of Resource Directed Measures of the Mhlanga Estuary. Draft Specialist Report for DWAF.

DWAF, 2003. Water Resource Protection and Assessment Policy Implementation Process. (Eds: Taljaard, S, Turpie, J and Adams, J.) Department of Water Affairs and Forestry.

Gillette, D, 2003. Breach Formation in Piping and Seismic Failures of Embankment Dams, US Bureau of Reclamation, Denver. (www.pswcrl.ars.usda.gov, accessed in October 2003)

Glavovic, B, 2000. Our Coast, Our Future, A New Approach to Coastal Management in South Africa, Common Ground Consulting for the Department of Environmental Affairs and Tourism.

Gurney, P, 2003. Personal communications: 25 August 2003.

Hopper, M, 2003. WXTide32 version 3.1. (http://wxtide32.com, accessed in February 2003)

Huizinga, P and van Niekerk, L, 2002. Mouth Dynamics and Hydrodynamics of Estuaries, *Coastal Engineering Course, University of Stellenbosch, September 2002.*

Huizinga, P, 1995. River Basin Management and Estuarine Needs: The Great Brak Case Study. Water Science Technology Journal, vol. 32, no.5-6, pp. 87-93.

Huizinga, P, 2000. Introduction and Discussion on Water Flow and Mouth Management of Estuaries, *NRF Estuaries Workshop.*

Huizinga, P, 2003. Personal communications: 9 June 2003, 10:33

IGBP, 2001. LOICZ methods, (http://data.ecology.su.se/MNODE/Methods/TOC.htm, accessed May 2003)

Jezewski, W A, Pyke, P D and Roberts, C P R 1984. Estuarine and Lake Freshwater Requirements, Technical Report No. TR123, DWAF

Midgley, DC, Pitmann, WV, Middleton, BJ, 1994. Surface Water Resources of South Africa, 1st Edition. *Water Research Commission Report* 298/1/94.

Midgley, DC, Pitmann, WV, Middleton, BJ, 1997. Surface Water Resources of South Africa, 2nd Edition Appendices. (Available on CDROM)

Olson, E, 1976. www.geol.uscb.edu/faculty/sylvester/Teton Dam (accessed in November 2003)

Perissinotto, R, 2003. Personal communication: 20 August 2003, 11:14

Perissinotto, R, Stretch, DD, Forbes, AT, Connell, A, Blair, A, Demetriades, N, Zietsman, I Kibirige, I, Thwala, X, Thomas, C, Iyer, K, 2003. WRC Programme K5/1247: Final Report.

Perry J.E., 1989. The impact of the September 1987 floods on the estuaries of Natal/Kwazulu; a hydro-photographic perspective. CSIR Research Report 640. Earth, Marine and Atmospheric Science and Technology.

Ponce, V M, 1976. Teton Dam Failure, http://kahuna.sdsu.edu/ (accessed in November 2003)

PPDC, Draft 2002. Estuaries Part II, UNPUBLISHED.

Ramm, A, Cerff, E, Harrison, T D, 1985(a). Natal Estuaries Status Report No. 33 – The Mhlabatshane Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1985(b). Natal Estuaries Status Report No. 8 – The Mvutshini Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1985(c). Natal Estuaries Status Report No. 7 – The Umhlangankulu Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1985(d). Natal Estuaries Status Report No. 6 – The Mpenjati Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1985(e). Natal Estuaries Status Report No. 5 – The Kandanlovu Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1985(f). Natal Estuaries Status Report No. 4 – The Kuboboyi Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1985(g). Natal Estuaries Status Report No. 3 – The Tongazi Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1985(h). Natal Estuaries Status Report No. 21 – The Sipingo Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1985(i). Natal Estuaries Status Report No. 20 – The Mzinto Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1985(j). Natal Estuaries Status Report No. 19 – The Mhlangeni Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1985(k). Natal Estuaries Status Report No. 18 – The Zotsha Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1985(l). Natal Estuaries Status Report No. 17 – The Boboyi Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1985(m). Natal Estuaries Status Report No. 16 – The Mbango Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1985(n). Natal Estuaries Status Report No. 31 – The Mnamfu Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1985(o). Natal Estuaries Status Report No. 30 – The Mfazazana Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1985(p). Natal Estuaries Status Report No. 24 – The Mzimkulu Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1985(q). Natal Estuaries Status Report No. 2 – The Sandlundlu Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1985(r). Natal Estuaries Status Report No. 9 – The Kaba Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1985(s). Natal Estuaries Status Report No. 10 – The Mbizana Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1985(t). Natal Estuaries Status Report No. 11 – The Bilanhlolo Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1985(u). Natal Estuaries Status Report No. 12 – The Uvuzana Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1985(v). Natal Estuaries Status Report No. 13 – The Kongweni Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1985(w). Natal Estuaries Status Report No. 14 – The Vungu Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1985(x). Natal Estuaries Status Report No. 15 – The Mdloti Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1985(y). Natal Estuaries Status Report No. 22 – The Mhlangamkulu Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1985(z). Natal Estuaries Status Report No. 23 – The Mtentweni Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1985(aa). Natal Estuaries Status Report No. 25 – The Damba Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1985(ab). Natal Estuaries Status Report No. 26 – The Mzumbe Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1985(ac). Natal Estuaries Status Report No. 27 – The Koshwana Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1985(ad). Natal Estuaries Status Report No. 28 – The Intshambili Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1985(ae). Natal Estuaries Status Report No. 29 – The Mhlungwa Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1985(af). Natal Estuaries Status Report No. 32 – The Kwamakosi Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1986(a). Natal Estuaries Status Report No. 4 – The Mhlanga Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1986(b). Natal Estuaries Status Report No. 63 – The Little Manzimtoti Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1986(c). Natal Estuaries Status Report No. 65 – The Mkomazi Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1986(d). Natal Estuaries Status Report No. 43 – The Mgeni Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1986(e). Natal Estuaries Status Report No. 39 – The Mdesingane Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1986(f). Natal Estuaries Status Report No. 55 – The Tugela Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1986(g). Natal Estuaries Status Report No. 46 – The Mahlongwa Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1986(h). Natal Estuaries Status Report No. 45 – The Mpambanyoni Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1986(i). Natal Estuaries Status Report No. 60 – The Zinkwasi Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1986(j). Natal Estuaries Status Report No. 61 – The Mhlali Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1986(k). Natal Estuaries Status Report No. 62 – The Manzimtoti Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1986(l). Natal Estuaries Status Report No. 64 – The Lovu Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1986(m). Natal Estuaries Status Report No. 47 – The Mahlongwana Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1986(n). Natal Estuaries Status Report No. 35 – The Mtwalume Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1986(o). Natal Estuaries Status Report No. 54 – The Matigulu Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1986(p). Natal Estuaries Status Report No. 56 – The Mvoti Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1986(q). Natal Estuaries Status Report No. 57 – The Nonoti Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1986(r). Natal Estuaries Status Report No. 58 – The Mdlotane Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1986(s). Natal Estuaries Status Report No. 59 – The Seteni Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1986(t). Natal Estuaries Status Report No. 38 – The Mkumbane Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1986(u). Natal Estuaries Status Report No. 37 – The Mvuzi Estuary, *National Institute for Water Research of the CSIR*

Ramm, A, Cerff, E, Harrison, T D, 1986(v). Natal Estuaries Status Report No. 36 – The Fafa Estuary, *National Institute for Water Research of the CSIR*

Reddering JSV, 1988. Coastal and catchment basin controls on estuary morphology of the south-eastern Cape coast. South African Journal of Science, Vol. 84, 154-157.

Schmidt, EJ, 1998. Impacts of Sugarcane Production and Changing Land Use on Catchment Hydrology, WRC, Report no. 419/1/98.

Schoonees, K, 2000. Annual Variation in Net Longshore Transport, Coastal Engineering Journal, vol. 40, 141-160.

Schoonees, K, 2002. Coastal Sediment Transport, *Coastal Engineering Course, University of Stellenbosch, September 2002.*

Schulze, RE, 1997. South African Atlas of Agrohydrology and -climatology. WRC, Pretoria, Report TT82/96.

Schumann, E, Largier, J, Slinger, J, 1999, Estuarine Hydrodynamics, *Estuaries of South Africa*, Eds: Allanson, B R & Baird, D, Cambridge University Press.

Swoffer instruments inc., 2002. Model 3000, operating instructions. (www.swoffer.com, accessed June 2003)

U.S. Army Corps of Engineers, 2002. Coastal Engineering Manual. Engineering Manual 1110-2-1100.

Whitfield, A K and Smith, J L B, 1999, Resource Directed Measures For Protection Of Water Resources: Estuarine Ecosystem Component, Water Resources Protection And Assessment Policy Implementation Process, Eds: MacKay, H and Weston, B. (http://www-dwaf.pwv.gov.za/docs/Water%20Resource%20Protection%20Policy/estuarine%20ecosystems/est App1 version1.0.doc., accessed August 2003)

Whitfield, AK 2000, Available Scientific Information On Individual South African Estuarine Systems, WRC Report 577/3/00

Whitfield, A, Bate, G, Colloty, B and Taylor, R, 2003. CERM Photohouse. (www.upe.ac.za/cerm/Guybate.html, accessed March 2003)

# APPENDICES

Contents:

APPENDIX A: SUMMARIES OF

JEZEWSKI (1984)

CSIR (1990)

RAMM ET AL (1985/6)

BEGG (1978)

BEGG (1984)

**Jezewski (1984)**

| | Evaporative Water requirement | | | | | | |
|---|---|---|---|---|---|---|---|
| | CSIR no. | Quartenary drainage region | Estuary Area (ha) | Mean Annual Gross Evap (mm) | Mean Annual Rainfall (mm) | Evaporative Requirement ($10^6$ $m^3$/a) | Remarks |
| Kosi | NN21 | W700 | 3500 | 1470 | 1000 | 23.860 | |
| Mgobezeleni | NN20 | W700 | 1.3 | 1420 | 1000 | 0.008 | |
| Lake St Lucia | NN19 | W305 | 32500 | 1400 | 900 | 222.950 | |
| Mfolozi | NN18 | W230 | 180 | 1350 | 1200 | 0.772 | |
| Nhlabane | NN17 | W122 | 17 | 1350 | 1300 | 0.061 | |
| Richard's Bay | NN16 | W122 | 1320 | 1330 | 1400 | 3.567 | evaporative requirement of the sanctuary area only |
| Mlalazi | NN15 | W130 | 129 | 1310 | 1200 | 0.505 | |
| Siyai (Siyaya) | NN14 | W130 | 5.9 | 1300 | 1200 | 0.023 | |
| Matigulu | NN13 | W110 | 122 | 1290 | 1100 | 0.540 | |
| Nyoni | NN12 | W110 | 70 | 1290 | 1100 | 0.310 | |
| Tugela | NN11 | V500 | 55 | 1260 | 1100 | 5.200 | |
| Zinkwasi | NN10 | U500 | 34.8 | 1250 | 1100 | 0.141 | |
| Nonoti | NN9 | U500 | 18 | 1250 | 1100 | 0.073 | |
| Mdlotane | NN8 | U500 | 9.4 | 1250 | 1100 | 0.038 | |
| Mvoti | NN7 | U403 | 18.4 | 1240 | 1100 | 0.073 | |
| Seteni | NN6 | U302 | 1.1 | 1230 | 1100 | 0.004 | |
| Mhlali | NN5 | U302 | 21 | 1230 | 1100 | 0.081 | |
| Tongati | NN4 | U302 | 9.4 | 1220 | 1100 | 0.042 | |
| Mdloti | NN3 | U301 | 18.3 | 1220 | 1000 | 0.080 | |
| Mhlanga | NN2 | U301 | 11.4 | 1200 | 1000 | 0.049 | |
| Mgeni | NN1 | U202 | 38.8 | 1200 | 1000 | 0.300 | |
| Durban Bay | NS53 | U602 | N/A | 1200 | 1000 | N/A | harbour |
| Mlazi | NS52 | U602 | N/A | 1200 | 1000 | N/A | concrete lined drainage canal |
| Sipingo | NS51 | U603 | 6.8 | 1200 | 1000 | 0.029 | |
| Mbokodweni | NS50 | U603 | 7.2 | 1200 | 1000 | 0.031 | |
| Manzimtoti | NS49 | U700 | 6.7 | 1200 | 1000 | 0.029 | |
| Little Manzimtoti | NS48 | U700 | 1.5 | 1200 | 1000 | 0.006 | |
| Lovu (Illovu) | NS47 | U700 | 20 | 1200 | 1000 | 0.086 | |
| Msimbazi | NS46 | U700 | 13.2 | 1200 | 1000 | 0.056 | |
| u Mgababa | NS45 | U700 | 17.6 | 1200 | 1000 | 0.075 | |
| Ngane | NS44 | U701 | 1.4 | 1200 | 1000 | 0.006 | |
| Mkomazi | NS43 | U100 | 55.8 | 1200 | 1000 | 0.239 | |
| Mahlongwana | NS42 | U804 | 6.8 | 1200 | 1000 | 0.029 | |
| Mahlongwa | NS41 | U804 | 6.6 | 1200 | 1000 | 0.028 | |
| Mpanbanyoni | NS40 | U804 | 2.3 | 1200 | 1000 | 0.01 | |
| Mzimayi (North) | NS39 | U803 | 0.9 | 1200 | 1000 | 0.004 | |
| Mzinto | NS38 | U803 | 7 | 1200 | 1000 | 0.03 | |
| Mkumbane | NS37 | U803 | 0.3 | 1200 | 1000 | 0.001 | |
| Sezela | NS36 | U803 | 9 | 1200 | 1000 | 0.039 | |
| Mdesingane | NS35 | U803 | 0.4 | 1200 | 1000 | 0.002 | |
| Fafa | NS34 | U803 | 30.1 | 1200 | 1000 | 0.129 | |
| Mvuzi | NS33 | U803 | 0.8 | 1200 | 1000 | 0.003 | |
| Mtwalume | NS32 | U802 | 24.8 | 1200 | 1000 | 0.106 | |
| Mnamfu | NS31 | U802 | 1.3 | 1200 | 1000 | 0.006 | |
| Kwa-Makosi | NS30 | U802 | 2.5 | 1200 | 1000 | 0.011 | |
| Mfazazana | NS29 | U802 | 2.1 | 1200 | 1000 | 0.009 | |
| Mhlungwa | NS28 | U802 | 3.1 | 1200 | 1000 | 0.013 | |
| Mzimayi (South) | NS27 | U802 | 2.3 | 1200 | 1000 | 0.01 | also known as Mhlabatshane R |
| Mzumbe | NS26 | U801 | 21.6 | 1200 | 1000 | 0.092 | |
| i Ntshambili | NS25 | U801 | 1.7 | 1200 | 1000 | 0.007 | |
| Koshwana | NS24 | U801 | 1.2 | 1200 | 1000 | 0.005 | |
| Damba | NS23 | U801 | 1.7 | 1200 | 1000 | 0.007 | |
| Mhlangamkulu | NS22 | U801 | 3.9 | 1200 | 1000 | 0.017 | |
| Mtentweni | NS21 | U801 | 8 | 1200 | 1000 | 0.034 | |
| Mzimkulu | NS20 | T502 | 74 | 1200 | 1000 | 0.317 | |
| Mbango | NS19 | T402 | 0.9 | 1200 | 1000 | 0.004 | |
| Boboyi | NS18 | T402 | 1.3 | 1200 | 1000 | 0.006 | |
| Zotsha | NS17 | T402 | 7.3 | 1200 | 1000 | 0.031 | |
| Mhlangeni | NS16 | T402 | 3.6 | 1200 | 1000 | 0.015 | |
| Vungu | NS15 | T402 | 1.1 | 1200 | 1000 | 0.005 | |
| Kongweni | NS14 | T402 | 1.4 | 1200 | 1000 | 0.006 | |
| Uvuzana | NS13 | T402 | 0.6 | 1200 | 1000 | 0.003 | |
| Bilanhlolo | NS12 | T402 | 2.6 | 1200 | 1000 | 0.011 | |
| Mvutshini | NS11 | T402 | 0.9 | 1200 | 1000 | 0.004 | |
| Mbizane | NS10 | T402 | 12.4 | 1200 | 1100 | 0.044 | |
| Kaba | NS9 | T402 | 2.4 | 1200 | 1100 | 0.009 | |
| Umhlangankulu | NS8 | T402 | 5.8 | 1200 | 1100 | 0.021 | |
| Mpenjati | NS7 | T402 | 11.6 | 1200 | 1100 | 0.042 | |
| Kandandhlovu | NS6 | T402 | 1.8 | 1200 | 1100 | 0.006 | |

| | Evaporative Water requirement | | | | | | |
|---|---|---|---|---|---|---|---|
| | CSIR no. | Quartenary drainage region | Estuary Area (ha) | Mean Annual Gross Evap (mm) | Mean Annual Rainfall (mm) | Evaporative Requirement ($10^6$ $m^3$/a) | Remarks |
| Tongazi | NS5 | T402 | 0.8 | 1200 | 1200 | 0.002 | |
| Ku-Boboyi | NS4 | T402 | 1.1 | 1200 | 1200 | 0.003 | |
| Sandlundlu | NS3 | T402 | 4 | 1200 | 1200 | 0.012 | |
| Zolwane | NS2 | T401 | 0.5 | 1200 | 1200 | 0.001 | |
| Mtamvuna | NS1 | T401 | 50.3 | 1200 | 1200 | 0.145 | International River |
| Great Kei | CSE59 | S701 | 298 | 1300 | 1000 | 1.594 | |
| Morgan | CSE57 | R303 | 30 | 1300 | 1000 | 0.161 | |
| Quko | CSE56 | R303 | 43 | 1300 | 1000 | 0.23 | |
| Haga-Haga | CSE54 | R303 | 4 | 1300 | 1000 | 0.021 | |
| Nyara | CSE53 | R303 | 17 | 1310 | 900 | 0.104 | |
| Kwenxura | CSE52 | R303 | 48 | 1310 | 900 | 0.295 | |
| Cefane | CSE51 | R303 | 64 | 1310 | 900 | 0.393 | |
| Cintsa | CSE50 | R303 | 23 | 1310 | 900 | 0.141 | |
| Bulura | CSE48 | R303 | 198 | 1320 | 900 | 1.236 | |
| Kwelera | CSE47 | R303 | 53 | 1320 | 900 | 0.331 | |
| Gqunube (Gonubi) | CSE46 | R302 | 84 | 1320 | 900 | 0.524 | |
| Qinira | CSE45 | R301 | 49 | 1320 | 900 | 0.305 | |
| Nahoon | CSE44 | R202 | 54 | 1320 | 900 | 0.337 | |
| Buffalo | CSE41 | R402 | 135 | 1330 | 850 | 0.902 | |
| Gxulu | CSE35 | R402 | 51 | 1350 | 800 | 0.368 | |
| Mcantsi | CSE34 | Q930 | 8 | 1350 | 800 | 0.058 | |
| Great Fish | CSE15 | P400 | 199 | 1400 | 700 | 1.672 | International River |
| Oos-Kleinemonde | CSE14 | P400 | 35 | 1410 | 700 | 0.297 | |
| Wes-Kleinemonde | CSE13 | P400 | 80 | 1420 | 700 | 0.687 | |
| Kowie | CSE10 | P400 | 825 | 1440 | 700 | 7.244 | |
| Kasuka | CSE9 | P400 | 38 | 1450 | 700 | 0.337 | |
| Kariega | CSE8 | P300 | 198 | 1470 | 700 | 1.795 | |
| Bushmans | CSE7 | P100 | 213 | 1470 | 700 | 1.931 | |
| Boknes | CSE6 | P200 | 27 | 1480 | 800 | 0.228 | |
| Sundays | CSE5 | N400 | 268 | 1550 | 500 | 3.008 | |
| Koega | CSE4 | M300 | 35 | 1550 | 500 | 0.393 | |
| Swartkops | CSE3 | M100 | 1100 | 1550 | 500 | 11.963 | |
| Van Stadens | CMS49 | M200 | 28 | 1530 | 600 | 0.289 | |
| Gamtoos | CMS48 | L900 | 175 | 1500 | 600 | 1.76 | |
| Kabeljous | CMS47 | K902 | 82 | 1450 | 600 | 0.785 | |
| Seekoei | CMS46 | K902 | 98 | 1400 | 600 | 0.892 | |
| Krom | CMS45 | K901 | 275 | 1350 | 600 | 2.372 | |
| Groot (West) | CMS23 | K700 | 42 | 1300 | 1000 | 0.225 | |
| Keurbooms | CMS19 | K601 | 373 | 1300 | 700 | 2.779 | |
| Piesang | CMS18 | K602 | 15 | 1300 | 700 | 0.112 | |
| Noetsie | CMS14 | K602 | 8 | 1300 | 800 | 0.054 | |
| Knysa | CMS13 | K500 | 1633 | 1300 | 800 | 11.023 | |
| Goukamma | CMS12 | K402 | 50 | 1300 | 800 | 0.338 | |
| Swartvlei | CMS11 | K401 | 1413 | 1300 | 800 | 9.538 | |
| Touws | CMS10 | K300 | 40 | 1300 | 800 | 0.27 | |
| Kaaimans | CMS9 | K300 | 8 | 1300 | 700 | 0.06 | |
| Maalgate | CMS5 | K300 | 13.5 | 1300 | 800 | 0.091 | |
| Great Brak | CMS3 | K200 | 79 | 1300 | 800 | 0.533 | |
| Little Brak | CMS2 | K102 | 96 | 1300 | 700 | 0.715 | |
| Hartenbos | CMS1 | K101 | 31 | 1300 | 700 | 0.231 | |
| Gourits | CSW25 | J402 | 188 | 1300 | 400 | 1.795 | |
| Kafferkuils | CSW24 | H900 | 263 | 1300 | 400 | 2.512 | |
| Druiwenhoks | CSW23 | H800 | 96 | 1310 | 400 | 0.926 | |
| Bree (Breede) | CSW22 | H700 | 1113 | 1310 | 700 | 8.398 | |
| Heuningnes | CSW19 | G501 | 110 | 1340 | 400 | 1.092 | |
| Ratel | CSW18 | G501 | 10 | 1350 | 600 | 0.086 | |
| Uilkraals | CSW17 | G404 | 260 | 1350 | 600 | 2.24 | |
| Klein | CSW16 | G403 | 1280 | 1350 | 600 | 11.04 | |
| Onrus | CSW14 | G403 | 8 | 1360 | 600 | 0.07 | |
| Bot | CSW13 | G402 | 1490 | 1360 | 700 | 11.95 | |
| Palmiet | CSW12 | G401 | 18 | 1360 | 1000 | 0.25 | |
| Buffels (East) | CSW11 | G401 | 6 | 1370 | 1000 | 0.036 | |
| Rooiels | CSW10 | G401 | 1.2 | 1370 | 1000 | 0.007 | |
| Lourens | CSW7 | G205 | 4 | 1390 | 800 | 0.03 | |
| Eerste | CSW6 | G204 | 15 | 1390 | 700 | 0.125 | |
| Sand | CSW4 | G203 | 121 | 1390 | 1000 | 0.751 | |
| Silvermine | CSW3 | G203 | 1 | 1380 | 1000 | 0.006 | |
| Else | CSW2 | G203 | 10 | 1380 | 800 | 0.075 | |
| Houtbaai | CW27 | G203 | 5 | 1380 | 1000 | 0.31 | |
| Diep/Rietvlei | CW25/24 | G203 | 428 | 1390 | 600 | 3.854 | |
| Great Berg | CW15 | G105 | 798 | 1450 | 300 | 9.317 | |
| Verlore | CW13 | G301 | 1520 | 1490 | 400 | 17.26 | |
| Olifants | CW10 | E304 | 648 | 1600 | 150 | 9.169 | |
| Groen | CW7 | F500 | 28 | 1700 | 100 | 0.433 | Non-perrenial river |
| Spoeg | CW5 | F402 | 54 | 1750 | 100 | 0.86 | Non-perrenial river |
| Orange | CW1 | D803 | N/A | 2000 | 50 | N/A | River mouth |

| | Flooding Water Requirement | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Catchment Area ($km^2$) | Mean Annual Runoff ($10^6 m^3/a$) | Longest Collector (km) | Average Catchment slope | Time of Concentration (h) | 2yr Flood Peak Discharge Q ($m^3/s$) | Calculated Flooding Requirement ($10^6\ m^3/a$) | Adopted Flooding Requirement ($10^6\ m^3/a$) | Remarks |
| Kosi | 500 | Not available | 30 | 0.0015 | 11.1 | 74 | 2.957 | 2.957 | |
| Mgobezeleni | 33 | Not available | 8 | 0.0038 | 2.8 | 19 | 0.192 | 0.192 | |
| Lake St Lucia | 7515 | 395 | - | - | - | - | 84.716 | 27.650 | estimated at 7% MAR |
| Mfolozi | 10075 | 885 | 388 | 0.0032 | 59.7 | 340 | 109.609 | 61.950 | estimated at 7% MAR |
| Nhlabane | 104 | 29 | 15 | 0.0043 | 4.4 | 33.5 | 0.531 | 0.531 | |
| Richard's Bay | 4235 | 645 | 200 | 0.0055 | 29.1 | 218 | 34.257 | 45.150 | estimated at 7% MAR |
| Mlalazi | 510 | 122 | 60 | 0.0097 | 9.3 | 75 | 3.767 | 3.767 | |
| Siyai (Siyaya) | 18 | Not available | 5 | 0.0027 | 2.2 | 13.7 | 0.109 | 0.109 | |
| Matigulu | 880 | 180 | 75 | 0.0081 | 11.8 | 99 | 6.308 | 6.308 | Estuary mouth in common |
| Nyoni | 1150 | 20 | 35 | 0.0035 | 9.0 | 35.5 | 1.150 | 1.150 | |
| Tugela | 29101 | 4597 | 563 | 0.0025 | 78.5 | 570 | 241.623 | 300.000 | |
| Zinkwasi | 73 | 14.3 | 20 | 0.011 | 3.8 | 28.3 | 0.387 | 0.387 | |
| Nonoti | 326 | 55 | 50 | 0.0121 | 7.4 | 60 | 1.598 | 1.598 | |
| Mdlotane | 43 | 9.9 | 9 | 0.0061 | 2.6 | 21.5 | 0.201 | 0.201 | |
| Mvoti | 2829 | 482 | 190 | 0.0067 | 25.9 | 178 | 24.895 | 24.895 | |
| Seteni | 16 | Not available | 3 | 0.0167 | 0.7 | 13 | 0.033 | 0.033 | |
| Mhlali | 320 | 62 | 50 | 0.0102 | 7.9 | 59 | 1.678 | 1.678 | |
| Tongati | 436 | 84 | 55 | 0.0101 | 8.5 | 69 | 2.111 | 2.111 | |
| Mdloti | 527 | 102 | 75 | 0.0070 | 12.5 | 76 | 5.130 | 5.130 | |
| Mhlanga | 118 | 23 | 25 | 0.0056 | 5.8 | 36 | 0.752 | 0.752 | |
| Mgeni | 4432 | 683 | 248 | 0.0058 | 33.6 | 223 | 40.461 | 19.900 | |
| Durban Bay | 242 | 30 | 45 | 0.0162 | 6.1 | - | n/a | n/a | harbour |
| Mlazi | 972 | 119 | 75 | 0.0066 | 12.7 | - | n/a | n/a | concrete lined drainage |
| Sipingo | 39 | 5.7 | 20 | 0.0155 | 3.3 | 20.3 | 0.241 | 0.241 | |
| Mbokodweni | 295 | 35.3 | 60 | 0.0128 | 8.3 | 57 | 1.703 | 1.703 | |
| Manzimtoti | 44.5 | 6.2 | 18 | 0.1940 | 2.8 | 22 | 0.222 | 0.222 | |
| Little Manzimtoti | 12.5 | 1.8 | 10 | 0.0170 | 1.9 | 11.5 | 0.079 | 0.079 | |
| Lovu (Illovu) | 893 | 120 | 100 | 0.0087 | 14.3 | 100 | 7.722 | 7.722 | |
| Msimbazi | 36.4 | 4.9 | 13 | 0.0146 | 2.4 | 19.5 | 0.168 | 0.168 | |
| u Mgababa | 37 | 4.9 | 15 | 0.0167 | 2.6 | 19.8 | 0.185 | 0.185 | |
| Ngane | 16.5 | 2.2 | 10 | 0.0180 | 1.8 | 13.3 | 0.086 | 0.086 | |
| Mkomazi | 4310 | 1034 | 285 | 0.0052 | 39.0 | 220 | 46.332 | 46.332 | |
| Mahlongwana | 17 | Not available | 8 | 0.0250 | 1.4 | 13.4 | 0.068 | 0.068 | |
| Mahlongwa | 107 | 14 | 33 | 0.0125 | 5.3 | 34 | 0.649 | 0.649 | |
| Mpanbanyoni | 562 | 71 | 85 | 0.0101 | 11.9 | 79 | 5.077 | 5.077 | |
| Mzimayi (North) | 31 | 3.7 | 20 | 0.0132 | 3.5 | 18 | 0.227 | 0.227 | |
| Mzinto | 164 | 19.8 | 33 | 0.0180 | 4.6 | 42.4 | 0.702 | 0.702 | |
| Mkumbane | 28 | 3.4 | 15 | 0.0167 | 2.6 | 17.3 | 0.162 | 0.162 | |
| Sezela | 20 | 2.4 | 12 | 0.0167 | 2.3 | 14.5 | 0.120 | 0.120 | |
| Mdesingane | 6 | 0.7 | 5 | 0.0100 | 1.3 | 7.9 | 0.037 | 0.037 | |
| Fafa | 239 | 30 | 65 | 0.0111 | 9.3 | 51 | 1.707 | 1.707 | |
| Mvuzi | 8 | Not available | 7 | 0.0214 | 1.3 | 9.1 | 0.043 | 0.043 | |
| Mtwalume | 565 | 71 | 83 | 0.0108 | 11.4 | 79 | 4.863 | 4.863 | |
| Mnamfu | 15 | 2.1 | 10 | 0.0240 | 1.6 | 12.5 | 0.072 | 0.072 | |
| Kwa-Makosi | 10 | 1.5 | 8 | 0.0250 | 1.4 | 10.2 | 0.051 | 0.051 | |
| Mfazazana | 15 | 2.1 | 10 | 0.0250 | 1.6 | 12.5 | 0.072 | 0.072 | |
| Mhlungwa | 31 | 4.4 | 16 | 0.0158 | 2.8 | 18 | 0.181 | 0.181 | |
| Mzimayi (South) | 41.5 | 5.9 | 17 | 0.0191 | 2.7 | 21.2 | 0.206 | 0.206 | |
| Mzumbe | 536 | 68 | 83 | 0.0075 | 13.1 | 77 | 5.447 | 5.447 | |
| i Ntshambili | 34 | 4 | 13 | 0.0154 | 2.4 | 19 | 0.164 | 0.164 | |
| Koshwana | 12 | 1.4 | 7 | 0.0286 | 1.2 | 11.3 | 0.049 | 0.049 | |
| Damba | 26 | 3 | 15 | 0.0200 | 2.4 | 16.6 | 0.143 | 0.143 | |
| Mhlangamkulu | 12 | 1.4 | 7 | 0.0214 | 1.3 | 11.3 | 0.053 | 0.053 | |
| Mtentweni | 53 | 6.2 | 17 | 0.0202 | 2.6 | 24 | 0.225 | 0.225 | |
| Mzimkulu | 6745 | 1478 | 330 | 0.0054 | 43.1 | 275 | 64.004 | 64.004 | |
| Mbango | 12 | 3.4 | 8 | 0.0125 | 1.8 | 11.3 | 0.073 | 0.073 | |
| Boboyi | 31 | 8.6 | 15 | 0.0200 | 2.4 | 18 | 0.156 | 0.156 | |
| Zotsha | 71 | 14.8 | 22 | 0.0236 | 3.0 | 27.8 | 0.300 | 0.300 | |
| Mhlangeni | 44 | 9.2 | 12 | 0.0200 | 2.0 | 21.8 | 0.157 | 0.157 | |
| Vungu | 102 | 27.5 | 30 | 0.0213 | 4.0 | 33 | 0.475 | 0.475 | |
| Kongweni | 18 | 4.9 | 6 | 0.0317 | 1.0 | 13.7 | 0.049 | 0.049 | |
| Uvuzana | 7 | 1.9 | 3 | 0.0429 | 0.6 | 8.5 | 0.018 | 0.018 | |
| Bilanhlolo | 19 | 5.1 | 11.5 | 0.0234 | 1.8 | 14.1 | 0.091 | 0.091 | |
| Mvutshini | 6 | 1.6 | 6.5 | 0.0292 | 1.1 | 7.9 | 0.031 | 0.031 | |
| Mbizane | 165 | 34 | 28 | 0.0145 | 4.4 | 42.5 | 0.673 | 0.673 | |
| Kaba | 12 | 2.9 | 8.5 | 0.0259 | 1.4 | 11.3 | 0.057 | 0.057 | |
| Umhlangankulu | 10 | 2.4 | 6.5 | 0.0231 | 1.2 | 10.2 | 0.044 | 0.044 | |
| Mpenjati | 87 | 20.7 | 20 | 0.0271 | 2.7 | 30.9 | 0.300 | 0.300 | |
| Kandandhlovu | 11 | 3.7 | 8 | 0.0413 | 1.1 | 10.8 | 0.043 | 0.043 | |

| | Flooding Water Requirement | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Catchment Area ($km^2$) | Mean Annual Runoff ($10^6 m^3/a$) | Longest Collector (km) | Average Catchment slope | Time of Concentration (h) | 2yr Flood Peak Discharge Q ($m^3/s$) | Calculated Flooding Requirement ($10^6\ m^3/a$) | Adopted Flooding Requirement ($10^6\ m^3/a$) | Remarks |
| Tongazi | 20 | 6.7 | 10 | 0.0375 | 1.4 | 14.5 | 0.073 | 0.073 | |
| Ku-Boboyi | 4 | 1.3 | 4 | 0.0263 | 0.8 | 6.4 | 0.018 | 0.018 | |
| Sandlundlu | 19 | 6.3 | 8 | 0.0413 | 1.1 | 14.1 | 0.056 | 0.056 | |
| Zolwane | 7 | 1.3 | 6.5 | 0.0420 | 1.0 | 8.5 | 0.031 | 0.031 | |
| Mtamvuna | 1560 | 303.7 | 160 | 0.0050 | 25.4 | 132 | 18.105 | 18.105 | |
| Great Kei | 20566 | 1064 | 421 | 0.0029 | 66.0 | 740 | 263.736 | 74.480 | estimated at 7% MAR |
| Morgan | 27.9 | 6 | 13 | 0.0215 | 2.1 | 24.3 | 0.184 | 0.184 | |
| Quko | 172.7 | 37.2 | 41 | 0.0068 | 7.9 | 74 | 2.105 | 2.105 | |
| Haga-Haga | 18 | 3.9 | 12 | 0.0168 | 2.2 | 19.3 | 0.153 | 0.153 | |
| Nyara | 36.4 | 7.9 | 18.5 | 0.0108 | 3.6 | 27.6 | 0.358 | 0.358 | |
| Kwenxura | 146.9 | 17.1 | 40 | 0.0086 | 7.1 | 56 | 1.431 | 1.200 | estimated at 7% MAR |
| Cefane | 38.8 | 4.5 | 23 | 0.0150 | 3.7 | 28.8 | 0.383 | 0.383 | |
| Cintsa | 43.7 | 5.1 | 22 | 0.0133 | 3.8 | 30.3 | 0.415 | 0.360 | estimated at 7% MAR |
| Bulura | 41 | 3.7 | 20 | 0.0073 | 4.4 | 29.4 | 0.466 | 0.260 | estimated at 7% MAR |
| Kwelera | 424 | 38.3 | 80 | 0.0052 | 14.7 | 95 | 5.027 | 2.680 | estimated at 7% MAR |
| Gqunube (Gonubi) | 665 | 47 | 95 | 0.0073 | 14.7 | 119 | 9.446 | 3.290 | estimated at 7% MAR |
| Qinira | 90 | 9 | 21 | 0.0087 | 4.3 | 43.7 | 0.676 | 0.676 | |
| Nahoon | 590 | 34 | 83 | 0.0057 | 14.6 | 113 | 8.909 | 2.380 | estimated at 7% MAR |
| Buffalo | 1290 | 92 | 118 | 0.0047 | 20.6 | 168 | 18.688 | 6.440 | estimated at 7% MAR |
| Gxulu | 105 | 12 | 31 | 0.0074 | 6.2 | 47.5 | 1.060 | 0.840 | estimated at 7% MAR |
| Mcantsi | 21 | 2 | 12 | 0.0163 | 2.2 | 21 | 0.166 | 0.166 | estimated at 7% MAR |
| Great Fish | 29284 | 526 | 785 | 0.0015 | 137.4 | 800 | 593.568 | 36.820 | estimated at 7% MAR |
| Oos-Kleinemonde | 48.5 | 2.1 | 17.5 | 0.0110 | 3.4 | 32 | 0.392 | 0.150 | estimated at 7% MAR |
| Wes-Kleinemonde | 89.4 | 3.9 | 34 | 0.0063 | 7.1 | 43.5 | 1.112 | 0.270 | estimated at 7% MAR |
| Kowie | 765 | 25 | 78 | 0.0041 | 15.8 | 128 | 10.921 | 1.750 | estimated at 7% MAR |
| Kasuka | 113 | Not available | 20 | 0.0100 | 3.9 | 49 | 0.688 | 0.688 | estimated at 7% MAR |
| Kariega | 685 | 16 | 115 | 0.0036 | 22.4 | 122 | 14.757 | 1.120 | estimated at 7% MAR |
| Bushmans | 2675 | 38 | 260 | 0.0022 | 50.7 | 240 | 65.707 | 2.660 | estimated at 7% MAR |
| Boknes | 200 | 10 | 25 | 0.0073 | 5.3 | 65.5 | 1.250 | 0.700 | estimated at 7% MAR |
| Sundays | 20790 | 204 | 438 | 0.0027 | 69.9 | 675 | 254.786 | 14.280 | estimated at 7% MAR |
| Koega | 600 | 7 | 70 | 0.0055 | 13.0 | 114 | 8.003 | 0.490 | estimated at 7% MAR |
| Swartkops | 1335 | 79 | 110 | 0.0052 | 18.8 | 170 | 17.258 | 5.530 | estimated at 7% MAR |
| Van Stadens | 21.5 | 13.9 | 28 | 0.0159 | 4.3 | 21.2 | 0.328 | 0.328 | |
| Gamtoos | 34450 | 500.6 | 620 | 0.0020 | 102.6 | 870 | 482.015 | 35.040 | estimated at 7% MAR |
| Kabeljous | 262 | 16.3 | 33 | 0.0123 | 5.3 | 75 | 1.431 | 1.140 | estimated at 7% MAR |
| Seekoei | 250 | 15.7 | 36 | 0.0099 | 6.2 | 73.5 | 1.641 | 1.100 | estimated at 7% MAR |
| Krom | 1085 | 123 | 105 | 0.0049 | 18.5 | 153 | 15.285 | 8.610 | estimated at 7% MAR |
| Groot (West) | 180 | 46 | 30 | 0.0133 | 4.8 | 61.5 | 1.063 | 1.063 | |
| Keurbooms | 1080 | 177 | 80 | 0.0089 | 11.9 | 152 | 9.768 | 9.768 | |
| Piesang | 46 | 5.6 | 20 | 0.0135 | 3.5 | 31.5 | 0.397 | 0.397 | |
| Noetsie | 39 | 4.8 | 13 | 0.0277 | 1.9 | 28.8 | 0.197 | 0.197 | |
| Knysa | 525 | 133 | 58 | 0.0099 | 8.9 | 106 | 5.094 | 5.094 | |
| Goukamma | 235 | 53 | 45 | 0.0114 | 7.0 | 71 | 1.789 | 1.789 | |
| Swartvlei | 387 | 96 | - | - | - | - | 2.321 | 2.321 | |
| Touws | 155 | 39 | 44 | 0.0104 | 7.1 | 57.5 | 1.470 | 1.470 | |
| Kaaimans | 131 | 36 | 27 | 0.0220 | 3.6 | 52.5 | 0.680 | 0.680 | |
| Maalgate | 180 | 27 | 25 | 0.0143 | 4.1 | 61.5 | 0.908 | 0.908 | |
| Great Brak | 190 | 39 | 33 | 0.0178 | 4.6 | 64.2 | 1.063 | 1.063 | |
| Little Brak | 550 | 59.2 | 48 | 0.0099 | 7.7 | 109 | 4.532 | 4.532 | |
| Hartenbos | 205 | 5 | 33 | 0.0063 | 6.9 | 66.3 | 1.647 | 0.350 | estimated at 7% MAR |
| Gourits | 45450 | 539 | 410 | 0.0024 | 69.6 | 1000 | 375.840 | 37.730 | estimated at 7% MAR |
| Kafferkuils | 1155 | 106 | 65 | 0.0034 | 14.7 | 158 | 12.542 | 7.420 | estimated at 7% MAR |
| Duiwenhoks | 835 | 90 | 80 | 0.0040 | 16.2 | 134 | 11.722 | 6.300 | estimated at 7% MAR |
| Bree (Breede) | 12280 | 1758 | 340 | 0.0011 | 81.3 | 520 | 228.290 | 123.060 | estimated at 7% MAR |
| Heuningnes | 1185 | 38 | 99 | 0.0016 | 27.2 | 160 | 23.501 | 2.660 | estimated at 7% MAR |
| Ratel | 185 | 7 | 25 | 0.0101 | 4.5 | 63 | 1.021 | 0.490 | estimated at 7% MAR |
| Uilkraals | 375 | 18 | 48.5 | 0.0052 | 10.0 | 90 | 3.240 | 1.260 | estimated at 7% MAR |
| Klein | 793 | 38 | 82 | 0.0025 | 19.8 | 130 | 13.900 | 2.660 | estimated at 7% MAR |
| Onrus | 73 | 5 | 17.5 | 0.0204 | 2.7 | 82 | 0.797 | 0.350 | estimated at 7% MAR |
| Bot | 920 | 47 | 51 | 0.0050 | 10.5 | 293 | 16.613 | 3.290 | estimated at 7% MAR |
| Palmiet | 535 | 201 | 72 | 0.0072 | 11.9 | 223 | 14.330 | 2.700 | estimated at 7% MAR |
| Buffels (East) | 52 | 22 | 7.5 | 0.0576 | 0.9 | 69 | 0.224 | 0.224 | |
| Rooiels | 21 | 9 | 10 | 0.0576 | 1.2 | 43.8 | 0.189 | 0.189 | |
| Lourens | 140 | 122 | 19 | 0.0222 | 2.8 | 113 | 1.139 | 1.139 | |
| Eerste | 655 | 195 | 43 | 0.0077 | 7.8 | 247 | 10.404 | 10.404 | |
| Sand | 84 | 24 | 17 | 0.0045 | 4.7 | 42.2 | 0.714 | 0.714 | |
| Silvermine | 21 | 5 | 12 | 0.0474 | 1.5 | 20.9 | 0.113 | 0.113 | |
| Else | 13 | 3 | 6.5 | 0.0369 | 1.0 | 16.1 | 0.058 | 0.058 | |
| Houtbaai | 78 | 22.6 | 12 | 0.0070 | 1.3 | 41 | 0.192 | 0.192 | |
| Diep/Rietvlei | 1495 | 81 | 83 | 0.0020 | 21.8 | 180 | 21.190 | 5.670 | estimated at 7% MAR |
| Great Berg | 6500 | 489 | 277 | 0.0004 | 102.5 | 376 | 207.563 | 34.230 | estimated at 7% MAR |
| Verlore | 1895 | 39 | 108 | 0.0014 | 30.6 | 31.8 | 5.255 | 2.730 | estimated at 7% MAR |
| Olifants | 46080 | 1015.4 | 399 | 0.0017 | 77.8 | 158 | 66.379 | 66.379 | |
| Groen | 4470 | 34 | - | - | - | - | n/a | n/a | non-perrenial river |
| Spoeg | 1525 | 3 | - | - | - | - | n/a | n/a | non-perrenial river |
| Orange | 408045 | 11868 | 2615 | 0.0007 | 476.2 | 475 | 1221.450 | 534.060 | estimated at 4.5% MAR |

**CSIR, 1990. Hydro Factors Affecting Siltation in the Lower Reaches of Natal/KwaZulu Rivers,**

CSIR Report EMA-D 9006

| | | catchment area (km$^2$) | River length (km) | Source elevation (m) | River gradient (1: ) | Estuarine length in 1976 (km) | Decrease in estuary length this centuary | Sediment Yield (after Rooseboom 1975) Av. Max. yields tonnes/yr | tonnes/km2/yr |
|---|---|---|---|---|---|---|---|---|---|
| Mtamvuna | NS1 | 1553 | 162 | 1920 | 84 | 5 | | 434290 | 280 |
| Zolwane | NS2 | 7 | 6.5 | 259 | 25 | 0.21 | | 4200 | 600 |
| Sandlundlu | NS3 | 16 | 7.5 | 282 | 27 | 0.6 | | 9600 | 600 |
| Ku-Boboyi | NS4 | 3 | 4 | 107 | 37 | 0.53 | | 1800 | 600 |
| Tongazi | NS5 | 17 | 8.5 | 385 | 22 | 0.35 | | 10200 | 600 |
| Kandandhlovu | NS6 | 9 | 8 | 290 | 28 | 0.55 | | 5400 | 600 |
| Mpenjati | NS7 | 100 | 18 | 480 | 38 | 1.1 | Y | 60000 | 600 |
| Umhlangankulu | NS8 | 9 | 6.5 | 180 | 36 | 0.85 | | 3600 | 400 |
| Kaba | NS9 | 11 | 9 | 220 | 41 | 0.5 | | 4400 | 400 |
| Mbizane | NS10 | 145 | 26 | 480 | 54 | 1.5 | y | 72500 | 500 |
| Mvutshini | NS11 | 7 | 6.5 | 180 | 36 | 0.25 | | 2800 | 400 |
| Bilanhlolo | NS12 | 21 | 12 | 240 | 50 | 0.5 | | 8400 | 400 |
| Uvuzana | NS13 | 8 | 2.5 | 130 | 19 | 0.23 | | 3200 | 400 |
| Kongweni | NS14 | 20 | 6 | 180 | 33 | 0.85 | | 8000 | 400 |
| Vungu | NS15 | 124 | 24 | 610 | 39 | 0.18 | | 85200 | 400 |
| Mhlangeni | NS16 | 38 | 12.5 | 340 | 37 | 0.95 | y | 15200 | 400 |
| Zotsha | NS17 | 57 | 20 | 415 | 48 | 2.5 | | 22800 | 400 |
| Boboyi | NS18 | 32 | 14 | 370 | 38 | 0.38 | y | 12800 | 400 |
| Mbango | NS19 | 13 | 8 | 139 | 58 | 0.65 | | 5200 | 400 |
| Mzimkulu | NS20 | 6745 | 329 | 2440 | 135 | 5.5 | y | 2170020 | 322 |
| Mtentweni | NS21 | 50 | 20 | 340 | 59 | 2.3 | | 20000 | 400 |
| Mhlangamkulu | NS22 | 11 | 7 | 185 | 38 | 0.9 | | 4400 | 400 |
| Damba | NS23 | 25 | 11 | 300 | 37 | 0.5 | y | 10000 | 400 |
| Koshwana | NS24 | 11 | 6.3 | 200 | 32 | 0.48 | | 4400 | 400 |
| i Ntshambili | NS25 | 33 | 12.5 | 210 | 60 | 0.55 | y | 13200 | 400 |
| Mzumbe | NS26 | 536 | 84 | 933 | 90 | 0.95 | | 214400 | 400 |
| Mzimayi (South) | NS27 | 47 | 16 | 240 | 67 | 1 | | 18800 | 400 |
| Mhlungwa | NS28 | 32 | 18 | 222 | 81 | 1.5 | | 12800 | 400 |
| Mfazazana | NS29 | 16 | 10.5 | 278 | 38 | 0.53 | y | 6400 | 400 |
| Kwa-Makosi | NS30 | 16 | 7 | 183 | 38 | 0.75 | | 6400 | 400 |
| Mnamfu | NS31 | 16 | 9 | 233 | 39 | 0.75 | | 6400 | 400 |
| Mtwalume | NS32 | 565 | 85 | 985 | 86 | 1.7 | y | 226000 | 400 |
| Mvuzi | NS33 | 8 | 6.5 | 178 | 37 | 0.7 | | 3200 | 400 |
| Fafa | NS34 | 231 | 66 | 918 | 72 | 3 | y | 88150 | 382 |
| Mdesingane | NS35 | 6 | 5.2 | 76 | 68 | 0.5 | y | 2400 | 400 |
| Sezela | NS36 | 20 | 12 | 180 | 67 | 1.8 | | 8000 | 400 |
| Mkumbane | NS37 | 28 | 14 | 300 | 47 | 0.25 | y | 11200 | 400 |
| Mzinto | NS38 | 149 | 37 | 520 | 71 | 1.42 | | 59600 | 400 |
| Mzimayi (North) | NS39 | 31 | 20 | 178 | 112 | 0.25 | y | 12400 | 400 |
| Mpanbanyoni | NS40 | 562 | 100 | 962 | 104 | 0.25 | y | 184550 | 328 |
| Mahlongwa | NS41 | 92 | 23 | 430 | 53 | 1.9 | | 36800 | 400 |
| Mahlongwana | NS42 | 15 | 6 | 218 | 27 | 1.3 | | 6000 | 400 |
| Mkomazi | NS43 | 4310 | 298 | 2650 | 112 | 3 | y | 1616360 | 375 |
| Ngane | NS44 | 16 | 8 | 219 | 37 | 0.34 | | 6400 | 400 |
| u Mgababa | NS45 | 37 | 14.5 | 244 | 59 | 2.4 | | 14800 | 400 |
| Msimbazi | NS46 | 35 | 16 | 244 | 66 | 2.8 | | 14000 | 400 |
| Lovu (Illovu) | NS47 | 893 | 135 | 1280 | 105 | 1.1 | y | 398900 | 447 |
| Little Manzimtoti | NS48 | 18 | 15 | 165 | 91 | 0.8 | | 7200 | 400 |
| Manzimtoti | NS49 | 39 | 11.6 | 274 | 42 | 1.6 | | 15600 | 400 |
| Mbokodweni | NS50 | 283 | 59 | 732 | 81 | 0.7 | | 113200 | 400 |
| Sipingo | NS51 | 51 | 27 | 328 | 82 | 1.25 | y | 20400 | 400 |
| Mlazi | NS52 | 972 | 82 | 914 | 90 | | | 426800 | 439 |
| Durban Bay | NS53 | not studied | | | | | | | |
| Mgeni | NN1 | 4432 | 232 | 1829 | 127 | 6.2 | y | 1657670 | 374 |
| Mhlanga | NN2 | 118 | 28 | 324 | 86 | 2.2 | y | 47200 | 400 |
| Mdloti | NN3 | 527 | 81 | 854 | 95 | 1.5 | | 210800 | 400 |
| Tongati | NN4 | 436 | 50 | 747 | 67 | 2 | | 174400 | 400 |
| Mhlali | NN5 | 304 | 46.5 | 580 | 80 | 2 | y | 121600 | 400 |
| Seteni | NN6 | 16 | 5 | 61 | 82 | 0.35 | | 6400 | 400 |
| Mvoti | NN7 | 2829 | 197 | 1479 | 133 | 1.75 | y | 813850 | 288 |
| Mdlotane | NN8 | 43 | 13 | 122 | 107 | 2.25 | | 17200 | 400 |
| Nonoti | NN9 | 210 | 37.5 | 488 | 77 | 1.9 | | 84000 | 400 |
| Zinkwasi | NN10 | 73 | 22 | 229 | 96 | 7.4 | | 29200 | 400 |
| Tugela | NN11 | 29101 | 405 | 3109 | 130 | 0.8 | y | 8798000 | 302 |
| Nyoni | NN12 | 115 | 25 | 152 | 164 | 7 | | 41280 | 359 |
| Matigulu | NN13 | 880 | 96 | 762 | 126 | 7.5 | y | 224440 | 255 |
| Siyai (Siyaya) | NN14 | 18 | 8 | 59 | 136 | 2.5 | y | 1800 | 100 |
| Mlalazi | NN15 | 492 | 54 | 549 | 98 | 11 | | 49200 | 100 |
| Richard's Bay | NN16 | | | | | | | not studied | |
| Mhlatuze | | 3670 | 209 | 1265 | 165 | 0.5 | y | 1055470 | 288 |
| Nhlabane | NN17 | 104 | 12 | 43 | 279 | 3 | y | 10400 | 100 |
| Mfolozi | NN18 | 10075 | 395 | 1646 | 240 | 4.6 | y | 2364240 | 235 |
| Lake St Lucia | NN19 | not studied | | | | | | | |
| Mgobezeleni | NN20 | 33 | 6 | 15 | 400 | 0.75 | | 23300 | 100 |
| Kosi | NN21 | +/-500 | 30 | 75 | 400 | 16 | | 500000 | 100 |

| | Simulated runoff | Coefficients of variation (V%) | | | | Simulated runoff/precipitation | | |
|---|---|---|---|---|---|---|---|---|
| | MAR ($m^3 \times 10^6$) | annual | monthly | median annual runoff ($m^3 \times 10^6$) | median/ mean % | MAR (mm) | MAP (mm) | MAR/MAP (%) |
| Mtamvuna | 303.78 | 43.4 | 96.4 | 264.36 | 87 | 196 | 956 | 20.5 |
| Zolwane | 1.73 | 43.4 | 96.4 | 1.51 | 87 | 247 | 1019 | 24.5 |
| Sandlundlu | 6.4 | 51.9 | 125.6 | 5.65 | 88 | 400 | 1194 | 33.5 |
| Ku-Boboyi | 1.2 | 51.9 | 125.6 | 1.06 | 88 | 400 | 1194 | 33.5 |
| Tongazi | 6.8 | 51.9 | 125.6 | 6 | 88 | 400 | 1194 | 33.5 |
| Kandandhlovu | 3.6 | 51.9 | 125.6 | 3.18 | 88 | 400 | 1194 | 33.5 |
| Mpenjati | 25.52 | 51.9 | 125.6 | 22.51 | 88 | 255 | 1074 | 23.7 |
| Umhlangankulu | 2 | 51.9 | 125.6 | 1.76 | 88 | 222 | 1040 | 21.3 |
| Kaba | 2.44 | 51.9 | 125.6 | 2.15 | 88 | 222 | 1040 | 21.3 |
| Mbizane | 29.56 | 51.9 | 125.6 | 26.08 | 88 | 204 | 1019 | 20 |
| Mvutshini | 1.82 | 51.9 | 125.6 | 1.61 | 88 | 260 | 1091 | 23.8 |
| Bilanhlolo | 5.46 | 51.9 | 125.6 | 4.82 | 88 | 260 | 1091 | 23.8 |
| Uvuzana | 2.08 | 51.9 | 125.6 | 1.83 | 88 | 260 | 1091 | 23.8 |
| Kongweni | 5.2 | 51.9 | 125.6 | 4.59 | 88 | 260 | 1091 | 23.8 |
| Vungu | 26.44 | 51.9 | 125.6 | 23.32 | 88 | 213 | 1031 | 20.7 |
| Mhlangeni | 9.6 | 51.9 | 125.6 | 8.47 | 88 | 253 | 1073 | 23.6 |
| Zotsha | 14.4 | 51.9 | 125.6 | 12.7 | 88 | 253 | 1073 | 23.6 |
| Boboyi | 8.53 | 51.9 | 125.6 | 7.52 | 88 | 267 | 1080 | 24.7 |
| Mbango | 3.47 | 51.9 | 125.6 | 3.06 | 88 | 267 | 1080 | 24.7 |
| Mzimkulu | 1478.21 | 38.8 | 80 | 1345.6 | 91 | 219 | 960 | 22.8 |
| Mtentweni | 14.62 | 68 | 149.3 | 11.65 | 80 | 292 | 1030 | 28.3 |
| Mhlangamkulu | 3.22 | 68 | 149.3 | 2.57 | 80 | 292 | 1030 | 28.3 |
| Damba | 7.31 | 68 | 149.3 | 5.82 | 80 | 292 | 1030 | 28.3 |
| Koshwana | 3.22 | 68 | 149.3 | 2.57 | 80 | 292 | 1030 | 28.3 |
| i Ntshambili | 9.65 | 68 | 149.3 | 7.69 | 80 | 292 | 1030 | 28.3 |
| Mzumbe | 71.03 | 68 | 149.3 | 56.6 | 80 | 133 | 903 | 14.7 |
| Mzimayi (South) | 8.14 | 68 | 149.3 | 6.49 | 80 | 173 | 1038 | 16.7 |
| Mhlungwa | 5.55 | 68 | 149.3 | 4.42 | 80 | 173 | 1038 | 16.7 |
| Mfazazana | 2.77 | 68 | 149.3 | 2.21 | 80 | 173 | 1038 | 16.7 |
| Kwa-Makosi | 2.77 | 68 | 149.3 | 2.21 | 80 | 173 | 1038 | 16.7 |
| Mnamfu | 2.77 | 68 | 149.3 | 2.21 | 80 | 173 | 1038 | 16.7 |
| Mtwalume | 60.02 | 68 | 149.3 | 47.82 | 80 | 106 | 932 | 11.4 |
| Mvuzi | 0.84 | 68 | 149.3 | 0.67 | 80 | 105 | 920 | 11.4 |
| Fafa | 24.17 | 68 | 149.3 | 19.26 | 80 | 105 | 920 | 11.4 |
| Mdesingane | 0.9 | 68 | 149.3 | 0.72 | 80 | 150 | 985 | 15.2 |
| Sezela | 2.99 | 68 | 149.3 | 2.38 | 80 | 150 | 985 | 15.2 |
| Mkumbane | 4.18 | 68 | 149.3 | 3.34 | 80 | 150 | 985 | 15.2 |
| Mzinto | 22.29 | 68 | 149.3 | 17.76 | 80 | 150 | 985 | 15.2 |
| Mzimayi (North) | 4.64 | 68 | 149.3 | 3.7 | 80 | 150 | 985 | 15.2 |
| Mpanbanyoni | 52.02 | 68 | 149.3 | 41.45 | 80 | 93 | 895 | 10.4 |
| Mahlongwa | 12.04 | 68 | 149.3 | 9.59 | 80 | 131 | 1004 | 13 |
| Mahlongwana | 1.96 | 68 | 149.3 | 1.56 | 80 | 131 | 1004 | 13 |
| Mkomazi | 1036.17 | 42.8 | 84 | 954.45 | 92 | 240 | 982 | 24.4 |
| Ngane | 2.9 | 63.8 | 124.1 | 2.31 | 80 | 181 | 1040 | 17.4 |
| u Mgababa | 6.71 | 63.8 | 124.1 | 5.34 | 80 | 181 | 1040 | 17.4 |
| Msimbazi | 6.35 | 63.8 | 124.1 | 5.05 | 80 | 181 | 1040 | 17.4 |
| Lovu (Illovu) | 111.78 | 63.8 | 124.1 | 88.91 | 80 | 125 | 936 | 13.4 |
| Little Manzimtoti | 3.78 | 63.8 | 124.1 | 3.01 | 80 | 210 | 1079 | 19.5 |
| Manzimtoti | 8.2 | 63.8 | 124.1 | 6.52 | 80 | 210 | 1079 | 19.5 |
| Mbokodweni | 35.58 | 71.2 | 146 | 27.89 | 78 | 126 | 961 | 13.1 |
| Sipingo | 6.41 | 71.2 | 146 | 5.03 | 78 | 126 | 961 | 13.1 |
| Mlazi | 91 | 71.2 | 146 | 71.34 | 78 | 94 | 861 | 10.9 |
| Durban Bay | | | | | | | | |
| Mgeni | 682.88 | 57 | 107.1 | 561.45 | 82 | 154 | 945 | 16.3 |
| Mhlanga | 26 | 71.3 | 160.6 | 19.82 | 76 | 220 | 1028 | 21.4 |
| Mdloti | 116.99 | 71.3 | 160.6 | 89.16 | 76 | 222 | 1104 | 20.1 |
| Tongati | 74.99 | 71.3 | 160.6 | 57.15 | 76 | 172 | 1087 | 15.8 |
| Mhlali | 49.4 | 71.3 | 160.6 | 37.65 | 76 | 163 | 1085 | 15 |
| Seteni | 2.6 | 71.3 | 160.6 | 1.698 | 76 | 163 | 1085 | 15 |
| Mvoti | 468.19 | 85.6 | 146.4 | 335.9 | 72 | 166 | 1035 | 16 |
| Mdlotane | 9.1 | 85.6 | 146.4 | 6.53 | 72 | 212 | 1100 | 19.3 |
| Nonoti | 44.47 | 85.6 | 146.4 | 31.9 | 72 | 212 | 1100 | 19.3 |
| Zinkwasi | 15.46 | 85.6 | 146.4 | 11.09 | 72 | 212 | 1100 | 19.3 |
| Tugela | 4594.94 | 48.8 | 122.3 | 4045.79 | 88 | 158 | 894 | 17.7 |
| Nyoni | | | | | | | | |
| Matigulu | 201.07 | 77.1 | 156.5 | 149.22 | 74 | 202 | 1129 | 17.9 |
| Siyai (Siyaya) | 5.25 | 87.8 | 160.5 | 3.83 | 73 | 292 | 1286 | 22.7 |
| Mlalazi | 117.01 | 87.8 | 160.5 | 85.37 | 73 | 238 | 1209 | 19.7 |
| Richard's Bay | | | | | | | | |
| Mhlatuze | 467.5 | 84.8 | 142.3 | 352.9 | 76 | 127 | 876 | 14.5 |
| Nhlabane | 30.75 | 87.1 | 158.4 | 21.66 | 70 | 296 | 1256 | 23.6 |
| Mfolozi | 887.28 | 123.9 | 218.7 | 565.79 | 64 | 88 | 849 | 10.4 |
| Lake St Lucia | | | | | | | | |
| Mgobezeleni | nr | nr | nr | nr | nr | nr | nr | nr |
| Kosi | nr | nr | nr | nr | nr | nr | nr | nr |

Information obtained from Natal Estuaries Status Reports, by Ramm et al.

| Estuary | | Catchment Area ($km^2$) | River Length (km) | MAR (x $10^6$ $m^3$) | Closed (% of yr) | Elevation (m) | Estuary Length (m) |
|---|---|---|---|---|---|---|---|
| Zinkwasi | toc | 73 | 22 | 110 | 84 | 229 | 7400 |
| Nonoti | toc | 210 | 38 | 320 | 94 | 488 | 1900 |
| Mdlotane | toc | 43 | 13 | 70 | 95 | 122 | 2200 |
| Seteni | toc | 16 | 5 | 20 | 83 | 61 | 400 |
| Mhlali | toc | 304 | 46 | 380 | 11 | 580 | 2000 |
| Mdloti | toc | 527 | 81 | 890 | 64 | 854 | 1500 |
| Mhlanga | toc | 118 | 28 | 19.8 | 96 | 324 | 2.2 |
| Mgeni | toc | 4432 | 232 | 5610 | 0 | 1829 | 6200 |
| Manzimtoti | toc | 39 | 12 | 70 | 63 | 274 | 1600 |
| Little Manzimtoti | toc | 18 | 15 | 30 | 54 | 165 | 800 |
| Lovu | toc | 893 | 135 | 890 | 17 | 1280 | 1100 |
| Mahlongwa | toc | 92 | 23 | 100 | 75 | 430 | 1900 |
| Mpambanyoni | toc | 560 | 100 | 410 | 23 | 962 | 200 |
| Mzinto | toc | 149 | 37 | 180 | 93 | 520 | 1400 |
| Mkumbane | toc | 28 | 14 | 30 | 81 | 300 | 200 |
| Fafa | toc | 231 | 66 | 190 | 96 | 918 | 3000 |
| Mvuzi | toc | 8 | 6 | 10 | 99 | 178 | 700 |
| Mtwalume | toc | 565 | 85 | 480 | 31 | 985 | 1700 |
| Mnamfu | toc | 16 | 9 | 20 | 89 | 233 | 800 |
| Kwa-Makosi | toc | 16 | 7 | 20 | 83 | 183 | 800 |
| Mafazazana | toc | 16 | 10 | 20 | 89 | 278 | 500 |
| Mhlabatshane | toc | 47 | 16 | 50 | 25 | 240 | 1000 |
| Intshambili | toc | 33 | 12 | 80 | 90 | 210 | 600 |
| Koshwana | toc | 11 | 6 | 30 | 86 | 200 | 500 |
| Damba | toc | 25 | 11 | 60 | 95 | 300 | 500 |
| Mhlangankulu | toc | 9 | 6 | 20 | 92 | 180 | 800 |
| Mpenjati | toc | 100 | 18 | 230 | 65 | 480 | 1100 |
| Kandanlovu | toc | 9 | 8 | 30 | 80 | 290 | 600 |
| Tongazi | toc | 17 | 8 | 60 | 16 | 385 | 400 |
| Ku-Boboyi | toc | 3 | 4 | 10 | 83 | 107 | 500 |
| Sandlundlu | toc | 16 | 8 | 60 | 18 | 282 | 600 |
| Mzimkulu | open | 6745 | 329 | 13450 | 3 | 2440 | 5500 |
| Kaba | toc | 11 | 9 | 20 | 93 | 220 | 500 |
| Mbizana | toc | 145 | 26 | 260 | 68 | 480 | 1500 |
| Bilanhlolo | toc | 21 | 12 | 50 | 75 | 240 | 500 |
| Uvuzana | toc | 8 | 2 | 20 | 85 | 130 | 200 |
| Kongweni | toc | 20 | 6 | 50 | 60 | 180 | 800 |
| Vungu | toc | 124 | 24 | 230 | 9 | 610 | 200 |
| Mtentweni | toc | 50 | 50 | 120 | 70 | 340 | 2300 |
| Mzumbe | toc | 536 | 84 | 570 | 10 | 933 | 1000 |
| Mvoti | river mouth | 2829 | 197 | 3360 | 2 | 1479 | 1800 |
| Matigulu | open | 880 | 96 | 1340 | 5 | 762 | 7500 |
| Mkomazi | open | 4310 | 298 | 9540 | 1 | 2650 | 3000 |
| Sipingo | modified open | 51 | 27 | 50 | 99 | 328 | 1200 |
| Mvutshini | toc | 7 | 6 | 20 | 86 | 180 | 300 |
| Mhlangamkulu | toc | 11 | 7 | 30 | 97 | 185 | 900 |
| Mbango | toc | 13 | 8 | 30 | 95 | 139 | 600 |
| Mhlangeni | toc | 38 | 13 | 80 | 65 | 340 | 1000 |
| Zotsha | toc | 57 | 20 | 130 | 78 | 415 | 2500 |
| Tugela | river mouth | 129101 | 405 | 40460 | 0 | 3109 | 800 |
| Mhlungwa | toc | 32 | 18 | 4 | 93 | 222 | 1500 |
| Mahlongwa Lagoon | toc | 15 | 6 | 20 | 99 | 218 | 1300 |
| Mdesingane | toc | 6 | 5 | 1 | 65 | 76 | 500 |

**Summary of TOC Estuaries in Natal, from the Estuaries of Natal Series by G. Begg**

| Estuary | Catchment Area ($km^2$) | River Length (km) | MAR (x $10^6$ $m^3$) | Flow ($m^3$/s) | | | | | Morphometry of Lagoon | | | | | Sandbar (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Min. | Max. | Summer | Winter | Av. | Area (ha) | Axial length (km) | Shore length (km) | Flood Plain (m) | Width (m) | |
| Siyai / Siyaya | 18 | 8 | - | - | - | - | - | - | 8 | 2.5 | 5.2 | 60 to 100 | 45 | |
| Zinkwasi | 70 to 76 | 20 to 24 | 14.3 | | 0.42 | | | | 18.2 to 19.6 | 4.8 | 10.3 | 350 | 215 | 200 |
| Nonoti | 176 to 326 | 23 to 52 | 34.4 to 61.3 | 0.05 | 0.28 | | | Other: 0.64 | 18 | 1.9 | 4.2 | 300 | 240 | 700 |
| Mdlotane | 33.6 to 52 | 10 to 16 | 9.86 | | | | | less than 0.02, erratic | 9.4 | 2.25 | 5 | 180 | 100 | short |
| Seteni | 16 | 5 | | | | | | | 1.13 | 0.35 | 1 | 50 | 70 | |
| Mhlali | 256, 295, 331 | 38 to 55 | 49.85 to 59.76 | | | | | 1.1 - erratic | 21 | 1.25 to 2 | 6.4 | 400 to 500 | 180, 75 to 200 | 500 |
| Tongati | 370, 399, 413, 468 | 40 to 60 | 84.8 to 92.7 | | | 2.4 | 1.2 | 2.18 | 7.6 | 2 | 4.7 | 200 | 150 | 150 |
| Mdloti | 481,497,550,704 | 74 to 88 | 97, 105, 134 | 0.34 | 5 | | | 2 to 2.5 perrennial | 13.6 | 1.5 | 6.5 | 600 | 380 | 600 |
| Mhlanga | 85, 124, 196 | 28 | 19.7 to 29.5 | 0.02 | 1.75 | | | 0.28 | 11.4 | 2.2, 0.5, 1.6 | 5.3 | 500, 350 | 90 to 100 | 500 |
| Mgeni | 4385, 4400, 4639, 5084, 5850 | 230 to 235 | 707 | 4.5 | 532, 5700 | 18.4 | 6.5 | 12.5 to 13, 15.5 | 48 | 2.5 | 14.2 | 1000 | 30 to 40 | |
| Mbokodweni | 235, 241, 243, 256 | 47, 71 | 9.5 | 0 - abstracted | 1416 (100yr flood) | | | | 7.24 | 0.65 to 0.7 | 2.6 | 560 | 70 | 400 |
| Manzimtoti | 28 to 33 | 10,11.3, 14 | 1 to 2 | 0.028 | 0.28 | | | | 6.67 | 1.6 to 2 | 2.6 | 200 | 110 | 250 |
| Little Manzimtoti | 10 to 15 | 15 | | 0.28 | 1.14 | | 80% of flow sewage effluent | | 1.5 | 0.8 | 1.7 | 100 | 45 | |

| Estuary | Catchment Area ($km^2$) | River Length (km) | MAR (x $10^6$ $m^3$) | Flow ($m^3/s$) | | | | | Morphometry of Lagoon | | | | | Sandbar (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Min. | Max. | Summer | Winter | Av. | Area (ha) | Axial length (km) | Shore length (km) | Flood Plain (m) | Width (m) | |
| Lovu | 893, 916, 930, 945, 1036 | 135 | 98, 123, 125 | | | 7 | 5.5 | 6.2 | 10.5 | 1.1 | 3.8 | 800 | 230 | 250 |
| Msimbazi | 33.7, 34.2, 41.4 | 14.5, 18 | | 0.08 | 0.85 | | | | 13.2, 20 | 2.8 | 8.4 | 500 to 600 | 110 | 60 |
| Umgababa | 35 to 39 | 13 to 16 | 13.5 | | | 0.08 | 0 | | 17.6 | 2.4 | 350 | | 160 to 400 | |
| Ngane | 12.2 to 20.7 | 8 | | | | | | low | 1.36 | 0.34 | 750 | 250 | 60 | 70 |
| Mahlongwa | 17 | 6 | | | | | | perrenial | 6.84 | 1.3 | 3.1 | 200 | 150 | |
| Mahlongwa Lagoon | 98 to 104 | 23 | 14.7 | | | 0.2 | 0.03 | | 5.9 | 1.4 | 3.3 | 300 | 115 | 80 |
| Mpambanyoni | 517, 544, 564, 567 | 100 | 32.1, 36, 52.4 | | | | | 0.71 | 2.32 | 0.25 | 800 | 350 | 120 | 160 |
| Mzimayi | 31 | 20 | | | | | | | 0.9 | 0.25 | 570 | 130 | 30 | |
| Mzinto | 117, 142, 264 | 37 | 15.21, 35.23 | | | | | 0.37 | 7 | 1.42 | 3.8 | 300 | 250 | |
| Mkumbane | 22 to 34 | 13 to 15 | | | | | | 0.085 | 0.25 | 0.1 | 200 | 150 | 20 | 250 |
| Sezela | 19 to 21 | 10 to 14 | | | | | | 0.14 | 9 | 1.8 | 6.4 | 350 | 100 | 125 |
| Mdesingane | 6 | 5.25 | | | | | | | 0.39 | 0.5 | 1 | 100 | 25 | 50 |
| Fafa | 246, 251, 259 | 64, 68 | 25.6, 26.8, 40.7 | | | 5.6 | 1.4 | 0.62 to 1.5 | 27.8, 32.4 | 2.85, 3 | 6.5 | none | 300 | 400 |

| Estuary | Catchment Area ($km^2$) | River Length (km) | MAR (x $10^6$ $m^3$) | Flow ($m^3/s$) | | | | | Morphometry of Lagoon | | | | | Sandbar (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Min. | Max. | Summer | Winter | Av. | Area (ha) | Axial length (km) | Shore length (km) | Flood Plain (m) | Width (m) | |
| Mvuzi | 8 | 6.5 | | | | | | | 0.8 | 0.7 | 1.5 | 120 | 30 | |
| Mtwalume | 505, 569, 580 | 85 | 60 to 76 | | | | | 1.7 | 24.8 | 0.7 to 1.7 | 6 | 500 | 400 to 600 | 1000 |
| Mnamfu | 15 | 9 | | | | | | | 1.26 | 0.5 | 1 | 120 | 60 | |
| Kwa-Makosi | 10 to 16 | 7 to 9 | 1.5 | | | | | | 2.45 | 0.5 | 1.2 | 200 | 110 | |
| Mafazazana | 15 | 10.5 | | | | | | | 2.1 | 0.525 | 1.3 | 120 | 100 | |
| Mhlungwa | 31 | 18 | | | | | | 0.14 | 3.09 | 0.8 | 1.7 | 200 | 60 | |
| Mhlabatshane | 34 to 49 | 16 | | | | | | 0.11 | 2.27 | 0.55 | 1.2 | 100 | 60 | 40 |
| Intshambili | 34 | 12 to 13 | | | | | | 0.85 | 1.7 | 0.55 | 1.5 | 150 | 60 | 75 |
| Koshwana | 12 | 6.25 | | | | | | | 1.16 | 0.475 | 1.25 | 150 | 45 | |
| Damba | 26 | 11 | | | | | | 0.11 | 1.7 | 0.5 | 1.18 | 200 | 65 | 250 |
| Mhlangankulu | 12 | 7 | | | | | | | 3.94 | 0.9 | 2 | 200 | 180 | 40 |
| Mpenjati | 78, 83, 101 | 18 | 15, 17.8 | | | | | 0.51 | 11.6 | 1.1 | 3.85 | 430 | 300 | |
| Kandanhlovu | 11 | 8 | | | | | | | 1.8 | 0.55 | 1.2 | 20 | 70 | 150 |
| Tongazi | 20 | 8.5 | | | | | | | 0.76 | 0.35 | 0.725 | confined | 40 | 75 |
| Ku-Boboyi | 4 | 4 | | | | | | | 1.1 | 0.525 | 1.2 | 60 | 45 | 50 |
| Sandlundlu | 19 | 7.5 | | | | | ceases | | 4 | 0.6 | 1.2 | | 230 | |
| Zolwane | 7 | 6.5 | | | | | | perrenial | 0.5 | 0.21 | 0.475 | | 40 | 40 |
| Mtamvuna | 1561, 1580, 1585, 1630 | 161, 163 | 243, 319 | | | | | 8.5 | 52.7 | 5 to 5.25 | 10.3 | none | 235 | 350 to 700 |

# APPENDIX B: FRESHWATER REQUIREMENTS (JEZEWSKI, 1984)

| | Total Freshwater Requirement | | |
|---|---|---|---|
| - | Total Freshwater Requirement - Quantity ($10^6 m^3/a$) | Total Freshwater Requirement - % of Virgin MAR | Remarks |
| | | | |
| Kosi | 26.817 | n/a | |
| Mgobezeleni | 0.200 | n/a | |
| Lake St Lucia | 250.600 | 63.4 | |
| Mfolozi | 62.722 | 7.1 | |
| Nhlabane | 0.592 | 2 | |
| Richard's Bay | 48.717 | 7.6 | Freshwater requirements of sanctuary area only |
| Mlalazi | 4.272 | 3.5 | |
| Siyal (Siyaya) | 0.132 | n/a | |
| Matigulu | | | |
| Nyoni | 6.848 | 3.8 | |
| Tugela | 305.200 | 6.6 | |
| Zinkwasi | 0.528 | 3.7 | |
| Nonoti | 1.671 | 3 | |
| Mdlotane | 0.239 | 2.4 | |
| Mvoti | 24.968 | 5.2 | |
| Seteni | 0.037 | n/a | |
| Mhlali | 1.759 | 2.8 | |
| Tongati | 2.153 | 2.6 | |
| Mdloti | 5.210 | 5.1 | |
| Mhlanga | 0.801 | 3.5 | |
| Mgeni | 20.200 | 3 | |
| Durban Bay | n/a | n/a | |
| Mlazi | n/a | n/a | |
| Sipingo | 0.270 | 4.7 | |
| Mbokodweni | 1.734 | 4.9 | |
| Manzimtoti | 0.251 | 4 | |
| Little Manzimtoti | 0.085 | 4.7 | |
| Lovu (Illovu) | 7.808 | 6.5 | |
| Msimbazi | 0.224 | 4.6 | |
| u Mgababa | 0.260 | 5.3 | |
| Ngane | 0.092 | 4.2 | |
| Mkomazi | 46.571 | 4.5 | |
| Mahlongwana | 0.097 | n/a | |
| Mahlongwa | 0.677 | 4.8 | |
| Mpanbanyoni | 5.087 | 7.2 | |
| Mzimayi (North) | 0.231 | 6.2 | |
| Mzinto | 0.732 | 3.7 | |
| Mkumbane | 0.163 | 4.8 | |
| Sezela | 0.159 | 6.6 | |
| Mdesingane | 0.039 | 5.6 | |
| Fafa | 1.836 | 6.1 | |
| Mvuzi | 0.046 | n/a | |
| Mtwalume | 4.969 | 7 | |
| Mnamfu | 0.078 | 3.7 | |
| Kwa-Makosi | 0.062 | 4.1 | |
| Mfazazana | 0.081 | 3.9 | |
| Mhlungwa | 0.194 | 4.4 | |
| Mzimayi (South) | 0.216 | 3.7 | |
| Mzumbe | 5.539 | 8.1 | |
| i Ntshambili | 0.171 | 4.3 | |
| Koshwana | 0.054 | 3.9 | |
| Damba | 0.150 | 5 | |
| Mhlangamkulu | 0.070 | 5 | |
| Mtentweni | 0.259 | 4.2 | |
| Mzimkulu | 64.321 | 4.4 | |
| Mbango | 0.077 | 2.3 | |
| Boboyi | 0.162 | 1.9 | |
| Zotsha | 0.331 | 2.2 | |
| Mhlangeni | 0.172 | 1.9 | |
| Vungu | 0.480 | 1.7 | |
| Kongweni | 0.055 | 1.1 | |
| Uvuzana | 0.021 | 1.1 | |
| Bilanhlolo | 0.102 | 2 | |
| Mvutshini | 0.035 | 2.2 | |
| Mbizane | 0.717 | 2.1 | |
| Kaba | 0.066 | 2.3 | |
| Umhlangankulu | 0.065 | 2.7 | |

| | Total Freshwater Requirement | | |
|---|---|---|---|
| | Total Freshwater Requirement - Quantity ($10^6 m^3/a$) | Total Freshwater Requirement - % of Virgin MAR | Remarks |
| Mpenjati | 0.342 | 1.7 | |
| Kandandhlovu | 0.049 | 1.3 | |
| Tongazi | 0.075 | 1.1 | |
| Ku-Boboyi | 0.021 | 1.6 | |
| Sandlundlu | 0.068 | 1.1 | |
| Zolwane | 0.032 | 2.5 | |
| Mtamvuna | 18.250 | 6 | International river |
| Great Kei | 76.074 | 7.1 | International river |
| Morgan | 0.345 | 5.8 | |
| Quko | 2.335 | 6.3 | |
| Haga-Haga | 0.174 | 4.5 | |
| Nyara | 0.462 | 5.8 | |
| Kwenxura | 1.495 | 8.7 | |
| Cefane | 0.776 | 17.2 | |
| Cintsa | 0.501 | 9.8 | |
| Bulura | 1.496 | 40.4 | |
| Kwelera | 3.011 | 7.9 | |
| Gqunube (Gonubi) | 3.814 | 8.1 | |
| Qinira | 0.981 | 10.9 | |
| Nahoon | 2.717 | 8 | |
| Buffalo | 7.342 | 8 | |
| Gxulu | 1.208 | 10.1 | |
| Mcantsi | 0.224 | 11.2 | |
| Great Fish | 38.492 | 7.3 | International river |
| Oos-Kleinemonde | 0.447 | 21.3 | |
| Wes-Kleinemonde | 0.957 | 24.5 | |
| Kowie | 8.994 | 36 | |
| Kasuka | 1.025 | n/a | |
| Kariega | 2.915 | 18.2 | |
| Bushmans | 4.591 | 12.1 | |
| Boknes | 0.928 | 9.3 | |
| Sundays | 17.288 | 8.5 | |
| Koega | 0.883 | 12.6 | |
| Swartkops | 17.493 | 22.1 | |
| Van Stadens | 0.617 | 4.4 | |
| Gamtoos | 36.800 | 7.4 | |
| Kabeljous | 1.925 | 11.8 | |
| Seekoei | 1.992 | 12.7 | |
| Krom | 10.982 | 8.9 | |
| Groot (West) | 1.288 | 2.8 | |
| Keurbooms | 12.547 | 7.1 | |
| Piesang | 0.209 | 9.1 | |
| Noetsie | 0.251 | 5.2 | |
| Knysa | 16.117 | 12.1 | |
| Goukamma | 2.127 | 4 | |
| Swartvlei | 11.859 | 12.4 | |
| Touws | 1.740 | 4.5 | |
| Kaaimans | 0.740 | 2.1 | |
| Maalgate | 0.999 | 3.7 | |
| Great Brak | 1.596 | 4.1 | |
| Little Brak | 5.247 | 8.9 | |
| Hartenbos | 0.581 | 11.6 | |
| Gourits | 39.525 | 7.3 | |
| Kafferkuils | 9.932 | 9.4 | |
| Druiwenhoks | 7.226 | 8 | |
| Bree (Breede) | 131.458 | 7.5 | |
| Heuningnes | 3.752 | 9.9 | |
| Ratel | 0.576 | 8.2 | |
| Uilkraals | 3.500 | 19.4 | |
| Klein | 13.700 | 36.1 | |
| Onrus | 0.420 | 8.4 | |
| Bot | 15.240 | 32.4 | |
| Palmiet | 2.950 | 1.5 | |
| Buffels (East) | 0.260 | 1.2 | |
| Rooiels | 0.196 | 2.2 | |
| Lourens | 1.169 | 1 | |
| Eerste | 10.529 | 5.4 | |
| Sand | 1.465 | 6.1 | |

| | Total Freshwater Requirement | | |
|---|---|---|---|
| | Total Freshwater Requirement - Quantity ($10^6 m^3/a$) | Total Freshwater Requirement - % of Virgin MAR | Remarks |
| Silvermine | 0.119 | 2.4 | |
| Else | 0.133 | 4.4 | |
| Houtbaai | 0.223 | 1 | |
| Diep/Rietvlei | 9.524 | 11.8 | |
| Great Berg | 43.547 | 8.9 | |
| Verlore | 19.990 | 51.3 | |
| Olifants | 75.548 | 7.4 | |
| Groen | 0.433 | 1.3 | |
| Spoeg | 0.860 | 28.7 | |
| Orange | 534.060 | 4.5 | |
| Ncera | 0.785 | 10.3 | |
| Tyolomnqa | 3.946 | 12.3 | |
| Keiskamma | 14.932 | 8.7 | |
| Gqutywa | 0.789 | 13.2 | |
| Bira | 1.920 | 14.8 | |
| Mgwalana | 1.596 | 13.3 | |
| Mbashe | 89.700 | 10 | |
| Mtata | 45.200 | 10 | |
| Mzimvubu | 296.800 | 10 | |
| Mzimkulu | - | - | |
| Mtentu | 104.000 | 10 | |
| Mngazi | 42.000 | 10 | |
| Xora | 24.900 | 10 | |
| Qora | 54.300 | 10 | |

# APPENDIX C: FLOW DATA

**Summary of flow data at Mhlanga Estuary**

| Date | Measured Flow ($m^3/s$) | Method | Comment | Mhlanga WWTW discharge ($m^3/s$) | Total Streamflow ($m^3/s$) | Mouth State |
|---|---|---|---|---|---|---|
| 19-Apr | 0.86 | Float | Incl. WWTWs | | 0.86 | Open 2 days |
| 22-Jun | 1.08 | Float | Incl. WWTWs | | 1.08 | Closed 2 days |
| 14-Jul | 0.27 | Float | Incl. WWTWs | | 0.27 | Open 27 days |
| 16-Aug | 2.03 | Float | Incl. WWTWs | | 2.03 | Partly open 2 days |
| 13-Sep | 1.09 | Float | Incl. WWTWs | | 1.09 | Closed 3 days |
| 13-Nov | 0.34 | Float | Incl. WWTWs | | 0.34 | Partly open 3 days |
| 10-Dec | 0.68 | Float | Incl. WWTWs | | 0.68 | Open 4 days |
| 23-Jan | 8.35 | Float | Incl. WWTWs | | 8.35 | Open 7 days |
| 19-Feb | 0.40 | Float | Incl. WWTWs | | 0.40 | Closed 2 days |
| 21-Mar | 0.86 | Float | Incl. WWTWs | | 0.86 | Closed 21 days |
| 25-Mar | 0.30 | Swoffer | excl. Mhlanga WWTW | 0.067 | 0.37 | Open 4 days |
| 7-May | 0.19 | Swoffer | excl. Mhlanga WWTW | 0.065 | 0.25 | Closed 40 days |
| 23-May | 0.25 | Swoffer | excl. Mhlanga WWTW | 0.075 | 0.33 | Closed 56 days |
| 30-May | 0.17 | Swoffer | excl. Mhlanga WWTW | 0.068 | 0.24 | Closed 2 days |
| 14-Jun | 0.22 | Swoffer | excl. Mhlanga WWTW | 0.058 | 0.28 | Closed 17 days |
| 19-Jun | 0.21 | Swoffer | excl. Mhlanga WWTW | 0.067 | 0.28 | Closed 22 days |
| 25-Jun | 0.31 | Swoffer | excl. Mhlanga WWTW | 0.072 | 0.38 | Closed 28 days |
| 26-Jun | 0.39 | Swoffer | excl. Mhlanga WWTW | 0.065 | 0.45 | Open 1 day |
| 27-Jun | 0.26 | Swoffer | excl. Mhlanga WWTW | 0.072 | 0.33 | Open 2 days |
| 28-Jun | 0.35 | Swoffer | excl. Mhlanga WWTW | 0.068 | 0.42 | Open 3 days |
| 29-Jun | 0.34 | Swoffer | excl. Mhlanga WWTW | 0.056 | 0.40 | Open 4 days |
| 30-Jun | 0.24 | Swoffer | excl. Mhlanga WWTW | 0.071 | 0.31 | Partly open 1 day |
| 1-Jul | 0.25 | Swoffer | excl. Mhlanga WWTW | 0.081 | 0.33 | Closed 1 day |
| 2-Jul | 0.25 | Swoffer | excl. Mhlanga WWTW | 0.081 | 0.33 | Closed 2 days |
| 3-Jul | 0.24 | Swoffer | excl. Mhlanga WWTW | 0.081 | 0.32 | Closed 3 days |
| 4-Jul | 0.24 | Swoffer | excl. Mhlanga WWTW | 0.081 | 0.32 | Closed 4 days |
| 5-Jul | 0.23 | Swoffer | excl. Mhlanga WWTW | 0.081 | 0.31 | Closed 5 days |
| 6-Jul | 0.20 | Swoffer | excl. Mhlanga WWTW | 0.081 | 0.28 | Closed 6 days |
| 7-Jul | 0.22 | Swoffer | excl. Mhlanga WWTW | 0.081 | 0.30 | Closed 7 days |
| 8-Jul | 0.23 | Swoffer | excl. Mhlanga WWTW | 0.081 | 0.31 | Closed 8 days |

**Summary of flow data at Mdloti Estuary**

| Date | Measured Flow ($m^3/s$) | Method | Comment | Mdloti WWTW discharge ($m^3/s$) | Total Streamflow ($m^3/s$) | Mouth State |
|---|---|---|---|---|---|---|
| 18-Apr-02 | 1.68 | Float | incl. WWTWs | | 1.68 | Open 1 day |
| 22-Jun-02 | 0.66 | Float | excl. Mdloti WWTW | 0.010 | 0.67 | Closed 21 days |
| 14-Jul-02 | 0.39 | Float | excl. Mdloti WWTW | 0.012 | 0.40 | Closed 43 days |
| 16-Aug-02 | 4.77 | Float | excl. Mdloti WWTW | 0.007 | 4.78 | Open 1 day |
| 12-Sep-02 | 2.54 | Float | excl. Mdloti WWTW | 0.010 | 2.55 | Partly open 1 day |
| 12-Oct-02 | 3.06 | Float | excl. Mdloti WWTW | 0.011 | 3.07 | Closed 6 days |
| 12-Nov-02 | 1.14 | Float | excl. Mdloti WWTW | 0.011 | 1.15 | Closed 12 days |
| 09-Dec-02 | 1.53 | Float | excl. Mdloti WWTW | 0.012 | 1.54 | Closed * |
| 22-Jan-03 | 2.64 | Float | excl. Mdloti WWTW | 0.013 | 2.65 | Closed 8 days |
| 19-Feb-03 | 0.20 | Float | excl. Mdloti WWTW | 0.011 | 0.21 | Closed 11 days |
| 19-Jun-03 | 0.29 | Swoffer | excl. Mdloti WWTW | 0.010 | 0.30 | Closed 131 days |
| 25-Jun-03 | 0.26 | Swoffer | excl. Mdloti WWTW | 0.011 | 0.27 | Closed 137 days |
| 26-Jun-03 | 0.39 | Swoffer | excl. Mdloti WWTW | 0.014 | 0.40 | Closed 138 days |
| 27-Jun-03 | 0.23 | Swoffer | excl. Mdloti WWTW | 0.014 | 0.24 | Closed 139 days |
| 28-Jun-03 | 0.31 | Swoffer | excl. Mdloti WWTW | 0.013 | 0.32 | Closed 140 days |
| 29-Jun-03 | 0.55 | Swoffer | excl. Mdloti WWTW | 0.013 | 0.56 | Closed 141 days |
| 30-Jun-03 | 0.40 | Swoffer | excl. Mdloti WWTW | 0.013 | 0.41 | Closed 142 days |
| 01-Jul-03 | 0.25 | Swoffer | excl. Mdloti WWTW | 0.012 | 0.26 | Closed 143 days |
| 02-Jul-03 | 0.28 | Swoffer | excl. Mdloti WWTW | 0.012 | 0.29 | Closed 144 days |
| 03-Jul-03 | 0.25 | Swoffer | excl. Mdloti WWTW | 0.012 | 0.26 | Closed 145 days |
| 04-Jul-03 | 0.29 | Swoffer | excl. Mdloti WWTW | 0.012 | 0.30 | Closed 146 days |
| 05-Jul-03 | 0.24 | Swoffer | excl. Mdloti WWTW | 0.012 | 0.25 | Closed 147 days |
| 06-Jul-03 | 0.47 | Swoffer | excl. Mdloti WWTW | 0.012 | 0.48 | Closed 148 days |
| 07-Jul-03 | 0.42 | Swoffer | excl. Mdloti WWTW | 0.012 | 0.43 | Closed 149 days |
| 08-Jul-03 | 0.33 | Swoffer | excl. Mdloti WWTW | 0.012 | 0.34 | Closed 150 days |

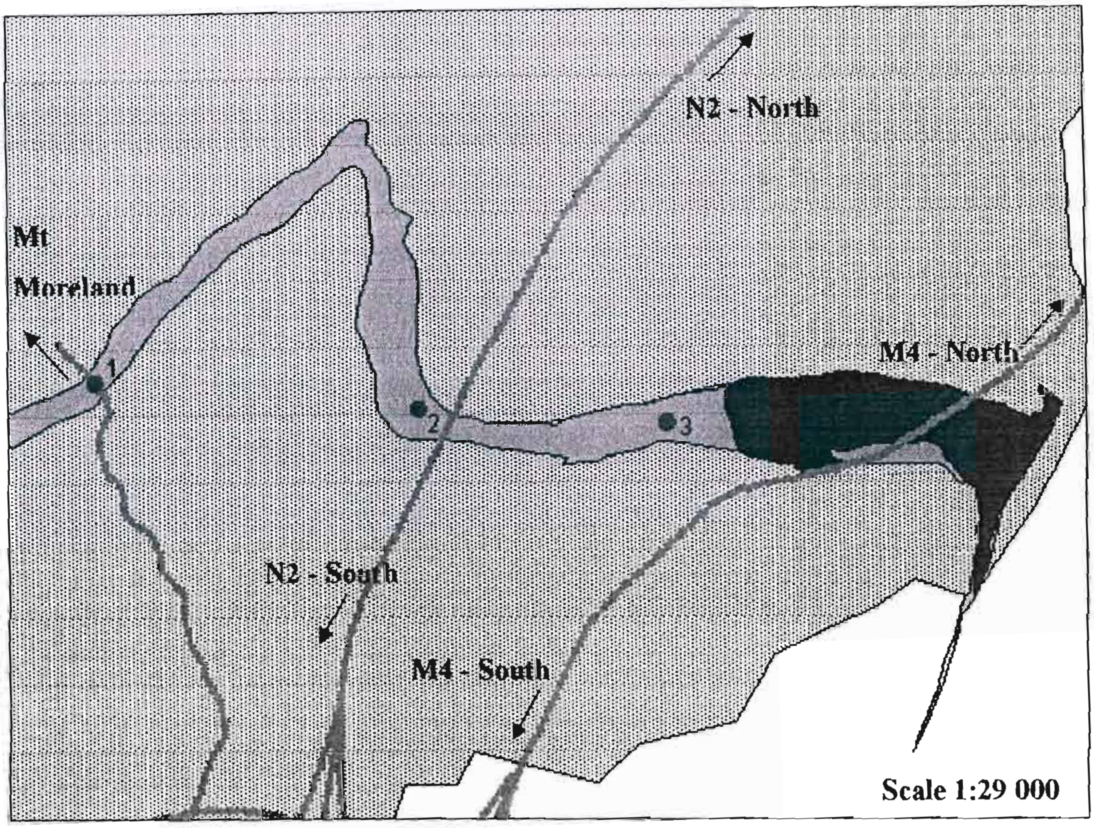



Figure showing the location of flow readings taken at Mdloti Estuary.

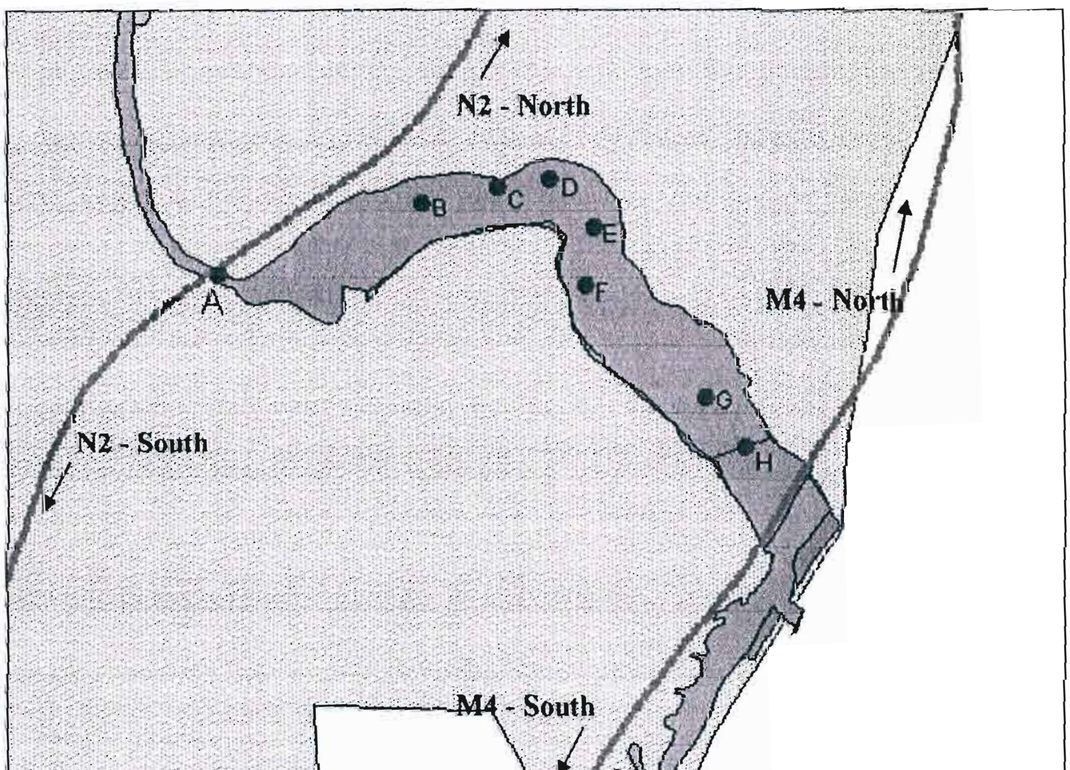



Figure showing the location of flow readings taken at Mhlanga Estuary.

**MHLANGA ESTUARY**

**Date:** 19-Apr-02
**Weather:** Sunny, very windy
**Estuary State:** Open
**Station Reference:** G

Data Collected:

| Width (m) | Depth (m) | Floats, Time in seconds | | | | Electronic Meter (Hz) | | | | Comment |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Big | Medium | Small | Surface | 100mm | 200mm | 300mm | 400mm | |
| 0 | 0.07 | - | - | - | - | - | - | - | - | -shallow |
| 1 | 0.15 | - | - | - | - | - | - | - | - | |
| 2 | 0.18 | - | - | - | - | 1 | - | - | - | |
| 3 | 0.25 | - | - | - | - | 3 | - | - | - | |
| 4 | 0.33 | - | - | - | - | 4 | 6 | - | - | |
| 5 | 0.385 | - | - | - | - | 18 | 13 | 9 | - | |
| 6 | 0.37 | 169 | 139 | 120 | * | 5 | 6 | 8 | - | |
| 7 | 0.39 | ** | ** | ** | ** | 17 | 17 | 15 | - | **wind |
| 8 | 0.415 | ** | ** | ** | ** | 21 | 19 | 22 | - | |
| 9 | 0.415 | 87 | 107 | 123 | 121 | 24 | 23 | 23 | - | |
| 10 | 0.425 | 80 | 76 | 97 | 117 | 28 | 28 | 20 | - | |
| 11 | 0.49 | 67 | 68 | 69 | 71 | 25 | 23 | 23 | 21 | |
| 12 | 0.54 | 63 | 61 | 59 | 59 | 32 | 28 | 24 | 22 | |
| 13 | 0.6 | 69 | 83 | 70 | 63 | 31 | 28 | 26 | 21 | |
| 14 | 0.74 | 60 | 65 | 61 | 61 | 34 | 30 | 26 | 25 | |
| 15 | 0.89 | * | * | * | * | 34 | 33 | 28 | 29 | *reeds |
| 16 | 1.07 | * | * | * | * | 21 | 15 | 15 | 22 | |

| | | |
|---|---|---|
| Area = | 7.2565 | $m^2$ |
| Av. Vel = | 0.1182 | m/s |
| Flow = | 0.8574 | $m^3/s$ |

**MHLANGA ESTUARY**

**Date:** 22-Jun-02
**Weather:** Sunny, clear, breeze
**Estuary State:** Closed, fairly full
**Tidal Situation:**
**Station Reference:** E

Data Collected:

| Width (m) | Depth (m) | Time in seconds at depth (m): 0.2 | 0.44 | Surface | Comment |
|---|---|---|---|---|---|
| 0 | 1.1 | - | - | - | Reeds |
| 1 | 1.03 | - | - | - | Reeds |
| 2 | 1.03 | 90 | 80 | * | * wind |
| 3 | 1.04 | | 87 | | |
| 4 | 1.04 | 135 | 90 | 95 | |
| 5 | 1.03 | | | | |
| 6 | 0.95 | 80 | 95 | 120 | |
| 7 | 1.1 | | | | |
| 8 | 1.055 | * | * | * | Reeds interferred |
| 9 | 1.07 | * | * | * | |
| 10 | 0.97 | * | * | * | |
| 11 | 0 | - | - | - | Bank |

| | | |
|---|---|---|
| Area = | 10.46375 | $m^2$ |
| Av. Vel = | 0.103211 | m/s |
| Flow = | 1.079974 | $m^3/s$ |

**MHLANGA ESTUARY**

**Date:** 14-Jul-02
**Weather:** Sunny, clear, slight cross wind
**Estuary State:** Open
**Station Reference:** F

Data Collected:

| Width (m) | Depth (m) | Time in seconds at depth (m): 0.2 | 0.07 | Surface | Vel. (m/s) | Comment |
|---|---|---|---|---|---|---|
| 0 | 0 | | | | 0 | Bank |
| 1 | 0.41 | | | | 0 | Cross flow & reed interference |
| 2 | 0.37 | | | 214 | 0.046729 | |
| 3 | 0.36 | | | 213 | 0.046948 | |
| 4 | 0.35 | 141 | 130 | 120 | 0.076726 | |
| 5 | 0.37 | 135 | 95 | 87 | 0.094637 | |
| 6 | 0.4 | 97 | 86 | 110 | 0.102389 | |
| 7 | 0.38 | 90 | 84 | 80 | 0.11811 | |
| 8 | 0.34 | 85 | 95 | 92 | 0.110294 | |
| 9 | 0.3 | 90 | 84 | 99 | 0.10989 | |
| 10 | 0.26 | 101 | 93 | 82 | 0.108696 | |
| 11 | 0.21 | | 100 | 91 | 0.104712 | |
| 12 | 0.18 | | 132 | 125 | 0.077821 | |
| 13 | 0.09 | | 180 | 134 | 0.063694 | |
| 14 | 0.04 | | | | 0 | Flow minimal, virtually 0 |
| 15 | 0.04 | | | | 0 | |
| 16 | 0 | | | | 0 | |

| | | |
|---|---|---|
| Area = | 3.858824 | $m^2$ |
| Av. Vel = | 0.07071 | m/s |
| Flow = | 0.272857 | $m^3/s$ |

**Mhlanga Estuary**

**Date:** 16-Aug-02
**Weather:** Overcast, preceding days were cold and rainy
**Estuary State:** Partly open
**Tidal Situation:** between low and high (*The Kingfisher, Tide Timetable 2002*)
**Station Reference:** D

Data Collected:

| Width (m) | Depth (m) | Time in seconds at depth (m): | | | Vel. (m/s) | Comment |
|---|---|---|---|---|---|---|
| | | 0.4 | 0.2 | Surface | | |
| 0 | 0 | - | - | - | - | Bank |
| 1 | 0.8 | 30.94 | | | 0.323206 | |
| 2 | 0.7 | | | 22 | 0.454545 | |
| 3 | 0.8 | 24 | | | 0.416667 | |
| 4 | 0.8 | | | 24 | 0.416667 | |
| 5 | 0.7 | | 25.13 | | 0.397931 | |
| 6 | 0.7 | | | 29.58 | 0.338066 | |
| 7 | 0.5 | 62* | | | 0.16129 | *Stuck a little |
| 8 | 0 | - | - | - | - | Bank |

| | | |
|---|---|---|
| Area = | 5.2 | $m^2$ |
| Av. Vel = | 0.39118 | m/s |
| **Flow =** | **2.034138** | **$m^3/s$** |

**MHLANGA ESTUARY**

**Date:** 13-Sep-02
**Weather:** Cloudy, light rain
**Estuary State:** Closed
**Station Reference:** B

Data Collected:

| Width (m) | Depth (m) | Area ($m^2$) | Time in seconds at depth (m): 0.4 | 0.8 | Surface | Vel. (m/s) | Comment |
|---|---|---|---|---|---|---|---|
| 0.35 | 0.30 | 0 | | | | | Bank |
| 1 | 0.70 | 0.325 | | | | | |
| 2 | 1.00 | 0.85 | | | | | |
| 3 | 1.00 | 1 | | | | | |
| 4 | 1.10 | 1.05 | | | | | |
| 5 | 1.05 | 1.075 | 180 | | | 0.093889 | |
| 6 | 1.10 | 1.075 | | | | | |
| 7 | 1.10 | 1.1 | | | | | |
| 8 | 1.10 | 1.1 | | | | | |
| 9 | 1.10 | 1.1 | 151 | | | 0.111921 | |
| 10 | 1.00 | 1.05 | | | | | |
| 11 | 0.70 | 0.85 | | | | | |

Surface velocities noticeably higher
Distance = 16.9m

| | | |
|---|---|---|
| Area = | 10.575 | $m^2$ |
| Av. Vel = | 0.102905 | m/s |
| Flow = | 1.088217 | $m^3/s$ |

**MHLANGA ESTUARY**

**Date:** 13-Nov-02
**Weather:** Sunny, calm (expecting SW buster later)
**Estuary State:** Med High - mouth partially open - perched channel about 8m wide and 200mm deep
**Tidal Situation:** Mid-tide - coming in I think
**Station Reference:** C

Data Collected:

| Width (m) | Depth (m) | Time in seconds at depth (m): | | | Vel. (m/s) | Area (m^2) | Vel*Area (m^3/s) | Comment | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0.3 | 0.5 | Surface | | | | | |
| 0 | 0.00 | | | | 0.000 | 0.00 | 0.000 | Bank | Surface velocities |
| 1 | 0.35 | 53 | | | 0.094 | 0.18 | 0.017 | | noticeably higher |
| 2 | 0.80 | 61 | | | 0.082 | 0.58 | 0.047 | | Distance = 5 m |
| 3 | 0.68 | 56 | | | 0.089 | 0.74 | 0.066 | | |
| 4 | 0.56 | 57 | | | 0.088 | 0.62 | 0.054 | | |
| 5 | 0.53 | 57 | | 53 | 0.088 | 0.55 | 0.048 | | |
| 6 | 0.56 | 50 | | | 0.100 | 0.55 | 0.055 | | |
| 7 | 0.57 | 50 | | | 0.100 | 0.57 | 0.057 | | |
| 8 | 0.57 | | | | 0.000 | 0.57 | 0.000 | reeds | |
| 9 | 0.55 | | | | 0.000 | 0.56 | 0.000 | reeds | No flow in reeds out to 2.5 |
| 10 | 0.00 | | | | 0.000 | 0.28 | 0.000 | Bank | |
| | | | | | Sums = | 5.17 | 0.34 | | |

| | | |
|---|---|---|
| Area = | 5.17 | $m^2$ |
| Av. Vel = | 0.058276 | m/s |
| Flow = | 0.301285 | $m^3/s$ |

**MHLANGA ESTUARY**

Date: 10-Dec-02
Weather: Dull, overcast, no wind
Estuary State: Closed
Station Reference: B

Data Collected:

Times for 10m

| | | | Timing distance = 10 m | | | | Vel interpolated between measurements (zero in reeds) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Width (m) | Depth (m) | Time in seconds at depth (m): | | | | Velocity (m/s) | Area (m2) | Velocity*Area (m3/s) | Comment | |
| | | | 0.4D | 0.6D | 0.8D | Surface | | | | | |
| LB | 0 | 0.10 | | | | | 0.000 | 0.050 | 0.000 | Reeds | |
| | 1 | 0.39 | | | | | 0.000 | 0.390 | 0.000 | Reeds | Times for 10m |
| | 2 | 0.42 | | | | | 0.100 | 0.420 | 0.042 | | |
| | 3 | 0.38 | | | | | 0.120 | 0.380 | 0.046 | | |
| | 4 | 0.40 | | | | | 0.143 | 0.400 | 0.057 | | |
| | 5 | 0.47 | | | | | 0.143 | 0.470 | 0.067 | | |
| | 6 | 0.52 | 56 | 70 | | | 0.143 | 0.520 | 0.074 | | |
| | 7 | 0.51 | | | | | 0.138 | 0.510 | 0.070 | | |
| | 8 | 0.53 | | | | | 0.136 | 0.530 | 0.072 | | |
| | 9 | 0.56 | | | | | 0.134 | 0.560 | 0.075 | | |
| | 10 | 0.55 | | 76 | | | 0.132 | 0.550 | 0.072 | | |
| | 11 | 0.50 | 90 | | | | 0.111 | 0.500 | 0.056 | | |
| | 12 | 0.44 | | | | | 0.111 | 0.440 | 0.049 | | |
| RB | 13 | 0.16 | | | | | 0.000 | 0.160 | 0.000 | | |
| | | | | | | | Sum = | 5.880 | 0.681 | | |

**Note: There was a subsurface cross current towards left bank (due to river bend?)**

| | | |
|---|---|---|
| Area = | 5.960 | $m^2$ |
| Av. Vel. = | 0.101 | m/s |
| Flow = | 0.601 | $m^3/s$ |

**MHLANGA ESTUARY**

**Date:** 23-Jan-03
**Weather:** P/cloudy, warm - becoming sunny. Wind SW med-strong. Severe thunderstorms last night. N2 bridge causeway flooded, strong flow estimated 8m^3/s
**Estuary State:** Open (centrally) with outflow. Water levels med-low (to top of pile-caps re pics)
**Station Reference:** G

Data Collected:

Times for 10m

Timing distance = 10 m

Vel interpolated between measurements (zero in reeds)

| | Width (m) | Depth (m) | Time in seconds at depth (m): 0.4D | 0.6D | 0.8D | Surface | Velocity (m/s) | Area (m2) | Velocity*Area (m3/s) | Comment | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LB | 0 | 0.00 | | | | | 0.00 | 0.00 | 0.00 | Reeds | Actual steep sandy bank |
| | 1 | 0.40 | | | | | 0.15 | 0.20 | 0.03 | | |
| | 2 | 0.34 | | | | | 0.30 | 0.37 | 0.11 | | |
| | 3 | 0.34 | | 23 | | | 0.43 | 0.34 | 0.15 | | |
| | 4 | 0.33 | | | | | 0.47 | 0.34 | 0.16 | | |
| | 5 | 0.33 | | | | | 0.50 | 0.33 | 0.17 | | |
| | 6 | 0.34 | | | | | 0.53 | 0.34 | 0.18 | | |
| | 7 | 0.36 | | 17 | 19 | | 0.59 | 0.35 | 0.21 | | |
| | 8 | 0.37 | | | | | 0.60 | 0.37 | 0.22 | | |
| | 9 | 0.52 | | | | | 0.61 | 0.45 | 0.27 | | |
| | 10 | 0.52 | | 16 | | | 0.63 | 0.52 | 0.33 | | |
| | 11 | 0.53 | | | | | 0.63 | 0.53 | 0.33 | | |
| | 12 | 0.55 | | | | | 0.63 | 0.54 | 0.34 | | |
| | 13 | 0.58 | | | | | 0.63 | 0.57 | 0.35 | | |
| | 14 | 0.62 | | 16 | | | 0.63 | 0.60 | 0.38 | | |
| | 15 | 0.65 | | | | | 0.63 | 0.64 | 0.40 | | |
| | 16 | 0.65 | | | | | 0.66 | 0.65 | 0.43 | | |
| | 17 | 0.63 | | | | | 0.69 | 0.64 | 0.44 | | |
| | 18 | 0.60 | | | | | 0.72 | 0.62 | 0.44 | | |
| | 19 | 0.60 | | | | | 0.75 | 0.60 | 0.45 | | |
| | 20 | 0.57 | | | | | 0.78 | 0.59 | 0.46 | | |
| | 21 | 0.55 | | 12.5 | | | 0.80 | 0.56 | 0.45 | | |
| | 22 | 0.52 | | | | | 0.78 | 0.54 | 0.42 | | |
| | 23 | 0.50 | | | | | 0.73 | 0.51 | 0.37 | | |
| | 24 | 0.50 | | | | | 0.68 | 0.50 | 0.34 | | |
| | 25 | 0.52 | | 16 | | | 0.63 | 0.51 | 0.32 | | |
| | 26 | 0.53 | | | | | 0.60 | 0.53 | 0.32 | | |
| | 27 | 0.54 | | | | | 0.40 | 0.54 | 0.21 | | |
| | 28 | 0.45 | | | | | 0.20 | 0.50 | 0.10 | | |
| RB | 28.8 | 0.00 | | | | | 0.00 | 0.18 | 0.00 | Reeds | Clear, steep sandy bank |
| | | | | | | | Sum = | 13.90 | 8.35 | | |

| | | |
|---|---|---|
| Area = | 13.9400 | $m^2$ |
| Av. Vel. = | 0.5451 | m/s |
| Flow = | 7.5987 | $m^3/s$ |

**Note: This is a relatively straight section of river, with relatively uniform depth - expect good accuracy**

**MHLANGA ESTUARY**

**Date:** 19-Feb-03
**Weather:** Sunny, windy
**Estuary State:** Closed
**Station Reference:** B

Data Collected:

Times for 10m

Timing distance = 10 m

Vel interpolated between measurements (zero in reeds)

| Width (m) | Depth (m) | Time in seconds at depth (m): 0.4D | 0.6D | 0.8D | Surface | Velocity (m/s) | Area (m2) | Velocity* Area | Comment |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 1.80 | | | | | 0.00 | 0.90 | 0.00 | Reeds |
| 1 | 1.32 | | | | | 0.02 | 1.56 | 0.03 | |
| 2 | 1.60 | | 269 | | | 0.04 | 1.46 | 0.05 | |
| 3 | 1.52 | | | | | 0.06 | 1.56 | 0.09 | |
| 4 | 1.55 | | | | | 0.07 | 1.54 | 0.10 | |
| 5 | 1.42 | | 120 | | | 0.08 | 1.49 | 0.12 | |
| 6 | 1.49 | | | | | 0.04 | 1.46 | 0.06 | |
| 7 | 1.46 | | | | | 0.00 | 1.48 | 0.00 | Reeds |
| 8 | 1.48 | | | | | 0.00 | 1.47 | 0.00 | Reeds |
| | | | | | | Sum = | 12.90 | 0.45 | |

| | | |
|---|---|---|
| Area = | 12.0000 | $m^2$ |
| Av. Vel. = | 0.0334 | m/s |
| Flow = | 0.4007 | $m^3/s$ |

**MHLANGA ESTUARY**

**Date:** 21-Mar-03
**Weather:** Sunny
**Estuary State:** Open
**Station Reference:** H

| Section | Date | Time | Distance | Depth | Velocity | Unit | | area | v.a |
|---|---|---|---|---|---|---|---|---|---|
| 2 | 21-Mar-03 | 13:41 | 0 | 0 | 0 | m | Bank | 0 | 0 |
| 2 | 21-Mar-03 | 13:46 | 1 | 0.505 | 0.125 | m | | 0.505 | 0.063 |
| 2 | 21-Mar-03 | 13:48 | 2 | 0.65 | 0.128 | m | | 0.650 | 0.083 |
| 2 | 21-Mar-03 | 13:50 | 3 | 0.68 | 0.116 | m | | 0.680 | 0.079 |
| 2 | 21-Mar-03 | 13:52 | 4 | 0.75 | 0.102 | m | | 0.750 | 0.077 |
| 2 | 21-Mar-03 | 13:53 | 5 | 0.72 | 0.1 | m | | 0.720 | 0.072 |
| 2 | 21-Mar-03 | 13:57 | 6 | 0.65 | 0.112 | m | | 0.650 | 0.073 |
| 2 | 21-Mar-03 | 13:59 | 7 | 0.64 | 0.109 | m | | 0.640 | 0.070 |
| 2 | 21-Mar-03 | 14:00 | 8 | 0.55 | 0.103 | m | | 0.550 | 0.057 |
| 2 | 21-Mar-03 | 14:02 | 9 | 0.49 | 0.12 | m | | 0.490 | 0.059 |
| 2 | 21-Mar-03 | 14:03 | 10 | 0.38 | 0.135 | m | | 0.380 | 0.051 |
| 2 | 21-Mar-03 | 14:05 | 11 | 0.32 | 0.132 | m | | 0.320 | 0.042 |
| 2 | 21-Mar-03 | 14:07 | 12 | 0.6 | 0.1 | m | | 0.600 | 0.060 |
| 2 | 21-Mar-03 | 14:09 | 13 | 0.39 | 0.072 | m | | 0.390 | 0.028 |
| 2 | 21-Mar-03 | 14:10 | 14 | 0.4 | 0.071 | m | | 0.400 | 0.028 |
| 2 | 21-Mar-03 | 14:11 | 15 | 0.35 | 0.038 | m | | 0.350 | 0.013 |
| 2 | 21-Mar-03 | 14:12 | 16 | 0.21 | 0.012 | m | | 0.315 | 0.004 |
| 2 | 21-Mar-03 | 14:13 | 18 | 0 | 0 | m | Sand | 0 | 0 |
| | | | | | | | **Sum:** | **8.39** | **0.859** |

**Discharge (Swoffer)** **0.85**

**Discharge (Calculated)** **0.859**

**MHLANGA ESTUARY**

**Date:** 25-Mar-03
**Weather:** Sunny
**Estuary State:** Closed
**Station Reference:** A

| Section | Date | Time | Distance | Depth | Velocity | Unit | | area | v.a |
|---|---|---|---|---|---|---|---|---|---|
| 3 | 25-Mar-03 | 11:03 | 0 | 0 | 0 | m | Gabion | 0 | 0 |
| 3 | 25-Mar-03 | 11:19 | 1 | 0.22 | 0.439 | m | | 0.220 | 0.097 |
| 3 | 25-Mar-03 | 11:12 | 2 | 0.25 | 0.413 | m | | 0.250 | 0.103 |
| 3 | 25-Mar-03 | 11:13 | 3 | 0.15 | 0.412 | m | | 0.150 | 0.062 |
| 3 | 25-Mar-03 | 11:15 | 4 | 0.12 | 0.274 | m | | 0.120 | 0.033 |
| 3 | 25-Mar-03 | 11:16 | 5 | 0.05 | 0.17 | m | | 0.050 | 0.009 |
| 3 | 25-Mar-03 | 11:17 | 6 | 0.015 | 0 | m | | 0.015 | 0.000 |
| 3 | 25-Mar-03 | 11:17 | 7 | 0 | 0 | m | Sand | 0 | 0 |
| | | | | | | | | **0.805** | **0.303** |

**Discharge (Swoffer)** **0.3**

**Discharge (Calculated)** **0.303**

**MHLANGA ESTUARY**

**Location:** A
**Mouth State:** Closed

| Section | Date | Time | Distance | Depth | Velocity | Unit | Comment | area | v.a |
|---|---|---|---|---|---|---|---|---|---|
| 4 | 7-MAY-03 | 12:47 | 0 | 1.25 | 0 | m | Gabion | 0.625 | 0 |
| 4 | 7-MAY-03 | 12:49 | 0.5 | 0.2 | 0.121 | m | | 0.1 | 0.0121 |
| 4 | 7-MAY-03 | 12:51 | 1 | 0.24 | 0.241 | m | | 0.18 | 0.04338 |
| 4 | 7-MAY-03 | 12:52 | 2 | 0.2 | 0.418 | m | | 0.2 | 0.0836 |
| 4 | 7-MAY-03 | 12:54 | 3 | 0.14 | 0.314 | m | | 0.14 | 0.04396 |
| 4 | 7-MAY-03 | 12:56 | 4 | 0.06 | 0.112 | m | | 0.06 | 0.00672 |
| 4 | 7-MAY-03 | 12:56 | 5 | 0.04 | 0 | m | | 0.04 | 0 |
| 4 | 7-MAY-03 | 12:57 | 6 | 0 | 0 | m | Sand | 0 | 0 |
| | | | | | | | | **1.345** | **0.18976** |

**Discharge (Swoffer)** **0.18**

**Discharge (Calculated)** **0.190**

**MHLANGA ESTUARY**

**Location:** A
**Mouth State:** Open

| Section | Date | Time | Distance | Depth | Velocity | Unit | Comment | area | v.a |
|---|---|---|---|---|---|---|---|---|---|
| 5 | 23-May-03 | 12:03 | 0 | 0 | 0 | m | Gabion | 0 | 0 |
| 5 | 23-May-03 | 11:54 | 0.5 | 0.19 | 0.136 | m | | 0.095 | 0.01292 |
| 5 | 23-May-03 | 11:57 | 1 | 0.26 | 0.311 | m | | 0.195 | 0.060645 |
| 5 | 23-May-03 | 11:59 | 2 | 0.21 | 0.444 | m | | 0.1575 | 0.06993 |
| 5 | 23-May-03 | 12:05 | 2.5 | 0.19 | 0.388 | m | | 0.095 | 0.03686 |
| 5 | 23-May-03 | 12:00 | 3 | 0.16 | 0.314 | m | | 0.12 | 0.03768 |
| 5 | 23-May-03 | 12:01 | 4 | 0.14 | 0.166 | m | | 0.14 | 0.02324 |
| 5 | 23-May-03 | 12:03 | 5 | 0.07 | 0.087 | m | | 0.105 | 0.009135 |
| 5 | 23-May-03 | 12:03 | 7 | 0 | 0 | m | Sand | 0 | 0 |
| | | | | | | | | **0.908** | **0.250** |

**Discharge (Swoffer)** **0.25**

**Discharge (Calculated)** **0.250**

**MHLANGA ESTUARY**

**Location:** A
**Mouth State:** Closed

| Section | Date | Time | Distance | Depth | Velocity | Unit | Comment | area | v.a |
|---|---|---|---|---|---|---|---|---|---|
| 6 | 30-May-03 | 10:43 | 0 | 0 | 0 | m | Gabion | 0 | 0 |
| 6 | 30-May-03 | 10:45 | 0.5 | 0.19 | 0 | m | | 0.095 | 0 |
| 6 | 30-May-03 | 10:46 | 1 | 0.22 | 0.291 | m | | 0.11 | 0.03201 |
| 6 | 30-May-03 | 10:47 | 1.5 | 0.18 | 0.341 | m | | 0.09 | 0.03069 |
| 6 | 30-May-03 | 10:48 | 2 | 0.17 | 0.411 | m | | 0.085 | 0.034935 |
| 6 | 30-May-03 | 10:49 | 2.5 | 0.15 | 0.36 | m | | 0.075 | 0.027 |
| 6 | 30-May-03 | 10:51 | 3 | 0.15 | 0.312 | m | | 0.1125 | 0.0351 |
| 6 | 30-May-03 | 10:52 | 4 | 0.09 | 0.096 | m | | 0.09 | 0.00864 |
| 6 | 30-May-03 | 10:53 | 5 | 0.05 | 0 | m | | 0.0375 | 0 |
| 6 | 30-May-03 | 10:53 | 5.5 | 0 | 0 | m | Sand | 0 | 0 |
| | | | | | | | | **0.695** | **0.168** |

**Discharge (Swoffer)** **0.16**

**Discharge (Calculated)** **0.168**

**MHLANGA ESTUARY**

**Location:** A
**Mouth State:** Closed

| Section | Date | Time | Distance | Depth | Velocity | Unit | Comment | area | v.a |
|---|---|---|---|---|---|---|---|---|---|
| 7 | 14-Jun-03 | 9:25 | 0 | 0.1 | 0 | m | | 0.05 | 0 |
| 7 | 14-Jun-03 | 9:27 | 1 | 0.27 | 0.295 | m | | 0.2025 | 0.059738 |
| 7 | 14-Jun-03 | 9:28 | 1.5 | 0.24 | 0.307 | m | | 0.12 | 0.03684 |
| 7 | 14-Jun-03 | 9:30 | 2 | 0.19 | 0.367 | m | | 0.095 | 0.034865 |
| 7 | 14-Jun-03 | 9:32 | 2.5 | 0.18 | 0.401 | m | | 0.09 | 0.03609 |
| 7 | 14-Jun-03 | 9:33 | 3 | 0.17 | 0.307 | m | | 0.085 | 0.026095 |
| 7 | 14-Jun-03 | 9:34 | 3.5 | 0.15 | 0.223 | m | | 0.075 | 0.016725 |
| 7 | 14-Jun-03 | 9:36 | 4 | 0.12 | 0.107 | m | | 0.09 | 0.00963 |
| 7 | 14-Jun-03 | 9:37 | 5 | 0.08 | 0 | m | | 0.08 | 0 |
| 7 | 14-Jun-03 | 9:37 | 6 | 0.04 | 0 | m | | 0.04 | 0 |
| 7 | 14-Jun-03 | 9:37 | 7 | 0 | 0 | m | | 0 | 0 |
| | | | | | | | | **0.928** | **0.220** |

**Discharge (Swoffer)** **0.22**

**Discharge (Calculated)** **0.220**

**MHLANGA ESTUARY**

**Location:** A
**Mouth State:** Closed

| Section | Date | Time | Distance | Depth | Velocity | Unit | Comment | area | v.a |
|---|---|---|---|---|---|---|---|---|---|
| 9 | 19-Jun-03 | 12:57 | 0 | 0 | 0 | m | | 0 | 0 |
| 9 | 19-Jun-03 | 12:59 | 0.5 | 0.25 | 0.018 | m | | 0.100 | 0.002 |
| 9 | 19-Jun-03 | 13:00 | 0.8 | 0.26 | 0.156 | m | | 0.130 | 0.020 |
| 9 | 19-Jun-03 | 13:01 | 1.5 | 0.26 | 0.34 | m | | 0.156 | 0.053 |
| 9 | 19-Jun-03 | 13:02 | 2 | 0.24 | 0.406 | m | | 0.120 | 0.049 |
| 9 | 19-Jun-03 | 13:03 | 2.5 | 0.22 | 0.381 | m | | 0.110 | 0.042 |
| 9 | 19-Jun-03 | 13:04 | 3 | 0.19 | 0.323 | m | | 0.143 | 0.046 |
| 9 | 19-Jun-03 | 13:04 | 4 | 0.15 | 0 | m | | 0.3 | 0 |
| 9 | 19-Jun-03 | 13:05 | 7 | 0 | 0 | m | | 0 | 0 |
| | | | | | | | | **1.059** | **0.212** |

**Discharge (Swoffer)** **0.21**

**Discharge (Calculated)** **0.212**

**MHLANGA ESTUARY**

**Location:** A
**Mouth State:** Closed

| Section | Date | Time | Distance | Depth | Velocity | Unit | Comment | area | v.a |
|---|---|---|---|---|---|---|---|---|---|
| 10 | 25-Jun-03 | 8:28 | 0 | 0.15 | 0 | m | | 0.038 | 0 |
| 10 | 25-Jun-03 | 8:30 | 0.5 | 0.22 | 0.172 | m | | 0.110 | 0.019 |
| 10 | 25-Jun-03 | 8:32 | 1 | 0.31 | 0.303 | m | | 0.155 | 0.047 |
| 10 | 25-Jun-03 | 8:33 | 1.5 | 0.26 | 0.368 | m | | 0.130 | 0.048 |
| 10 | 25-Jun-03 | 8:35 | 2 | 0.25 | 0.475 | m | | 0.125 | 0.059 |
| 10 | 25-Jun-03 | 8:36 | 2.5 | 0.24 | 0.440 | m | | 0.120 | 0.053 |
| 10 | 25-Jun-03 | 8:37 | 3 | 0.21 | 0.369 | m | | 0.105 | 0.039 |
| 10 | 25-Jun-03 | 8:38 | 3.5 | 0.22 | 0.260 | m | | 0.110 | 0.029 |
| 10 | 25-Jun-03 | 8:40 | 4 | 0.18 | 0.120 | m | | 0.135 | 0.016 |
| 10 | 25-Jun-03 | 8:40 | 5 | 0.15 | 0 | m | | 0.225 | 0 |
| 10 | 25-Jun-03 | 8:40 | 7 | 0 | 0 | m | | 0 | 0 |
| | | | | | | | | **1.253** | **0.309** |

**Discharge (Swoffer)** **0.3**

**Discharge (Calculated)** **0.309**

**MHLANGA ESTUARY**

**Location:** A
**Mouth State:** Open

| Section | Date | Time | Distance | Depth | Velocity | Unit | Comment | area | v.a |
|---|---|---|---|---|---|---|---|---|---|
| 12 | 26-Jun-03 | 8:33 | 0 | 0 | 0 | m | | 0 | 0 |
| 12 | 26-Jun-03 | 8:34 | 0.5 | 0.25 | 0.186 | m | | 0.125 | 0.023 |
| 12 | 26-Jun-03 | 8:35 | 1 | 0.28 | 0.422 | m | | 0.140 | 0.059 |
| 12 | 26-Jun-03 | 8:36 | 1.5 | 0.27 | 0.458 | m | | 0.133 | 0.061 |
| 12 | 26-Jun-03 | 8:38 | 2 | 0.25 | 0.538 | m | | 0.125 | 0.067 |
| 12 | 26-Jun-03 | 8:39 | 2.5 | 0.24 | 0.410 | m | | 0.120 | 0.049 |
| 12 | 26-Jun-03 | 8:39 | 3 | 0.21 | 0.401 | m | | 0.105 | 0.042 |
| 12 | 26-Jun-03 | 8:40 | 3.5 | 0.25 | 0.340 | m | | 0.125 | 0.043 |
| 12 | 26-Jun-03 | 8:41 | 4 | 0.22 | 0.211 | m | | 0.110 | 0.023 |
| 12 | 26-Jun-03 | 8:42 | 4.5 | 0.19 | 0.099 | m | | 0.095 | 0.009 |
| 12 | 26-Jun-03 | 8:43 | 5 | 0.17 | 0.073 | m | | 0.128 | 0.009 |
| 12 | 26-Jun-03 | 8:43 | 6 | 0.11 | 0 | m | | 0.138 | 0 |
| 12 | 26-Jun-03 | 8:44 | 7.5 | 0 | 0 | m | | 0 | 0 |
| | | | | | | | | **1.205** | **0.386** |

**Discharge (Swoffer)** **0.38**

**Discharge (Calculated)** **0.386**

**MHLANGA ESTUARY**

**Location:** A
**Mouth State:** Open

| Section | Date | Time | Distance | Depth | Velocity | Unit | Comment | area | v.a |
|---|---|---|---|---|---|---|---|---|---|
| 14 | 27-Jun-03 | 9:50 | 0 | 0.11 | 0 | m | | 0.028 | 0 |
| 14 | 27-Jun-03 | 9:51 | 0.5 | 0.24 | 0.083 | m | | 0.120 | 0.010 |
| 14 | 27-Jun-03 | 9:52 | 1 | 0.26 | 0.382 | m | | 0.130 | 0.050 |
| 14 | 27-Jun-03 | 9:53 | 1.5 | 0.24 | 0.441 | m | | 0.120 | 0.053 |
| 14 | 27-Jun-03 | 9:54 | 2 | 0.2 | 0.435 | m | | 0.100 | 0.044 |
| 14 | 27-Jun-03 | 9:55 | 2.5 | 0.17 | 0.412 | m | | 0.085 | 0.035 |
| 14 | 27-Jun-03 | 9:56 | 3 | 0.16 | 0.314 | m | | 0.080 | 0.025 |
| 14 | 27-Jun-03 | 9:57 | 3.5 | 0.14 | 0.262 | m | | 0.070 | 0.018 |
| 14 | 27-Jun-03 | 9:58 | 4 | 0.15 | 0.146 | m | | 0.113 | 0.016 |
| 14 | 27-Jun-03 | 9:59 | 5 | 0.1 | 0 | m | | 0.100 | 0 |
| 14 | 27-Jun-03 | 9:59 | 6 | 0.05 | 0 | m | | 0.050 | 0 |
| 14 | 27-Jun-03 | 9:59 | 7 | 0 | 0 | m | | 0 | 0 |
| | | | | | | | | **0.995** | **0.251** |

**Discharge (Swoffer)** **0.25**

**Discharge (Calculated)** **0.251**

MHLANGA ESTUARY

**Location:** A
**Mouth State:** Open

| Section | Date | Time | Distance | Depth | Velocity | Unit | Comment | area | v.a |
|---|---|---|---|---|---|---|---|---|---|
| 16 | 28-Jun-03 | 10:45 | 0 | 0.16 | 0 | m | | 0.04 | 0 |
| 16 | 28-Jun-03 | 10:47 | 0.5 | 0.27 | 0.101 | m | | 0.135 | 0.014 |
| 16 | 28-Jun-03 | 10:48 | 1 | 0.3 | 0.444 | m | | 0.150 | 0.067 |
| 16 | 28-Jun-03 | 10:51 | 1.5 | 0.32 | 0.419 | m | | 0.160 | 0.067 |
| 16 | 28-Jun-03 | 10:52 | 2 | 0.3 | 0.477 | m | | 0.150 | 0.072 |
| 16 | 28-Jun-03 | 10:53 | 2.5 | 0.24 | 0.441 | m | | 0.120 | 0.053 |
| 16 | 28-Jun-03 | 10:54 | 3 | 0.2 | 0.371 | m | | 0.100 | 0.037 |
| 16 | 28-Jun-03 | 10:55 | 3.5 | 0.17 | 0.257 | m | | 0.085 | 0.022 |
| 16 | 28-Jun-03 | 10:56 | 4 | 0.19 | 0.114 | m | | 0.143 | 0.016 |
| 16 | 28-Jun-03 | 10:56 | 5 | 0.15 | 0 | m | | 0.225 | 0 |
| 16 | 28-Jun-03 | 10:56 | 7 | 0 | 0 | m | | 0 | 0 |
| | | | | | | | | **1.308** | **0.347** |

**Discharge (Swoffer)** **0.34**

**Discharge (Calculated)** **0.347**

**MHLANGA ESTUARY**

**Location:** A
**Mouth State:** Open

| Section | Date | Time | Distance | Depth | Velocity | Unit | Comment | area | v.a |
|---|---|---|---|---|---|---|---|---|---|
| 18 | 29-Jun-03 | 8:20 | 0 | 0.19 | 0 | m | | 0.048 | 0 |
| 18 | 29-Jun-03 | 8:21 | 0.5 | 0.24 | 0.187 | m | | 0.120 | 0.022 |
| 18 | 29-Jun-03 | 8:23 | 1 | 0.28 | 0.355 | m | | 0.140 | 0.050 |
| 18 | 29-Jun-03 | 8:23 | 1.5 | 0.28 | 0.370 | m | | 0.140 | 0.052 |
| 18 | 29-Jun-03 | 8:25 | 2 | 0.27 | 0.388 | m | | 0.135 | 0.052 |
| 18 | 29-Jun-03 | 8:25 | 2.5 | 0.225 | 0.457 | m | | 0.113 | 0.051 |
| 18 | 29-Jun-03 | 8:26 | 3 | 0.18 | 0.379 | m | | 0.090 | 0.034 |
| 18 | 29-Jun-03 | 8:27 | 3.5 | 0.155 | 0.329 | m | | 0.078 | 0.025 |
| 18 | 29-Jun-03 | 8:28 | 4 | 0.16 | 0.272 | m | | 0.120 | 0.033 |
| 18 | 29-Jun-03 | 8:29 | 5 | 0.15 | 0.088 | m | | 0.225 | 0.020 |
| 18 | 29-Jun-03 | 8:29 | 7 | 0 | 0 | m | | 0 | 0 |
| | | | | | | | | **1.208** | **0.340** |

**Discharge (Swoffer)** **0.33**

**Discharge (Calculated)** **0.340**

**MHLANGA ESTUARY**

**Location:** A
**Mouth State:** Partly open

| Section | Date | Time | Distance | Depth | Velocity | Unit | Comment | area | v.a |
|---|---|---|---|---|---|---|---|---|---|
| 21 | 30-Jun-03 | 9:51 | 0 | 0.15 | 0 | m | Gabion | 0.038 | 0 |
| 21 | 30-Jun-03 | 9:52 | 0.5 | 0.2 | 0.126 | m | | 0.100 | 0.013 |
| 21 | 30-Jun-03 | 9:53 | 1 | 0.24 | 0.319 | m | | 0.120 | 0.038 |
| 21 | 30-Jun-03 | 9:54 | 1.5 | 0.255 | 0.378 | m | | 0.128 | 0.048 |
| 21 | 30-Jun-03 | 9:55 | 2 | 0.23 | 0.404 | m | | 0.115 | 0.046 |
| 21 | 30-Jun-03 | 9:56 | 2.5 | 0.18 | 0.351 | m | | 0.090 | 0.032 |
| 21 | 30-Jun-03 | 9:56 | 3 | 0.16 | 0.288 | m | | 0.080 | 0.023 |
| 21 | 30-Jun-03 | 9:57 | 3.5 | 0.13 | 0.214 | m | | 0.065 | 0.014 |
| 21 | 30-Jun-03 | 9:58 | 4 | 0.15 | 0.163 | m | | 0.113 | 0.018 |
| 21 | 30-Jun-03 | 9:59 | 5 | 0.1 | 0.061 | m | | 0.150 | 0.009 |
| 21 | 30-Jun-03 | 9:59 | 7 | 0 | 0 | m | Sand | 0 | 0 |
| | | | | | | | | **0.998** | **0.241563** |

**Discharge (Swoffer)** **0.24**

**Discharge (Calculated)** **0.242**

**MHLANGA ESTUARY**

**Location:** A
**Mouth State:** Closed

| Section | Date | Time | Distance | Depth | Velocity | Unit | Comment | area | v.a |
|---|---|---|---|---|---|---|---|---|---|
| 23 | 1-JUL-03 | 9:58 | 0 | 0.095 | 0 | m | | 0.024 | 0.000 |
| 23 | 1-JUL-03 | 9:59 | 0.5 | 0.195 | 0.11 | m | | 0.098 | 0.011 |
| 23 | 1-JUL-03 | 10:00 | 1 | 0.25 | 0.336 | m | | 0.125 | 0.042 |
| 23 | 1-JUL-03 | 10:01 | 1.5 | 0.25 | 0.359 | m | | 0.125 | 0.045 |
| 23 | 1-JUL-03 | 10:02 | 2 | 0.255 | 0.438 | m | | 0.128 | 0.056 |
| 23 | 1-JUL-03 | 10:03 | 2.5 | 0.2 | 0.349 | m | | 0.100 | 0.035 |
| 23 | 1-JUL-03 | 10:03 | 3 | 0.155 | 0.283 | m | | 0.078 | 0.022 |
| 23 | 1-JUL-03 | 10:04 | 3.5 | 0.145 | 0.202 | m | | 0.073 | 0.015 |
| 23 | 1-JUL-03 | 10:05 | 4 | 0.145 | 0.122 | m | | 0.109 | 0.013 |
| 23 | 1-JUL-03 | 10:06 | 5 | 0.12 | 0.058 | m | | 0.180 | 0.010 |
| 23 | 1-JUL-03 | 10:07 | 7 | 0 | 0 | m | | 0 | 0.000 |
| | | | | | | | | **1.038** | **0.249** |

**Discharge (Swoffer)** **0.24**

**Discharge (Calculated)** **0.249**

**MHLANGA ESTUARY**

**Location:** A
**Mouth State:** Closed

| Section | Date | Time | Distance | Depth | Velocity | Unit | Comment | area | va |
|---|---|---|---|---|---|---|---|---|---|
| 25 | 2-JUL-03 | 9:52 | 0 | 0.08 | 0 | m | | 0.02 | 0 |
| 25 | 2-JUL-03 | 9:52 | 0.5 | 0.19 | 0.12 | m | | 0.095 | 0.0114 |
| 25 | 2-JUL-03 | 9:53 | 1 | 0.25 | 0.364 | m | | 0.125 | 0.0455 |
| 25 | 2-JUL-03 | 9:54 | 1.5 | 0.25 | 0.384 | m | | 0.125 | 0.048 |
| 25 | 2-JUL-03 | 9:55 | 2 | 0.23 | 0.437 | m | | 0.115 | 0.050255 |
| 25 | 2-JUL-03 | 9:56 | 2.5 | 0.195 | 0.383 | m | | 0.0975 | 0.037343 |
| 25 | 2-JUL-03 | 9:56 | 3 | 0.15 | 0.277 | m | | 0.075 | 0.020775 |
| 25 | 2-JUL-03 | 9:57 | 3.5 | 0.13 | 0.213 | m | | 0.065 | 0.013845 |
| 25 | 2-JUL-03 | 9:58 | 4 | 0.14 | 0.138 | m | | 0.105 | 0.01449 |
| 25 | 2-JUL-03 | 9:59 | 5 | 0.105 | 0.061 | m | | 0.1575 | 0.009608 |
| 25 | 2-JUL-03 | 9:59 | 7 | 0 | 0 | m | | 0 | 0 |
| | | | | | | | | **0.98** | **0.251** |

**Discharge (Swoffer)** **0.25**

**Discharge (Calculated)** **0.251**

**MHLANGA ESTUARY**

**Location:** A
**Mouth State:** Closed

| Section | Date | Time | Distance | Depth | Velocity | Unit | Comment | area | v.a |
|---|---|---|---|---|---|---|---|---|---|
| 27 | 3-JUL-03 | 10:22 | 0 | 0.12 | 0 | m | | 0.03 | 0 |
| 27 | 3-JUL-03 | 10:23 | 0.5 | 0.23 | 0.155 | m | | 0.115 | 0.0178 |
| 27 | 3-JUL-03 | 10:24 | 1 | 0.23 | 0.346 | m | | 0.115 | 0.0398 |
| 27 | 3-JUL-03 | 10:25 | 1.5 | 0.24 | 0.438 | m | | 0.12 | 0.0526 |
| 27 | 3-JUL-03 | 10:26 | 2 | 0.22 | 0.406 | m | | 0.11 | 0.0447 |
| 27 | 3-JUL-03 | 10:27 | 2.5 | 0.16 | 0.356 | m | | 0.08 | 0.0285 |
| 27 | 3-JUL-03 | 10:27 | 3 | 0.15 | 0.239 | m | | 0.113 | 0.0269 |
| 27 | 3-JUL-03 | 10:28 | 4 | 0.12 | 0.12 | m | | 0.24 | 0.0288 |
| 27 | 3-JUL-03 | 10:28 | 7 | 0 | 0 | m | | 0 | 0 |
| | | | | | | | | **0.923** | **0.239** |

**Discharge (Swoffer)** **0.23**

**Discharge (Calculated)** **0.239**

**MHLANGA ESTUARY**

**Location:** A
**Mouth State:** Closed

| Section | Date | Time | Distance | Depth | Velocity | Unit | Comment | area | v.a |
|---|---|---|---|---|---|---|---|---|---|
| 29 | 4-JUL-03 | 10:50 | 0 | 0.04 | 0 | m | | 0.01 | 0 |
| 29 | 4-JUL-03 | 10:50 | 0.5 | 0.19 | 0.128 | m | | 0.095 | 0.012 |
| 29 | 4-JUL-03 | 10:51 | 1 | 0.25 | 0.325 | m | | 0.125 | 0.041 |
| 29 | 4-JUL-03 | 10:52 | 1.5 | 0.25 | 0.382 | m | | 0.125 | 0.048 |
| 29 | 4-JUL-03 | 10:53 | 2 | 0.23 | 0.43 | m | | 0.115 | 0.049 |
| 29 | 4-JUL-03 | 10:54 | 2.5 | 0.18 | 0.356 | m | | 0.09 | 0.032 |
| 29 | 4-JUL-03 | 10:54 | 3 | 0.15 | 0.232 | m | | 0.1125 | 0.026 |
| 29 | 4-JUL-03 | 10:55 | 4 | 0.13 | 0.113 | m | | 0.26 | 0.029 |
| 29 | 4-JUL-03 | 10:55 | 7 | 0 | 0 | m | | 0 | 0 |
| | | | | | | | | **0.933** | **0.238** |

**Discharge (Swoffer)** **0.23**

**Discharge (Calculated)** **0.238**

**MHLANGA ESTUARY**

**Location:** A
**Mouth State:** Closed

| Section | Date | Time | Distance | Depth | Velocity | Unit | Comment | area | v.a |
|---|---|---|---|---|---|---|---|---|---|
| 31 | 5-JUL-03 | 12:11 | 0 | 0.07 | 0 | m | | 0.018 | 0 |
| 31 | 5-JUL-03 | 12:12 | 0.5 | 0.19 | 0.103 | m | | 0.095 | 0.010 |
| 31 | 5-JUL-03 | 12:12 | 1 | 0.26 | 0.297 | m | | 0.130 | 0.039 |
| 31 | 5-JUL-03 | 12:13 | 1.5 | 0.24 | 0.409 | m | | 0.120 | 0.049 |
| 31 | 5-JUL-03 | 12:14 | 2 | 0.22 | 0.375 | m | | 0.110 | 0.041 |
| 31 | 5-JUL-03 | 12:14 | 2.5 | 0.19 | 0.292 | m | | 0.095 | 0.028 |
| 31 | 5-JUL-03 | 12:15 | 3 | 0.15 | 0.228 | m | | 0.113 | 0.026 |
| 31 | 5-JUL-03 | 12:16 | 4 | 0.14 | 0.118 | m | | 0.280 | 0.033 |
| 31 | 5-JUL-03 | 12:16 | 7 | 0 | 0 | m | | 0 | 0 |
| | | | | | | | | **0.960** | **0.225** |

**Discharge (Swoffer)** **0.22**

**Discharge (Calculated)** **0.225**

**MHLANGA ESTUARY**

**Location:** A
**Mouth State:** Closed

| Section | Date | Time | Distance | Depth | Velocity | Unit | Comment | area | v.a |
|---|---|---|---|---|---|---|---|---|---|
| 33 | 6-JUL-03 | 12:03 | 0 | 0.15 | 0 | m | | 0.038 | 0 |
| 33 | 6-JUL-03 | 12:04 | 0.5 | 0.23 | 0.169 | m | | 0.115 | 0.019 |
| 33 | 6-JUL-03 | 12:05 | 1 | 0.23 | 0.282 | m | | 0.115 | 0.032 |
| 33 | 6-JUL-03 | 12:06 | 1.5 | 0.23 | 0.383 | m | | 0.115 | 0.044 |
| 33 | 6-JUL-03 | 12:07 | 2 | 0.21 | 0.334 | m | | 0.105 | 0.035 |
| 33 | 6-JUL-03 | 12:08 | 2.5 | 0.18 | 0.356 | m | | 0.090 | 0.032 |
| 33 | 6-JUL-03 | 12:08 | 3 | 0.15 | 0.208 | m | | 0.113 | 0.023 |
| 33 | 6-JUL-03 | 12:09 | 4 | 0.11 | 0.081 | m | | 0.220 | 0.018 |
| 33 | 6-JUL-03 | 12:09 | 7 | 0 | 0 | m | | 0 | 0 |
| | | | | | | | | **0.910** | **0.204** |

**Discharge (Swoffer)** **0.2**

**Discharge (Calculated)** **0.204**

**MHLANGA ESTUARY**

**Location:** A
**Mouth State:** Closed

| Section | Date | Time | Distance | Depth | Velocity | Unit | Comment | area | v.a |
|---|---|---|---|---|---|---|---|---|---|
| 35 | 7-JUL-03 | 13:25 | 0 | 0.15 | 0 | m | | 0.038 | 0 |
| 35 | 7-JUL-03 | 13:26 | 0.5 | 0.21 | 0.105 | m | | 0.105 | 0.011 |
| 35 | 7-JUL-03 | 13:27 | 1 | 0.25 | 0.288 | m | | 0.125 | 0.036 |
| 35 | 7-JUL-03 | 13:28 | 1.5 | 0.25 | 0.381 | m | | 0.125 | 0.048 |
| 35 | 7-JUL-03 | 13:28 | 2 | 0.22 | 0.406 | m | | 0.110 | 0.045 |
| 35 | 7-JUL-03 | 13:29 | 2.5 | 0.18 | 0.303 | m | | 0.090 | 0.027 |
| 35 | 7-JUL-03 | 13:30 | 3 | 0.155 | 0.231 | m | | 0.116 | 0.027 |
| 35 | 7-JUL-03 | 13:30 | 4 | 0.12 | 0.112 | m | | 0.240 | 0.027 |
| 35 | 7-JUL-03 | 13:30 | 7 | 0 | 0 | m | | 0 | 0 |
| | | | | | | | | **0.949** | **0.220** |

**Discharge (Swoffer)** **0.22**

**Discharge (Calculated)** **0.220**

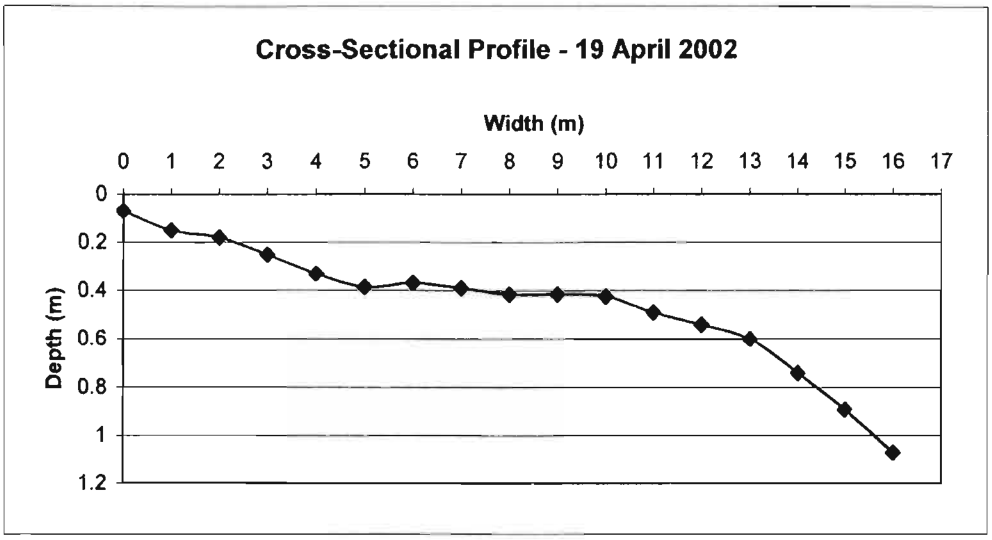
**MHLANGA ESTUARY**

**Location:** A
**Mouth State:** Closed

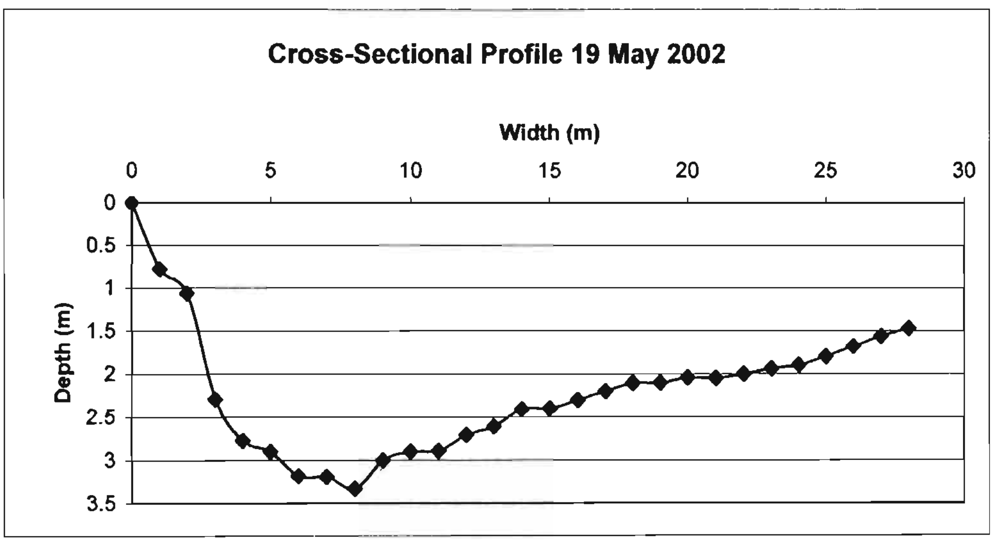
| Section | Date | Time | Distance | Depth | Velocity | Unit | Comment | area | v.a |
|---|---|---|---|---|---|---|---|---|---|
| 37 | 8-JUL-03 | 14:12 | 0 | 0.075 | 0 | m | | 0.019 | 0 |
| 37 | 8-JUL-03 | 14:13 | 0.5 | 0.23 | 0.14 | m | | 0.115 | 0.016 |
| 37 | 8-JUL-03 | 14:14 | 1 | 0.25 | 0.312 | m | | 0.125 | 0.039 |
| 37 | 8-JUL-03 | 14:15 | 1.5 | 0.25 | 0.406 | m | | 0.125 | 0.051 |
| 37 | 8-JUL-03 | 14:16 | 2 | 0.21 | 0.407 | m | | 0.105 | 0.043 |
| 37 | 8-JUL-03 | 14:17 | 2.5 | 0.175 | 0.368 | m | | 0.088 | 0.032 |
| 37 | 8-JUL-03 | 14:17 | 3 | 0.15 | 0.222 | m | | 0.113 | 0.025 |
| 37 | 8-JUL-03 | 14:18 | 4 | 0.13 | 0.081 | m | | 0.260 | 0.021 |
| 37 | 8-JUL-03 | 14:18 | 7 | 0 | 0 | m | | 0 | 0 |
| | | | | | | | | **0.949** | **0.227** |

**Discharge (Swoffer)** **0.22**

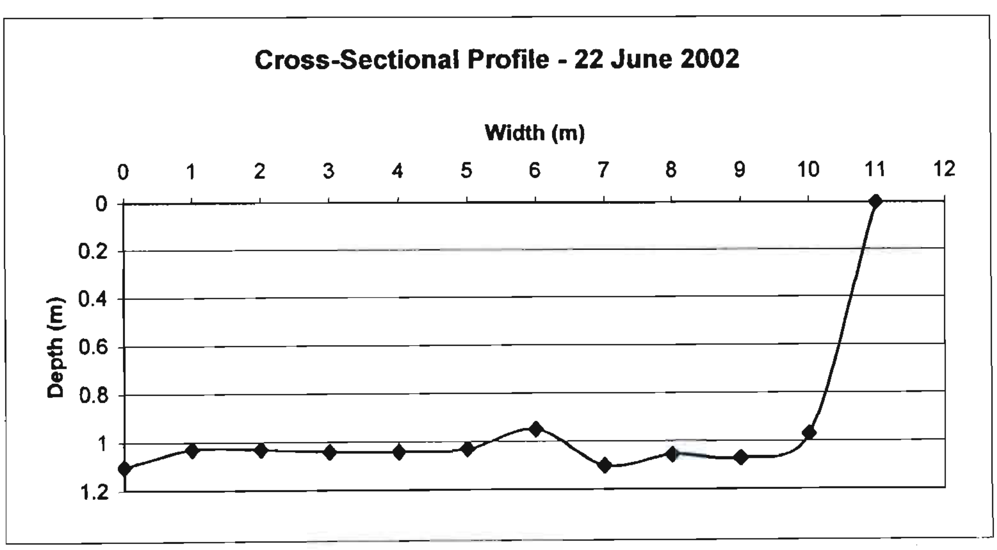
**Discharge (Calculated)** **0.227**



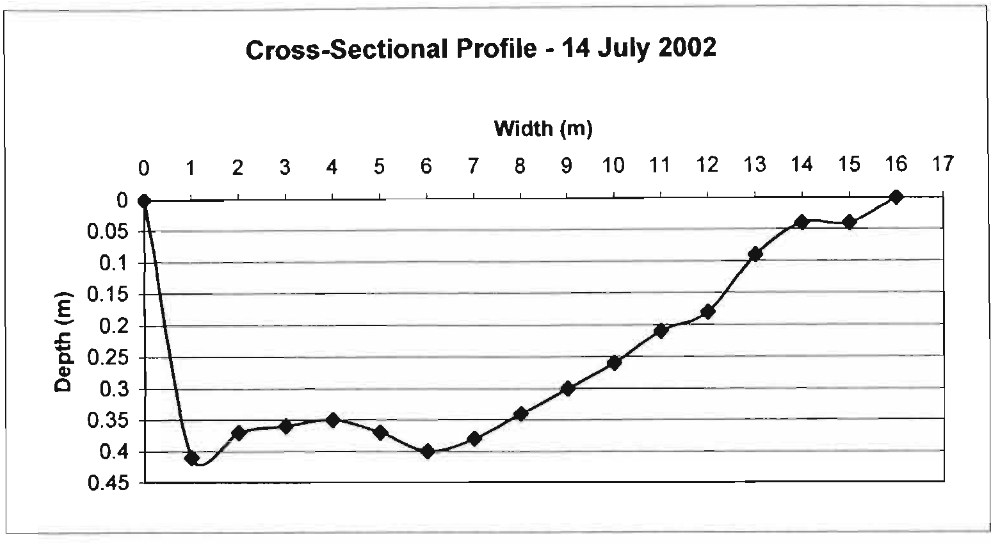
Cross-Sectional Profile - 19 April 2002
Width (m)
Depth (m)

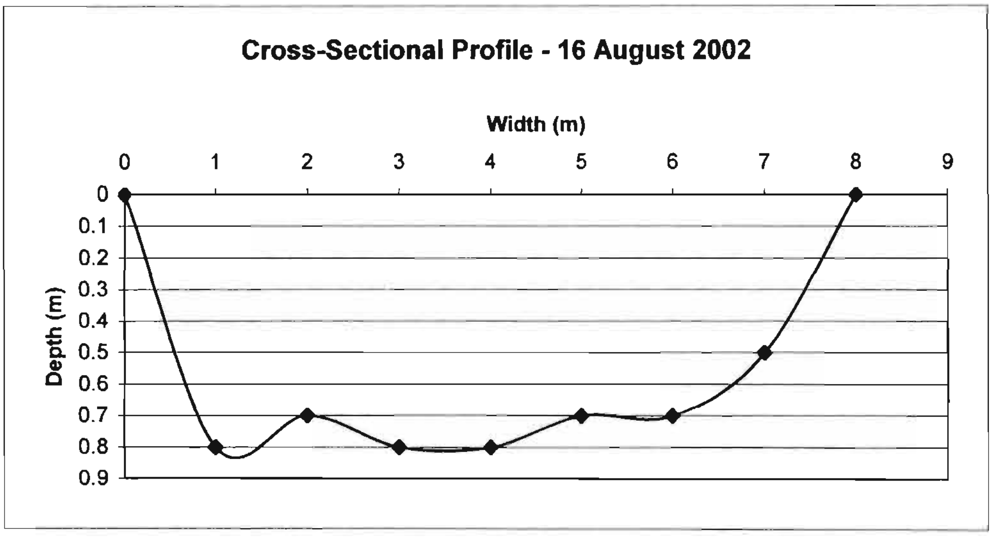



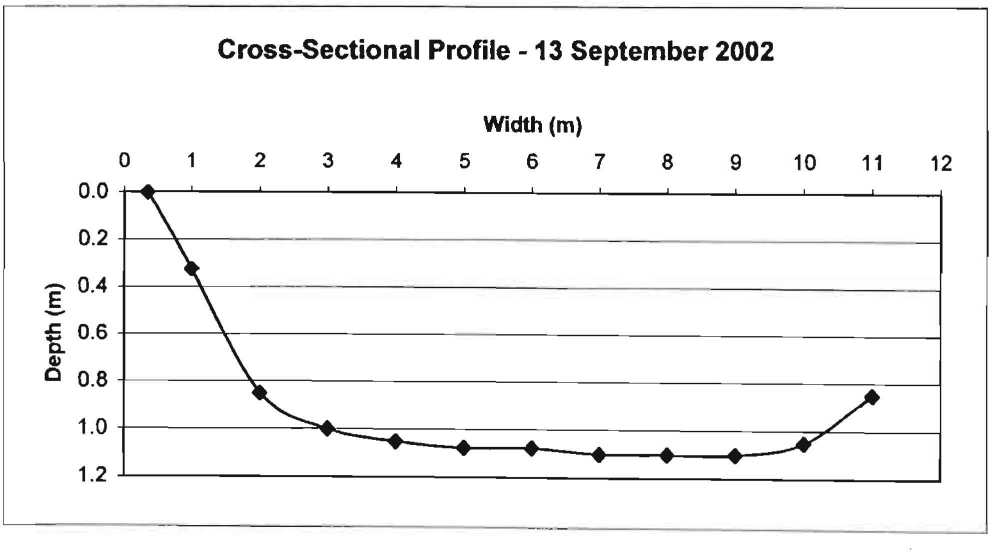
Cross-Sectional Profile 19 May 2002
Width (m)
Depth (m)

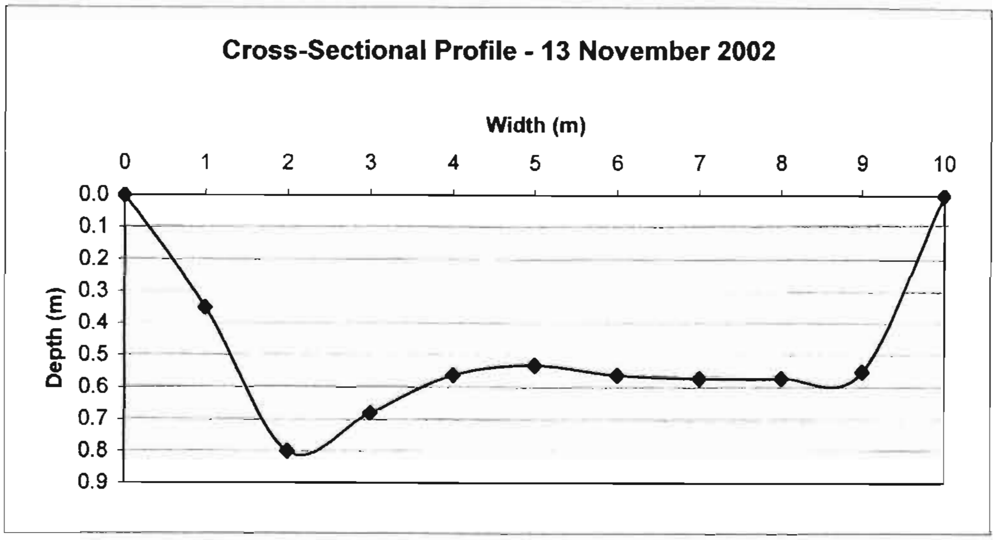



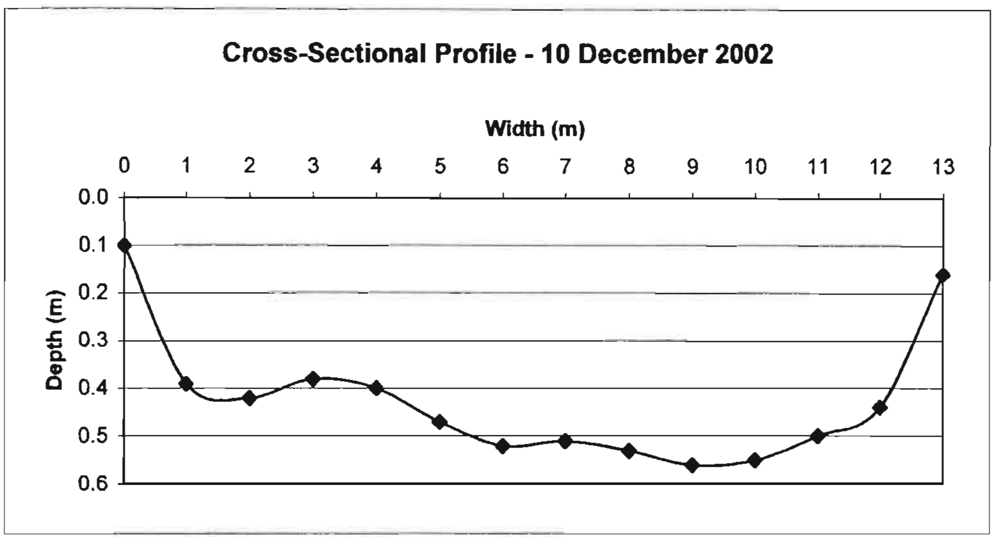
Cross-Sectional Profile - 22 June 2002
Width (m)
Depth (m)

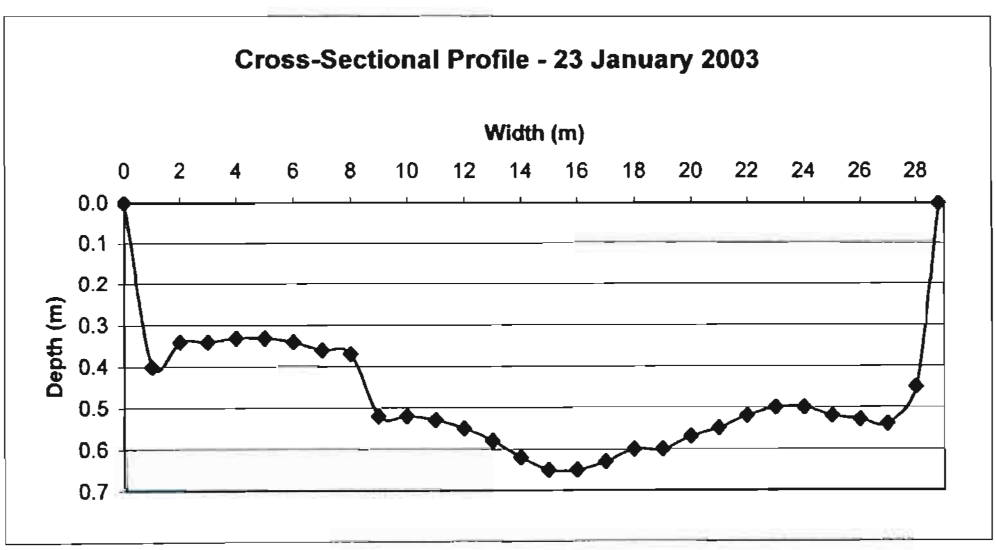

Cross-Sectional Profile - 14 July 2002
Width (m)
Depth (m)

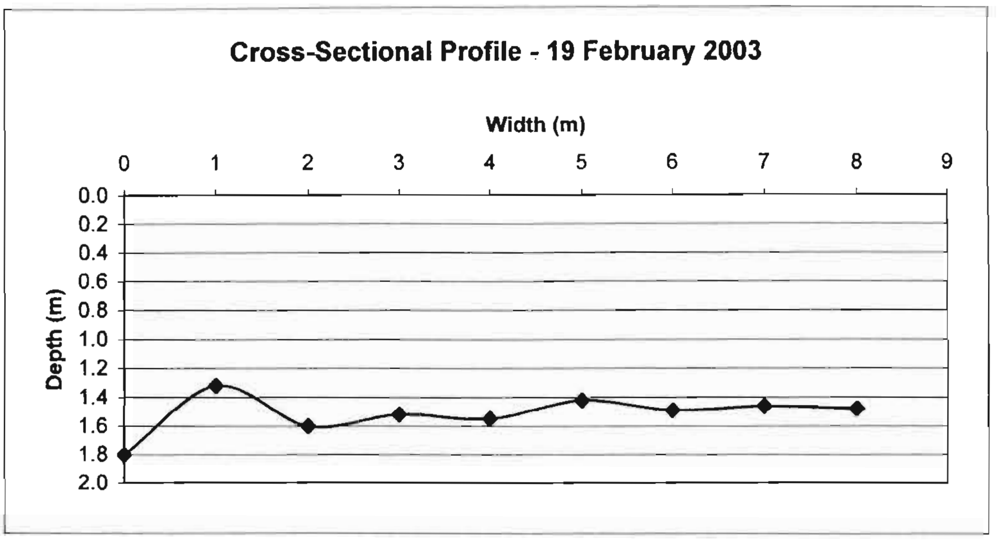

Cross-Sectional Profile - 16 August 2002
Width (m)
Depth (m)

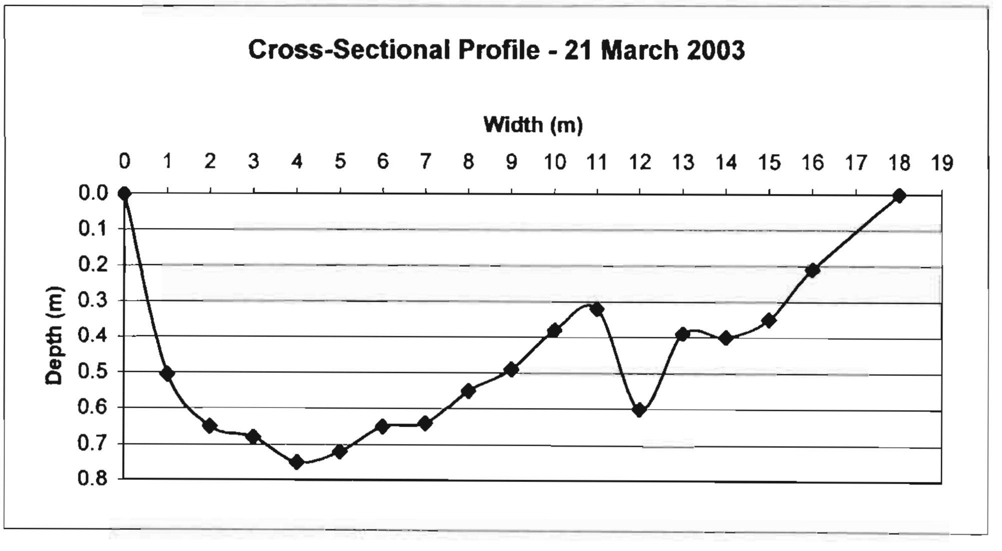

Cross-Sectional Profile - 13 September 2002
Width (m)
Depth (m)

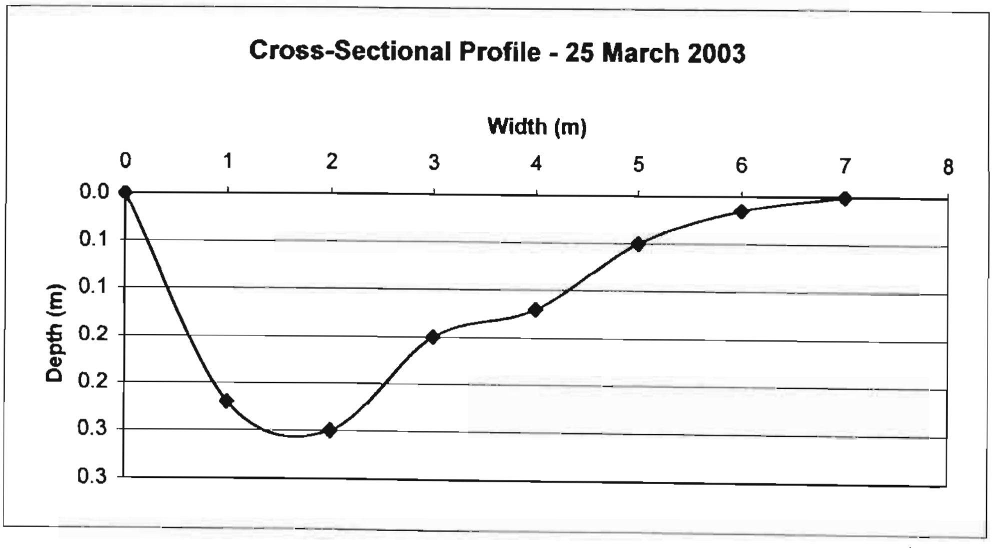

Cross-Sectional Profile - 13 November 2002
Width (m)
0
1
2
3
4
5
6
7
8
9
10
Depth (m)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

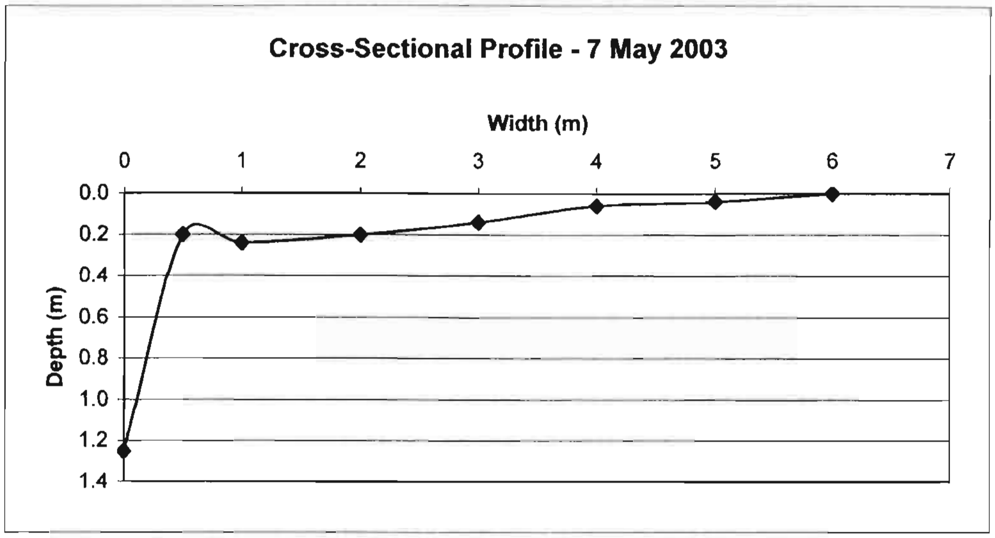

Cross-Sectional Profile - 10 December 2002
Width (m)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Depth (m)
0.0
0.1
0.2
0.3
0.4
0.5
0.6


Cross-Sectional Profile - 23 January 2003
Width (m)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
Depth (m)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7

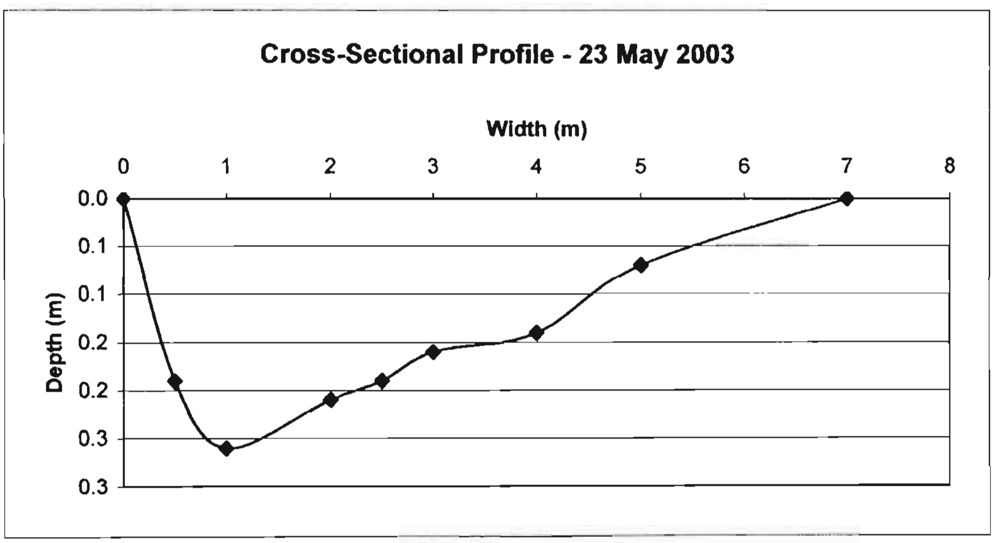

Cross-Sectional Profile - 19 February 2003
Width (m)
0
1
2
3
4
5
6
7
8
9
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
Depth (m)


Cross-Sectional Profile - 21 March 2003
Width (m)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Depth (m)

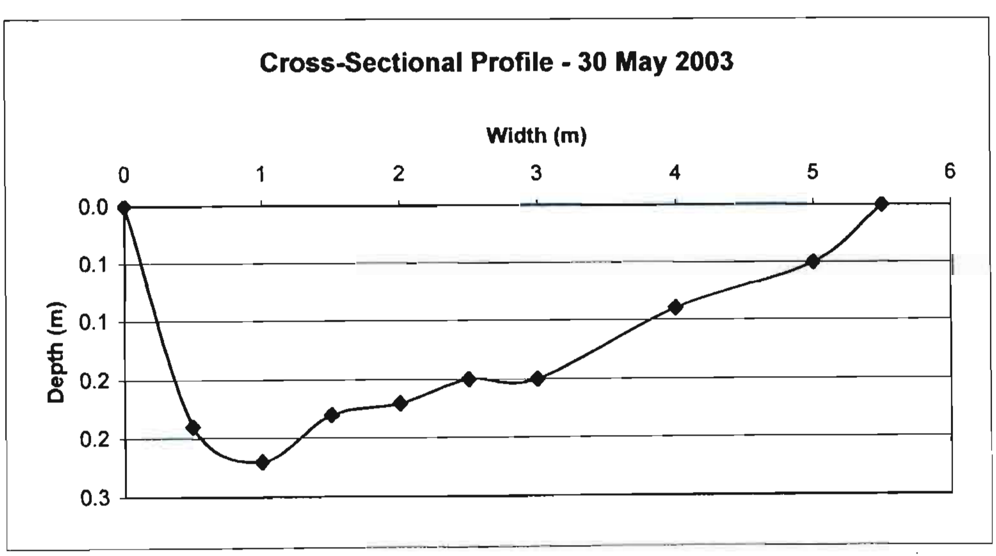

Cross-Sectional Profile - 25 March 2003
Width (m)
0
1
2
3
4
5
6
7
8
0.0
0.1
0.1
0.2
0.2
0.3
0.3
Depth (m)



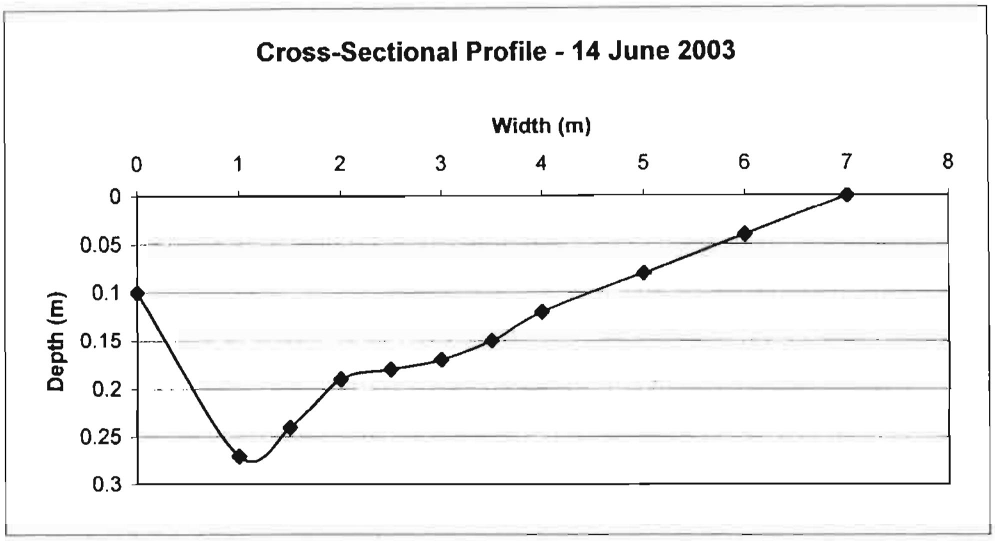
Cross-Sectional Profile - 7 May 2003
Width (m)
0
1
2
3
4
5
6
7
Depth (m)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4

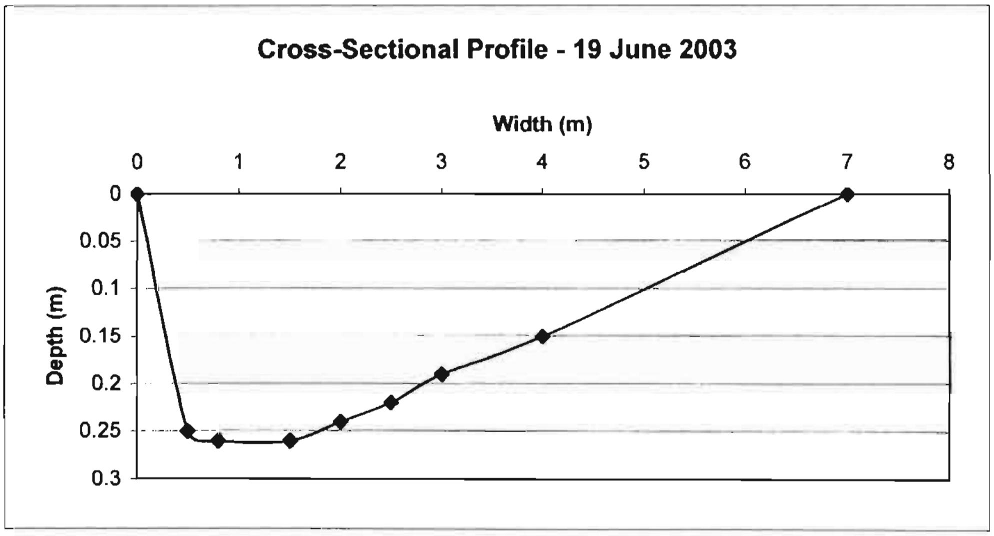



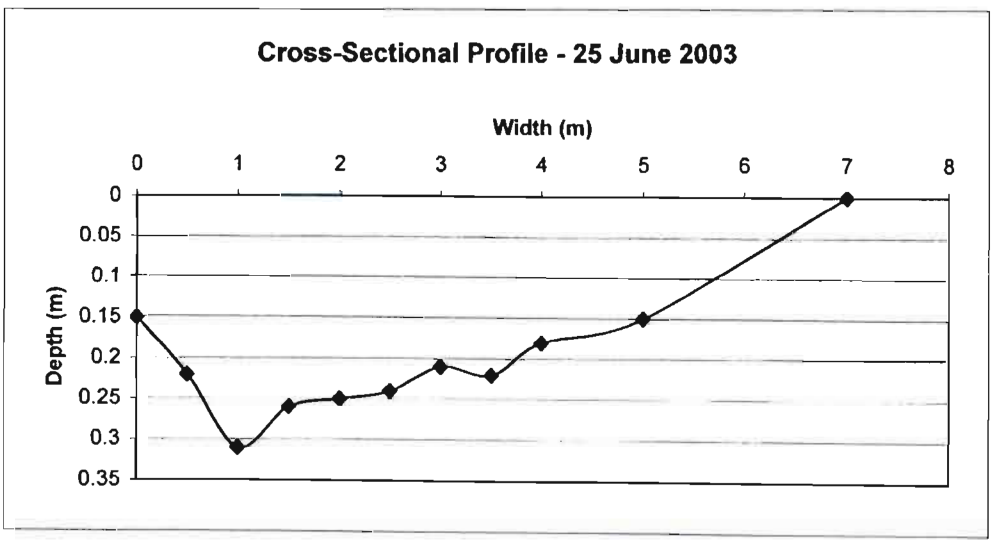
Cross-Sectional Profile - 23 May 2003
Width (m)
0
1
2
3
4
5
6
7
8
Depth (m)
0.0
0.1
0.1
0.2
0.2
0.3
0.3

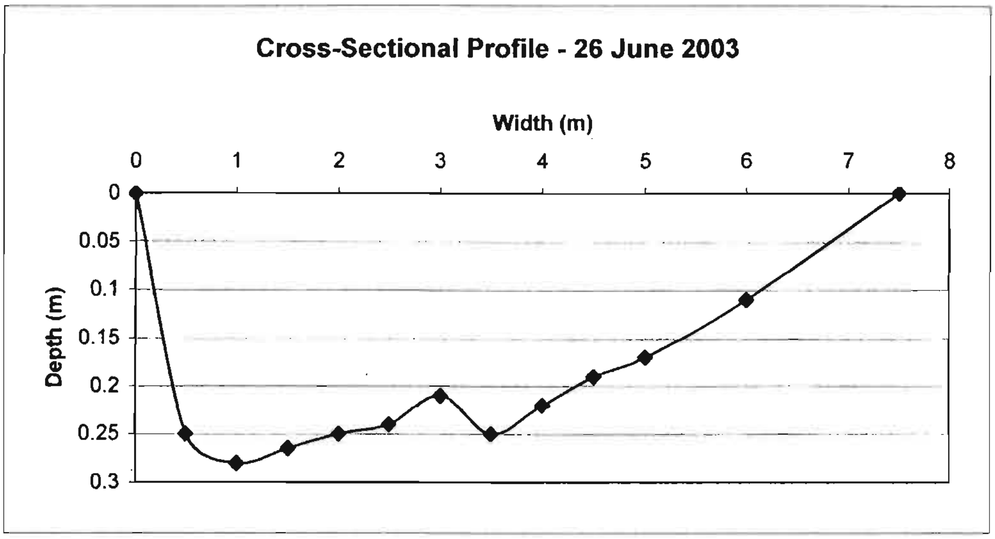



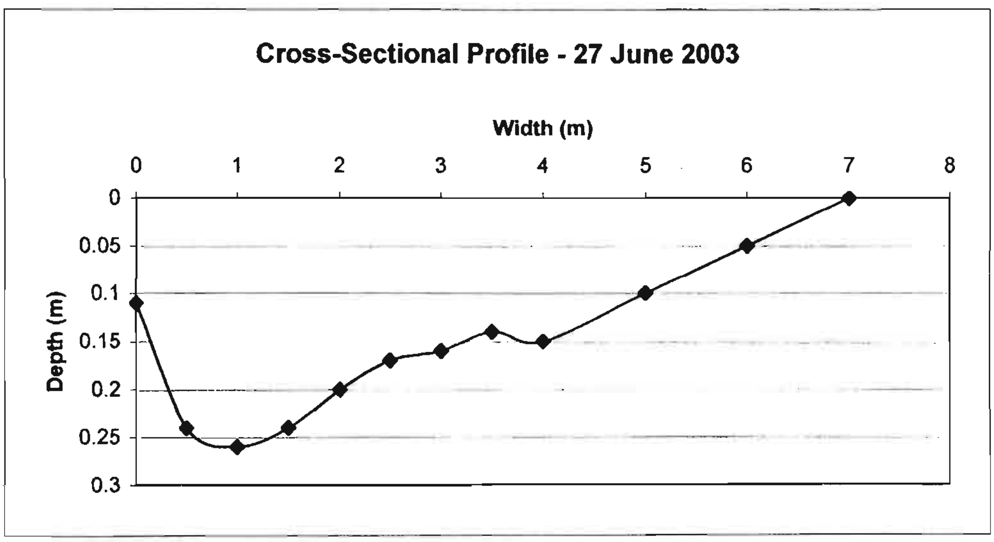
Cross-Sectional Profile - 30 May 2003
Width (m)
0
1
2
3
4
5
6
Depth (m)
0.0
0.1
0.1
0.2
0.2
0.3

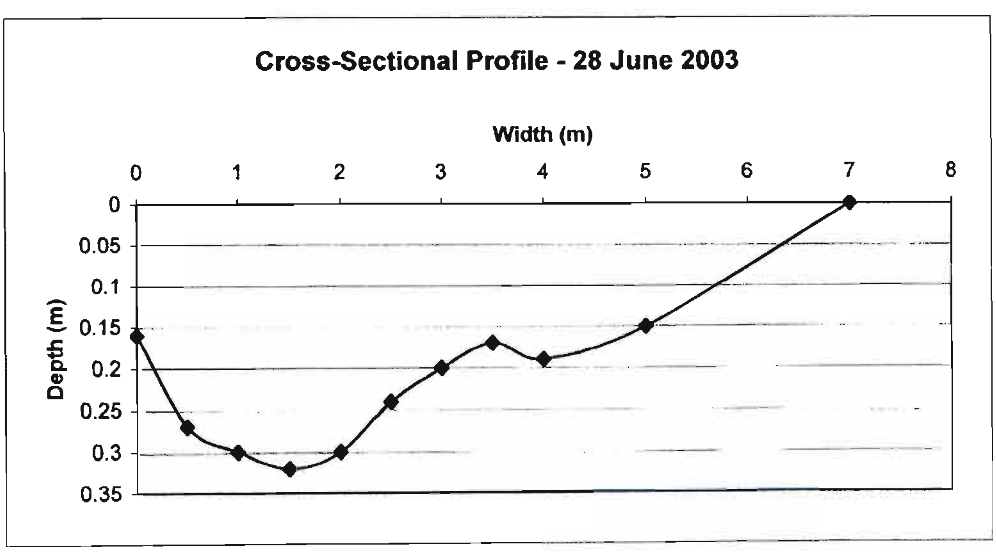

Cross-Sectional Profile - 14 June 2003
Width (m)
0
1
2
3
4
5
6
7
8
Depth (m)
0
0.05
0.1
0.15
0.2
0.25
0.3

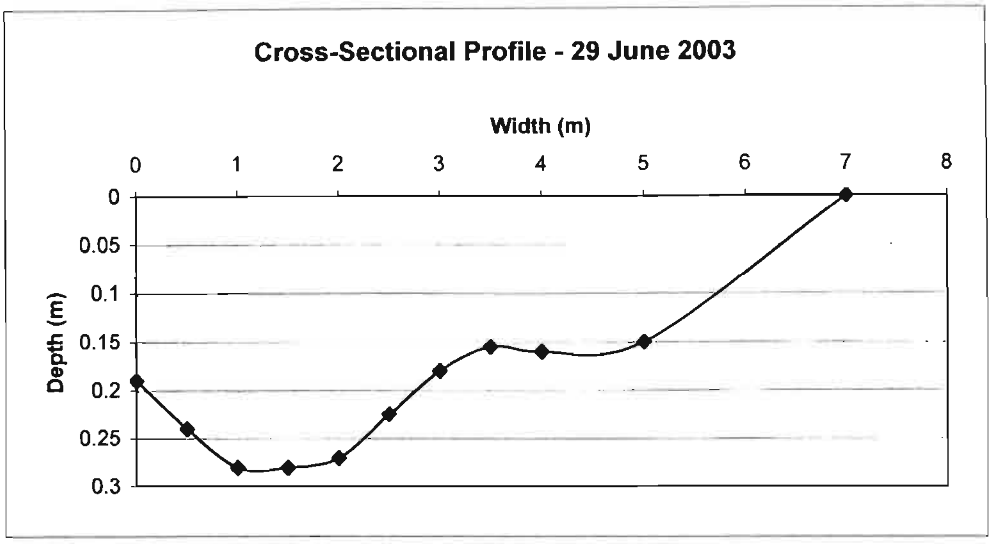

Cross-Sectional Profile - 19 June 2003
Width (m)
0
1
2
3
4
5
6
7
8
Depth (m)
0
0.05
0.1
0.15
0.2
0.25
0.3


Cross-Sectional Profile - 25 June 2003
Width (m)
0
1
2
3
4
5
6
7
8
Depth (m)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35

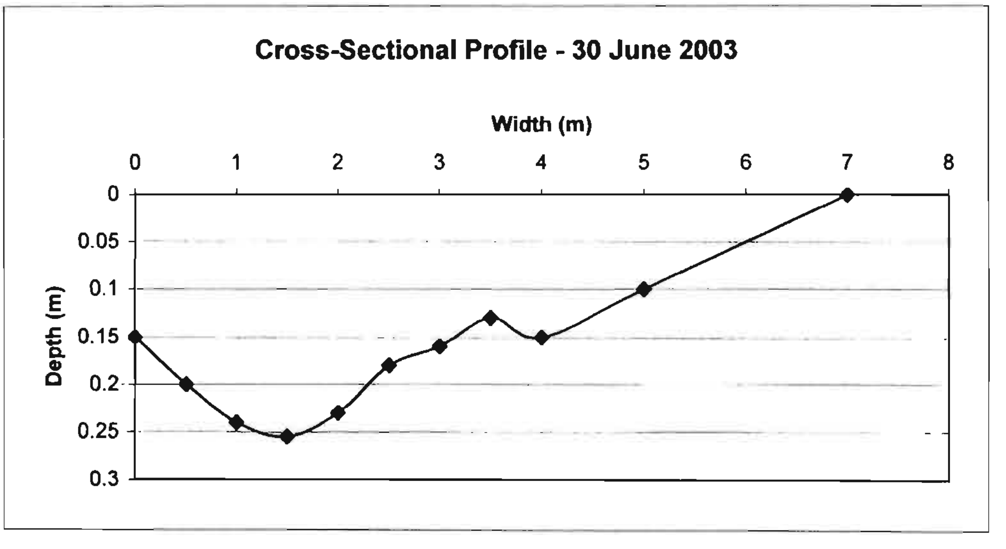

Cross-Sectional Profile - 26 June 2003
Width (m)
0
1
2
3
4
5
6
7
8
Depth (m)
0
0.05
0.1
0.15
0.2
0.25
0.3


Cross-Sectional Profile - 27 June 2003
Width (m)
0
1
2
3
4
5
6
7
8
Depth (m)
0
0.05
0.1
0.15
0.2
0.25
0.3

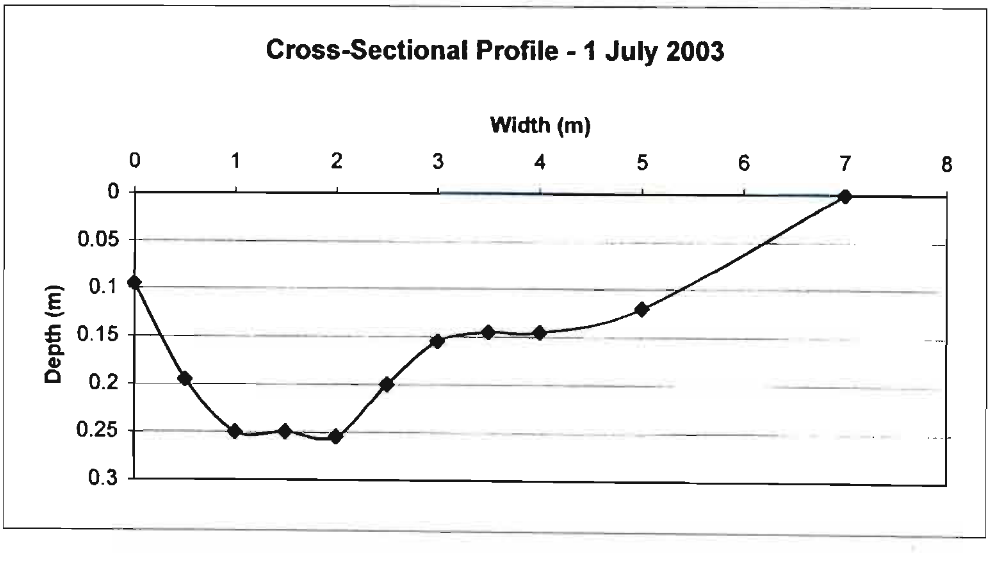

Cross-Sectional Profile - 28 June 2003
Width (m)
0
1
2
3
4
5
6
7
8
Depth (m)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35



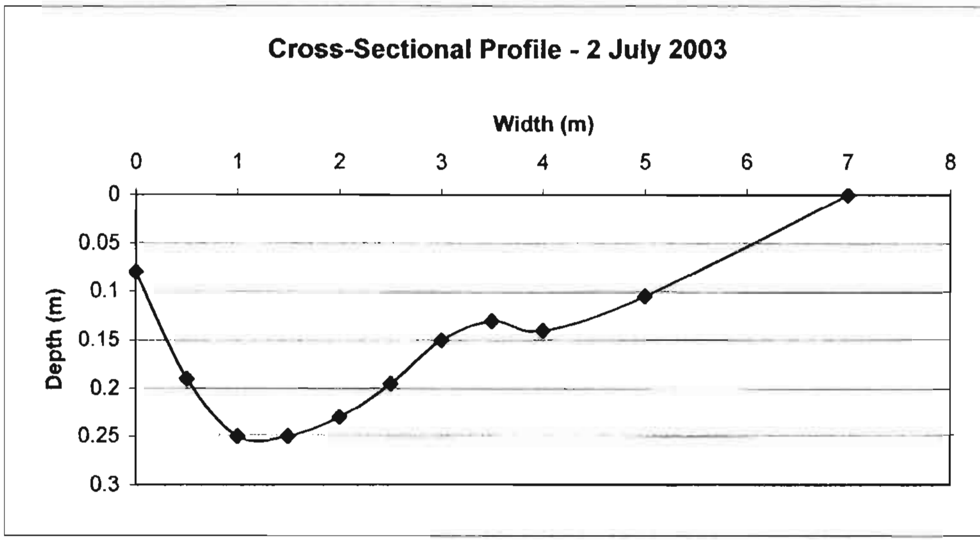
Cross-Sectional Profile - 29 June 2003
Width (m)
0 1 2 3 4 5 6 7 8
Depth (m)
0 0.05 0.1 0.15 0.2 0.25 0.3

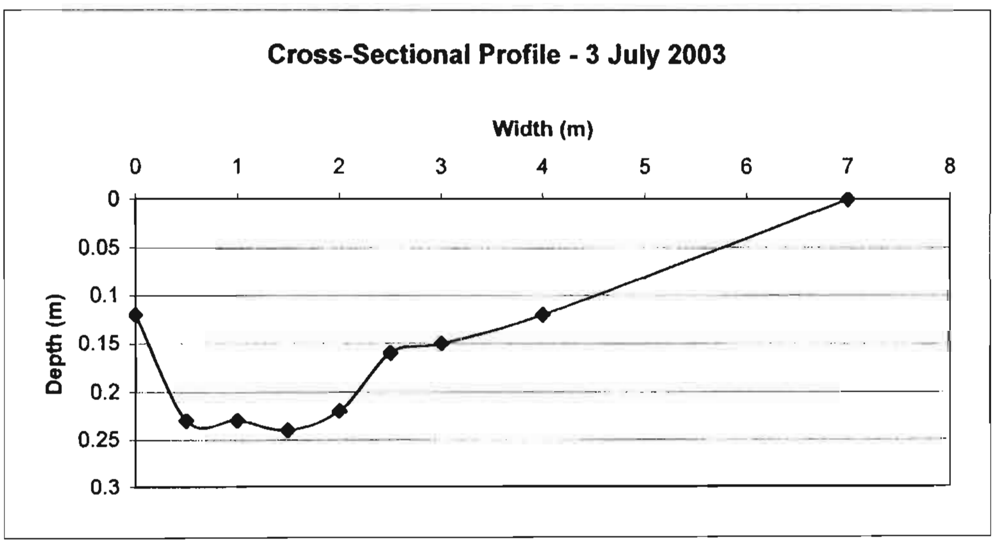



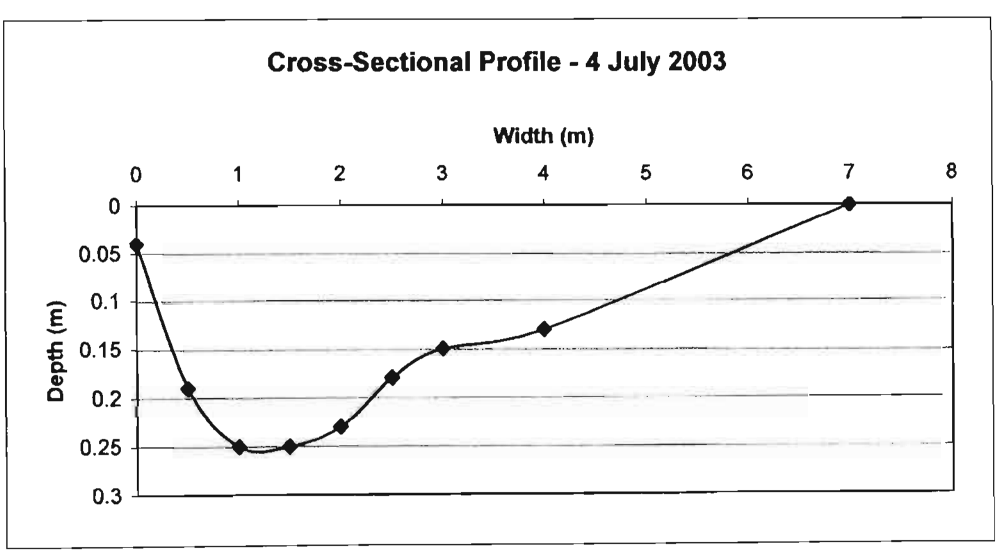
Cross-Sectional Profile - 30 June 2003
Width (m)
0 1 2 3 4 5 6 7 8
Depth (m)
0 0.05 0.1 0.15 0.2 0.25 0.3

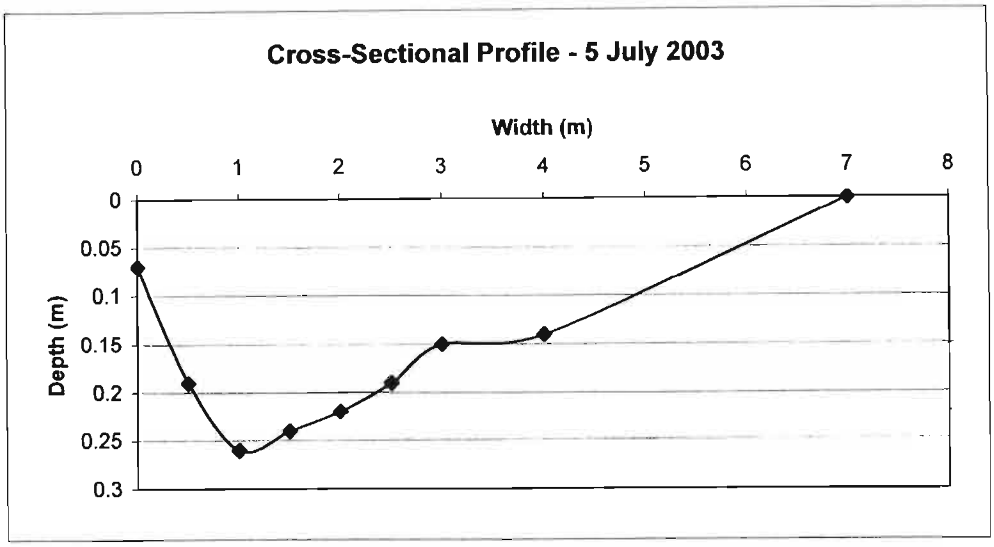



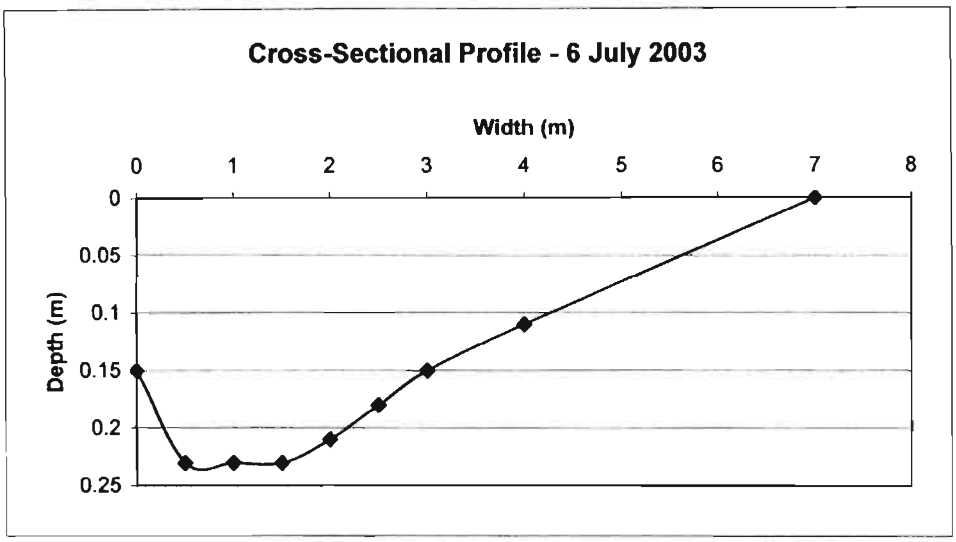
Cross-Sectional Profile - 1 July 2003
Width (m)
0 1 2 3 4 5 6 7 8
Depth (m)
0 0.05 0.1 0.15 0.2 0.25 0.3

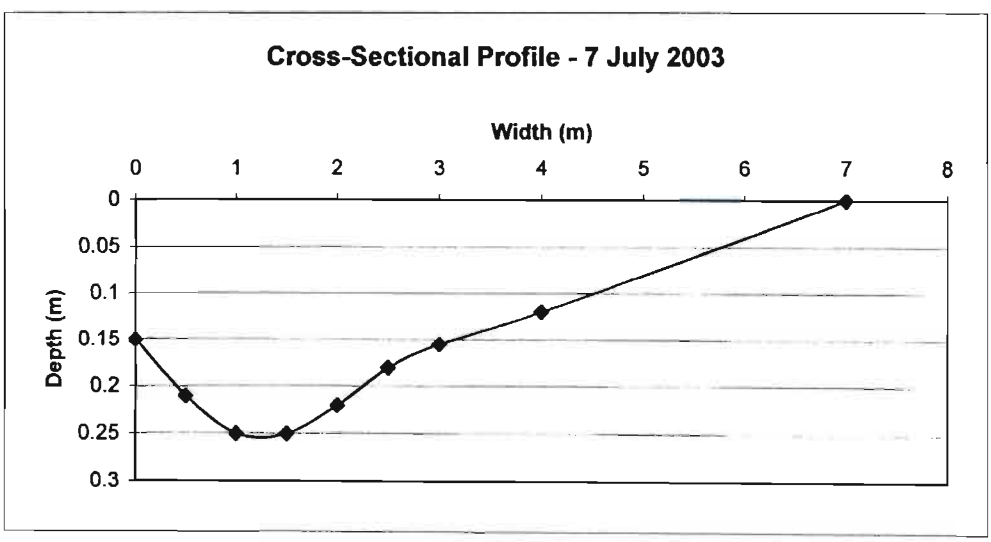

Cross-Sectional Profile - 2 July 2003
Width (m)
Depth (m)
0
1
2
3
4
5
6
7
8
0
0.05
0.1
0.15
0.2
0.25
0.3

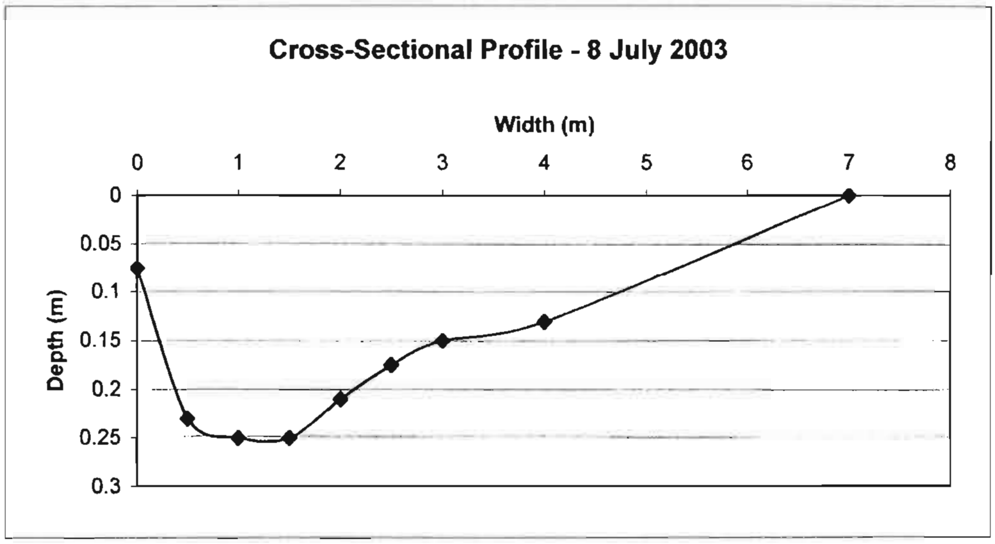

Cross-Sectional Profile - 3 July 2003
Width (m)
Depth (m)
0
1
2
3
4
5
6
7
8
0
0.05
0.1
0.15
0.2
0.25
0.3


Cross-Sectional Profile - 4 July 2003
Width (m)
Depth (m)
0
1
2
3
4
5
6
7
8
0
0.05
0.1
0.15
0.2
0.25
0.3


Cross-Sectional Profile - 5 July 2003
Width (m)
0
1
2
3
4
5
6
7
8
Depth (m)
0
0.05
0.1
0.15
0.2
0.25
0.3


Cross-Sectional Profile - 6 July 2003
Width (m)
0
1
2
3
4
5
6
7
8
Depth (m)
0
0.05
0.1
0.15
0.2
0.25


Cross-Sectional Profile - 7 July 2003
Width (m)
0
1
2
3
4
5
6
7
8
Depth (m)
0
0.05
0.1
0.15
0.2
0.25
0.3


Cross-Sectional Profile - 8 July 2003
Width (m)
0
1
2
3
4
5
6
7
8
Depth (m)
0
0.05
0.1
0.15
0.2
0.25
0.3

**MDLOTI ESTUARY**

**Date:** 18-Apr-02
**Weather:** Partly cloudy, very windy (cross wind)
**Estuary State:** Open
**Station Reference:** 3

Data Collected:

| Width (m) | Depth (m) | Time in seconds for floats to travel 10m | | | | Comment |
|---|---|---|---|---|---|---|
| | | Big | Medium | Small | Surface | |
| 0 | 0.000 | | | | | |
| 1 | 0.070 | | | | | |
| 2 | 0.090 | | | 40 | 42 | |
| 3 | 0.120 | | | | | |
| 4 | 0.110 | | | 40 | 45 | |
| 5 | 0.100 | | | | | |
| 6 | 0.140 | | | 23 | 30 | |
| 7 | 0.145 | | | | | |
| 8 | 0.170 | | | 30 | 28 | |
| 9 | 0.210 | | | | | |
| 10 | 0.260 | 39 | 32 | 36 | 26 | |
| 11 | 0.240 | | | | | |
| 12 | 0.210 | | 23 | 26 | 23 | |
| 13 | 0.320 | | | | | |
| 14 | 0.270 | 24 | | | 22 | |
| 15 | 0.330 | | | | | |
| 16 | 0.330 | 24 | 23 | 23 | 23 | |
| 17 | 0.340 | | | | | |
| 18 | 0.460 | 24 | 23 | 23 | 22 | |
| 19 | 0.500 | 24 | 23 | 24 | 22 | |
| 20 | 0.490 | | | | | |

| | | |
|---|---|---|
| Area = | 4.6714 | $m^2$ |
| Av. Vel. = | 0.3594 | m/s |
| Flow = | 1.6787 | $m^3/s$ |

**MDLOTI ESTUARY**

**Date:** 19-May-02
**Weather:** Sunny, still
**Estuary State:** Closed, fairly full
**Station Reference:** 2

Data Collected:

| Width (m) | Depth (m) | Electronic 400mm | Vel m/s | Area m^2 | Vel*Area m^3/s | Comment |
|---|---|---|---|---|---|---|
| 0 | 1.40 | 4 | 0.22 | 0.70 | 0.16 | Reeds |
| 1 | 1.40 | 1 | 0.06 | 1.40 | 0.08 | |
| 2 | 1.34 | 3 | 0.17 | 1.37 | 0.23 | |
| 3 | 1.39 | 6 | 0.33 | 1.37 | 0.46 | |
| 4 | 1.30 | 4 | 0.22 | 1.35 | 0.30 | |
| 5 | 1.31 | 4 | 0.22 | 1.31 | 0.29 | |
| 6 | 1.42 | 4 | 0.22 | 1.37 | 0.30 | |
| 7 | 1.40 | 3 | 0.17 | 1.41 | 0.24 | |
| 8 | 1.37 | 5 | 0.28 | 1.39 | 0.38 | |
| 9 | 1.45 | 3 | 0.17 | 1.41 | 0.24 | |
| 10 | 1.38 | 3 | 0.17 | 1.42 | 0.24 | |
| 11 | 1.47 | 4 | 0.22 | 1.43 | 0.32 | |
| 12 | 1.31 | 4 | 0.22 | 1.39 | 0.31 | |
| 13 | 1.28 | 4 | 0.22 | 1.30 | 0.29 | |
| 14 | 1.30 | 4 | 0.22 | 1.29 | 0.29 | Small float 10m in 45s |
| 15 | 1.18 | 2 | 0.11 | 1.24 | 0.14 | |
| 16 | 1.17 | 3 | 0.17 | 1.76 | 0.29 | Reeds |
| | | | | 22.87 | 4.53 | |

| | | |
|---|---|---|
| Av Vel = | 0.20 | m/s |
| Area = | 22.87 | m^2 |
| Flow = | 4.56 | m^3/s |

**MDLOTI ESTUARY**

**Date:** 22-Jun-02
**Weather:** Sunny, clear, still
**Estuary State:** Closed, very full
**Station Reference:** 2

Data Collected:

| Width (m) | Depth (m) | Time in seconds at depth (m): | | | | Comment |
|---|---|---|---|---|---|---|
| | | 0.2 | 0.44 | 0.86 | Surface | |
| 0 | 1.56 | | | | | Reeds interferred |
| 1 | 1.51 | | | | | |
| 2 | 1.54 | | | | | |
| 3 | 1.40 | | | | | |
| 4 | 1.36 | | | | | |
| 5 | 1.28 | 454 | 307 | 266 | 246 | |
| 6 | 1.23 | | | | | |
| 7 | 1.23 | 288 | 215 | 223 | * | *Drifted |
| 8 | 1.20 | | | | | |
| 9 | 1.20 | * | * | 240 | 241 | *Reeds |
| 10 | 1.20 | | | | | Reeds interferred |
| 11 | 1.21 | | | | | |
| 12 | 1.22 | | | | | |
| 13 | 1.14 | | | | | |
| 14 | 1.10 | | | | | Reeds |

| | | |
|---|---|---|
| Area = | 18.0880 | $m^2$ |
| Av. Vel. = | 0.0363 | m/s |
| Flow = | 0.6564 | $m^3/s$ |

**MDLOTI ESTUARY**

**Date:** 14-Jul-02
**Weather:** Sunny, clear, calm
**Estuary State:** Closed, very full
**Station Reference:** 2

Data Collected:

| Width (m) | Depth (m) | Time in seconds at depth (m): | | | | Velocity (m/s) | Area (m^2) | Velocity*Area (m3/s) | Comment | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.2 | 0.44 | 0.86 | Surface | | | | | |
| 0 | 1.115 | | | | | 0.000 | 0.56 | 0.000 | Reeds | |
| 1 | 1.225 | 250* | | | | 0.024 | 1.17 | 0.028 | Reeds | *@ 6m |
| 2 | 1.33 | 310** | Reeds | 218 | Reeds | 0.033 | 1.28 | 0.042 | | **@ 6m |
| 3 | 1.45 | 235*** | 275 | 113 | 358 | 0.048 | 1.39 | 0.066 | | ***@ 9m |
| 4 | 1.12 | 350 | 289 | 209 | 329 | 0.034 | 1.29 | 0.044 | | |
| 5 | 1.12 | 218 | 215 | 285 | 244 | 0.042 | 1.12 | 0.047 | | |
| 6 | 1.06 | 235 | 330 | 252 | 318 | 0.035 | 1.09 | 0.038 | | |
| 7 | 1.21 | 307 | 229 | 217 | 489 | 0.032 | 1.14 | 0.037 | | |
| 8 | 1.18 | | 272 | 237 | 222 | 0.041 | 1.20 | 0.049 | | |
| 9 | 1.125 | | | | | 0.000 | 1.72 | 0.000 | Reeds | |
| | | | | | | | 11.94 | 0.35 | | |

**Note: There was a subsurface cross current**

| | | |
|---|---|---|
| Area = | 10.7415 | $m^2$ |
| Av. Vel. = | 0.0361 | m/s |
| Flow = | 0.3873 | $m^3/s$ |

**MDLOTI ESTUARY**

**Date:** 16-Aug-02
**Weather:** Overcast, preceding days were cold and rainy
**Estuary State:** Open
**Tidal Situation:** between high and low (*The Kingfisher, Tide Timetable 2002*)
**Station Reference:** 3

Data Collected:

| Width (m) | Depth (m) | Time in seconds at depth (m): 0.3 | 0.2 | 0.1 | Surface | Velocity (m/s) | Area (m^2) | Velocity*Area (m3/s) | Comment |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | | | | | 0.000 | 0.00 | 0.000 | |
| 1 | 0.22 | | | | 16.5 | 0.606 | 0.11 | 0.067 | |
| 2 | 0.27 | | | | | 0.530 | 0.25 | 0.130 | |
| 3 | 0.18 | | | | 21.34 | 0.469 | 0.23 | 0.105 | |
| 4 | 0.11 | | | | | 0.400 | 0.15 | 0.058 | |
| 5 | 0.07 | | | | | 0.200 | 0.09 | 0.018 | |
| 6 | 0 | | | | | 0.000 | 0.04 | 0.000 | Sand |
| 9 | 0 | | | | | 0.000 | 0.00 | 0.000 | Bank |
| 10 | 0.07 | | | | | 0.550 | 0.04 | 0.019 | |
| 11 | 0.07 | | | | 18 | 0.556 | 0.07 | 0.039 | |
| 12 | 0.11 | | | | | 0.550 | 0.09 | 0.050 | |
| 13 | 0.11 | | | | 18.5 | 0.541 | 0.11 | 0.059 | |
| 14 | 0.24 | | | | | 0.630 | 0.18 | 0.110 | |
| 15 | 0.26 | | | 15 | 15 | 0.667 | 0.25 | 0.167 | |
| 16 | 0.27 | | | | | 0.650 | 0.27 | 0.172 | |
| 17 | 0.33 | | 16.81 | | 14 | 0.649 | 0.30 | 0.195 | |
| 18 | 0.44 | | | | | 0.640 | 0.39 | 0.246 | |
| 19 | 0.58 | 14.46 | 14.91 | | 18.53 | 0.626 | 0.51 | 0.319 | |
| 20 | 0.55 | | | | | 0.610 | 0.57 | 0.345 | |
| 21 | 0.59 | 17 | 16.5 | | 17.8 | 0.585 | 0.57 | 0.333 | |
| 22 | 0.52 | | | | | 0.586 | 0.56 | 0.325 | |
| 23 | 0.53 | 18 | | | 16 | 0.588 | 0.53 | 0.309 | |
| 24 | 0.52 | | | | | 0.610 | 0.53 | 0.320 | |
| 25 | 0.7 | | 15.5 | | 16.69 | 0.621 | 0.61 | 0.379 | |
| 26 | 0.59 | | | | | 0.630 | 0.65 | 0.406 | |
| 27 | 0.7 | | | | 15.5 | 0.645 | 0.65 | 0.416 | |
| 28 | 0.9 | | | | | 0.630 | 0.80 | 0.504 | |
| 29 | 0.9 | | | | 16.09 | 0.622 | 0.90 | 0.559 | Reeds |
| | | | | | | | 8.05 | 5.00 | |

| | | |
|---|---|---|
| Area = | 9.2810 | m2 |
| Av. Vel. = | 0.5139 | m/s |
| **Flow =** | 4.7697 | **m3/s** |

**Note: Paddling was difficult under these conditions**

**MDLOTI ESTUARY**

**Date:** 12-Sep-02
**Weather:** Sunny, clear, windy
**Estuary State:** Closed, full, high waves overtopping (spring tide)
**Station Reference:** 2

Data Collected:

| Width (m) | Depth (m) | Time in seconds at depth (m): | | | | Velocity (m/s) | Area (m^2) | Velocity*Area (m3/s) | Comment |
|---|---|---|---|---|---|---|---|---|---|
| | | 0.4 | 0.6 | 0.8 | Surface | | | | |
| 0 | 0.90 | | | | | 0.000 | 0.45 | 0.000 | Reeds |
| 4 | 1.00 | | | | | 0.000 | 3.80 | 0.000 | Reeds |
| 6 | 1.00 | | | | | 0.060 | 2.00 | 0.120 | |
| 8 | 1.00 | 84 | | | | 0.119 | 2.00 | 0.238 | |
| 10 | 1.20 | | | | | 0.110 | 2.20 | 0.242 | |
| 12 | 1.30 | | | | | 0.100 | 2.50 | 0.250 | |
| 14 | 1.40 | | | | | 0.090 | 2.70 | 0.243 | |
| 16 | 1.25 | 80 | 141 | 145 | | 0.088 | 2.65 | 0.234 | |
| 18 | 1.30 | | | | | 0.090 | 2.55 | 0.230 | |
| 20 | 1.35 | | | | | 0.100 | 2.65 | 0.265 | |
| 22 | 1.50 | | | | | 0.110 | 2.85 | 0.314 | |
| 24 | 1.00 | 88 | | | | 0.114 | 2.50 | 0.284 | |
| 26 | 1.00 | | | | | 0.060 | 2.00 | 0.120 | |
| 28 | 1.00 | | | | | 0.000 | 2.00 | 0.000 | Reeds |
| 30 | 1.00 | | | | | 0.000 | 2.00 | 0.000 | Reeds |
| | | | | | | | 34.85 | 2.54 | |

**Note: There was a subsurface cross current**

| | | |
|---|---|---|
| Area = | 32.5000 | $m^2$ |
| Av. Vel. = | 0.0694 | m/s |
| Flow = | 2.2555 | $m^3/s$ |

**MDLOTI ESTUARY**

**Date:** 12-Oct-02
**Weather:** Windy, clear
**Estuary State:** Closed
**Tidal Situation:** Between high and low (*The Kingfisher, Tide Timetable 2002*)
**Station Reference:** 2

Data Collected:

| Width (m) | Depth (m) | Time in seconds at | | Velocity | Comment |
|---|---|---|---|---|---|
| | | 0.8 | Surface | | |
| 0 | 0.19 | | | | |
| 1 | 1.15 | | | | |
| 2 | 1.71 | | | | |
| 3 | 1.74 | | | | |
| 4 | 1.64 | | | | |
| 5 | 1.62 | | | | |
| 6 | 1.61 | | | | |
| 7 | 1.56 | | | | |
| 8 | 1.56 | 140 | 93 | 0.0858369 | |
| 9 | 1.52 | | | | |
| 10 | 1.59 | | | | |
| 11 | 1.70 | 150 | | 0.0666667 | |
| 12 | 1.68 | 114 | | 0.0877193 | |
| 13 | 1.71 | | | | |
| 14 | 1.80 | | 120 | 0.0833333 | |
| 15 | 1.80 | | | | |
| 16 | 1.70 | 150 | 90 | 0.0833333 | |
| 17 | 1.42 | | | | |
| 18 | 1.47 | | | | |
| 19 | 1.45 | | | | |
| 20 | 1.52 | | | | |
| 21 | 1.55 | | | | |
| 22 | 1.60 | | | | |
| 23 | 1.61 | | | | Reeds |
| 24 | 1.67 | | | | Reeds |

**Note: There was a subsurface cross current**

| | | |
|---|---|---|
| Area = | 37.6467 | m2 |
| Av. Vel. = | 0.0814 | m/s |
| **Flow =** | **3.0636** | **m3/s** |

**MDLOTI ESTUARY**

**Date:** 19-Feb-03
**Weather:** Sunny, windy
**Estuary State:** Closed, previous position of mouth still lower than rest of berm
**Station Reference:** 2

Data Collected:

| | | Timing distance = 5 m | | | | Vel interpolated between measurements (zero in reeds) | | | |
|---|---|---|---|---|---|---|---|---|---|
| Width (m) | Depth (m) | Time in seconds at depth (m): | | | | Velocity (m/s) | Area (m2) | Velocity*Area (m3/s) | Comment |
| | | 0.3 | 0.6 | 0.8 | Surface | | | | |
| 0 | 0.60 | | | | | 0.000 | 0.300 | 0.000 | Reeds |
| 1 | 0.60 | | | | | 0.011 | 0.600 | 0.007 | Flow too low |
| 2 | 0.60 | | 220 | | | 0.023 | 0.600 | 0.014 | Little flow, wind |
| 3 | 0.58 | | 275 | | | 0.018 | 0.580 | 0.011 | |
| 4 | 0.57 | | | | | 0.026 | 0.565 | 0.015 | |
| 5 | 0.55 | | | | | 0.026 | 0.550 | 0.014 | |
| 6 | 0.58 | | 148 | | | 0.034 | 0.580 | 0.020 | |
| 7 | 0.63 | | 114 | | 206 | 0.044 | 0.630 | 0.028 | less wind |
| 8 | 0.67 | | | | | 0.036 | 0.670 | 0.024 | |
| 9 | 0.77 | | 173 | | | 0.029 | 0.770 | 0.022 | |
| 10 | 0.82 | | 179 | | | 0.028 | 0.820 | 0.023 | wind |
| 11 | 0.79 | | 139 | | | 0.036 | 0.790 | 0.028 | less wind |
| 12 | 0.82 | | | | | 0.000 | 0.820 | 0.000 | Reeds |
| 13 | 1.58 | | | | | 0.000 | 1.580 | 0.000 | Reeds |
| | | | | | | Sum = | 9.855 | 0.205 | |

| | | |
|---|---|---|
| Area = | 9.0650 | $m^2$ |
| Av. Vel. = | 0.0222 | m/s |
| Flow = | 0.2014 | $m^3/s$ |

**Mdloti**

**Location:** 1
**Mouth State:** Closed

| Section | Date | Time | Distance | Depth | Velocity | Unit | Comment | area | v.a |
|---|---|---|---|---|---|---|---|---|---|
| 8 | 19-Jun-03 | 11:05 | 0 | 0.33 | 0.127 | m | | 0.0825 | 0.010478 |
| 8 | 19-Jun-03 | 11:06 | 0.5 | 0.37 | 0.5 | m | | 0.2035 | 0.10175 |
| 8 | 19-Jun-03 | 11:03 | 1.1 | 0.37 | 0.424 | m | | 0.3145 | 0.133348 |
| 8 | 19-Jun-03 | 11:01 | 2.2 | 0.3 | 0.292 | m | | 0.165 | 0.04818 |
| | | | | | | | | **0.766** | **0.294** |

**Discharge (Swoffer)** **0.24**

**Discharge (Calculated)** **0.294**

**MDLOTI ESTUARY**

**Location:** 1
**Mouth State:** Closed

| Section | Date | Time | Distance | Depth | Velocity | Unit | Comment | area | v.a |
|---|---|---|---|---|---|---|---|---|---|
| 11 | 25-Jun-03 | 9:51 | 0 | 0.21 | 0 | m | | 0.02625 | 0 |
| 11 | 25-Jun-03 | 9:53 | 0.25 | 0.11 | 0.805 | m | | 0.0275 | 0.022138 |
| 11 | 25-Jun-03 | 9:55 | 0.5 | 0.37 | 0.478 | m | | 0.0925 | 0.044215 |
| 11 | 25-Jun-03 | 9:56 | 0.75 | 0.3 | 0.884 | m | | 0.075 | 0.0663 |
| 11 | 25-Jun-03 | 9:57 | 1 | 0.23 | 0.834 | m | | 0.0575 | 0.047955 |
| 11 | 25-Jun-03 | 9:58 | 1.25 | 0.3 | 0.69 | m | | 0.1125 | 0.077625 |
| 11 | 25-Jun-03 | 9:59 | 1.75 | 0.25 | 0 | m | | 0.0625 | 0 |
| | | | | | | | | **0.454** | **0.258** |

**Discharge (Swoffer)** **0.25**

**Discharge (Calculated)** **0.258**

**MDLOTI ESTUARY**

**Location:** 1
**Mouth State:** Closed

| Section | Date | Time | Distance | Depth | Velocity | Unit | Comment | area | v.a |
|---|---|---|---|---|---|---|---|---|---|
| 13 | 26-Jun-03 | 9:48 | 0 | 0.22 | 0.44 | m | | 0.055 | 0.0242 |
| 13 | 26-Jun-03 | 9:50 | 0.5 | 0.28 | 0.899 | m | | 0.105 | 0.0944 |
| 13 | 26-Jun-03 | 9:51 | 0.75 | 0.32 | 0.946 | m | | 0.08 | 0.0757 |
| 13 | 26-Jun-03 | 9:54 | 1 | 0.29 | 0.527 | m | | 0.0725 | 0.0382 |
| 13 | 26-Jun-03 | 9:55 | 1.25 | 0.34 | 0.695 | m | | 0.085 | 0.0591 |
| 13 | 26-Jun-03 | 9:56 | 1.5 | 0.34 | 0.776 | m | | 0.085 | 0.0660 |
| 13 | 26-Jun-03 | 9:57 | 1.75 | 0.54 | 0.517 | m | | 0.0675 | 0.0349 |
| | | | | | | | | **0.550** | **0.392** |

**Discharge (Swoffer)** **0.35**

**Discharge (Calculated)** **0.392**

**MDLOTI ESTUARY**

**Location:** 1
**Mouth State:** Closed

| Section | Date | Time | Distance | Depth | Velocity | Angle | Unit | Comment | area | v.a |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0 | 0 | 0 | | | Edge | 0 | 0 |
| 15 | 27-Jun-03 | 10:52 | 0.5 | 0.33 | 0.212 | 0 | m | | 0.165 | 0.03498 |
| 15 | 27-Jun-03 | 10:51 | 1 | 0.34 | 0.726 | 0 | m | | 0.1275 | 0.092565 |
| 15 | 27-Jun-03 | 10:53 | 1.25 | 0.31 | 0.679 | 0 | m | | 0.155 | 0.105245 |
| | | | 2 | 0.1 | 0 | | | Edge | 0.0375 | 0 |
| | | | | | | | | | **0.448** | **0.233** |

**Discharge (Swoffer)** **0.12** (Excludes edges)

**Discharge (Calculated)** **0.233**

**MDLOTI ESTUARY**

**Location:** 1
**Mouth State:** Closed

| Section | Date | Time | Distance | Depth | Velocity | Unit | Comment | area | v.a |
|---|---|---|---|---|---|---|---|---|---|
| 17 | 28-Jun-03 | 11:51 | 0 | 0.15 | 0 | m | | 0.0375 | 0 |
| 17 | 28-Jun-03 | 11:54 | 0.5 | 0.14 | 0.37 | m | | 0.0525 | 0.01943 |
| 17 | 28-Jun-03 | 11:56 | 0.75 | 0.25 | 0.958 | m | | 0.0625 | 0.05988 |
| 17 | 28-Jun-03 | 11:57 | 1 | 0.4 | 0.662 | m | | 0.1 | 0.06620 |
| 17 | 28-Jun-03 | 11:58 | 1.25 | 0.22 | 0.484 | m | | 0.055 | 0.02662 |
| 17 | 28-Jun-03 | 11:59 | 1.5 | 0.25 | 0.848 | m | | 0.09375 | 0.07950 |
| 17 | 28-Jun-03 | 12:01 | 2 | 0.18 | 0.887 | m | | 0.0675 | 0.05987 |
| 17 | 28-Jun-03 | 12:01 | 2.25 | 0.25 | 0 | m | | 0.03125 | 0 |
| | | | | | | | | **0.500** | **0.311** |

**Discharge (Swoffer)** **0.31**

**Discharge (Calculated)** **0.311**

**MDLOTI ESTUARY**

**Location:** 1
**Mouth State:** Closed

| Section | Date | Time | Distance | Depth | Velocity | Unit | Comment | area | v.a |
|---|---|---|---|---|---|---|---|---|---|
| 19 | 29-Jun-03 | 11:06 | 0.25 | 0.25 | 0 | m | | 0.03125 | 0 |
| 19 | 29-Jun-03 | 11:07 | 0.5 | 0.36 | 0.731 | m | | 0.09 | 0.06579 |
| 19 | 29-Jun-03 | 11:09 | 0.75 | 0.37 | 0.964 | m | | 0.0925 | 0.08917 |
| 19 | 29-Jun-03 | 11:10 | 1 | 0.39 | 0.941 | m | | 0.14625 | 0.137621 |
| 19 | 29-Jun-03 | 11:12 | 1.5 | 0.34 | 0.832 | m | | 0.17 | 0.14144 |
| 19 | 29-Jun-03 | 11:13 | 2 | 0.25 | 0.889 | m | | 0.125 | 0.111125 |
| 19 | 29-Jun-03 | 11:13 | 2.5 | 0.3 | 0 | m | | 0.075 | 0 |
| | | | | | | | | **0.730** | **0.545** |

**Discharge (Swoffer)** **0.54**

**Discharge (Calculated)** **0.545**

**MDLOTI ESTUARY**

**Location:** 1
**Mouth State:** Closed

| Section | Date | Time | Distance | Depth | Velocity | Unit | Comment | area | v.a |
|---|---|---|---|---|---|---|---|---|---|
| 20 | 30-Jun-03 | 9:05 | 0 | 0.23 | 0 | m | bank | 0.0575 | 0 |
| 20 | 30-Jun-03 | 8:56 | 0.5 | 0.26 | 0.96 | m | | 0.0975 | 0.0936 |
| 20 | 30-Jun-03 | 8:57 | 0.75 | 0.37 | 0.487 | m | | 0.0925 | 0.045048 |
| 20 | 30-Jun-03 | 8:59 | 1 | 0.255 | 0.7 | m | | 0.06375 | 0.044625 |
| 20 | 30-Jun-03 | 9:00 | 1.25 | 0.33 | 0.933 | m | | 0.0825 | 0.076973 |
| 20 | 30-Jun-03 | 9:02 | 1.5 | 0.32 | 0.597 | m | | 0.12 | 0.07164 |
| 20 | 30-Jun-03 | 9:03 | 2 | 0.2 | 0.907 | m | | 0.075 | 0.068025 |
| 20 | 30-Jun-03 | 9:04 | 2.25 | 0.18 | 0 | m | reeds | 0.0225 | 0 |
| | | | | | | | | **0.611** | **0.400** |

**Discharge (Swoffer)** **0.39**

**Discharge (Calculated)** **0.400**

**MDLOTI ESTUARY**

**Location:** 1
**Mouth State:** Closed

| Section | Date | Time | Distance | Depth | Velocity | Unit | Comment | area | v.a |
|---|---|---|---|---|---|---|---|---|---|
| 22 | 1-JUL-03 | 8:53 | 0 | 0.205 | 0 | m | Bank | 0.025625 | 0 |
| 22 | 1-JUL-03 | 8:54 | 0.25 | 0.305 | 0.181 | m | | 0.07625 | 0.013801 |
| 22 | 1-JUL-03 | 8:55 | 0.5 | 0.29 | 0.132 | m | | 0.0725 | 0.00957 |
| 22 | 1-JUL-03 | 8:56 | 0.75 | 0.34 | 0.305 | m | | 0.085 | 0.025925 |
| 22 | 1-JUL-03 | 8:57 | 1 | 0.36 | 0.405 | m | | 0.09 | 0.03645 |
| 22 | 1-JUL-03 | 8:58 | 1.25 | 0.295 | 0.47 | m | | 0.07375 | 0.034663 |
| 22 | 1-JUL-03 | 8:59 | 1.5 | 0.26 | 0.198 | m | | 0.065 | 0.01287 |
| 22 | 1-JUL-03 | 9:00 | 1.75 | 0.35 | 0.601 | m | | 0.0875 | 0.052588 |
| 22 | 1-JUL-03 | 9:01 | 2 | 0.29 | 0.245 | m | | 0.0725 | 0.017763 |
| 22 | 1-JUL-03 | 9:02 | 2.25 | 0.43 | 0.405 | m | | 0.1075 | 0.043538 |
| 22 | 1-JUL-03 | 9:03 | 2.5 | 0.25 | 0 | m | Reeds | 0.03125 | 0 |
| | | | | | | | | **0.787** | **0.247** |

**Discharge (Swoffer)** **0.24**

**Discharge (Calculated)** **0.247**

**MDLOTI ESTUARY**

**Location:** 1
**Mouth State:** Closed

| Section | Date | Time | Distance | Depth | Velocity | Unit | Comment | area | va |
|---|---|---|---|---|---|---|---|---|---|
| 24 | 2-JUL-03 | 8:59 | 0 | 0.16 | 0 | m | | 0.02 | 0 |
| 24 | 2-JUL-03 | 9:00 | 0.25 | 0.35 | 0.532 | m | | 0.0875 | 0.04655 |
| 24 | 2-JUL-03 | 9:01 | 0.5 | 0.3 | 0.624 | m | | 0.075 | 0.0468 |
| 24 | 2-JUL-03 | 9:02 | 0.75 | 0.37 | 0.292 | m | | 0.0925 | 0.02701 |
| 24 | 2-JUL-03 | 9:03 | 1 | 0.33 | 0.255 | m | | 0.0825 | 0.021038 |
| 24 | 2-JUL-03 | 9:04 | 1.25 | 0.3 | 0.584 | m | | 0.075 | 0.0438 |
| 24 | 2-JUL-03 | 9:05 | 1.5 | 0.35 | 0.509 | m | | 0.0875 | 0.044538 |
| 24 | 2-JUL-03 | 9:06 | 1.75 | 0.4 | 0.472 | m | | 0.1 | 0.0472 |
| 24 | 2-JUL-03 | 9:07 | 2 | 0.1 | 0 | m | | 0.0125 | 0 |
| | | | | | | | | **0.633** | **0.277** |

**Discharge (Swoffer)** **0.27**

**Discharge (Calculated)** **0.277**

**MDLOTI ESTUARY**

**Location:** 1
**Mouth State:** Closed

| Section | Date | Time | Distance | Depth | Velocity | Unit | Comment | area | v.a |
|---|---|---|---|---|---|---|---|---|---|
| 26 | 3-JUL-03 | 9:26 | 0 | 0.26 | 0 | m | | 0.0325 | 0 |
| 26 | 3-JUL-03 | 9:27 | 0.25 | 0.195 | 0.244 | m | | 0.04875 | 0.011895 |
| 26 | 3-JUL-03 | 9:28 | 0.5 | 0.34 | 0.281 | m | | 0.085 | 0.023885 |
| 26 | 3-JUL-03 | 9:29 | 0.75 | 0.29 | 0.359 | m | | 0.0725 | 0.026028 |
| 26 | 3-JUL-03 | 9:30 | 1 | 0.25 | 0.455 | m | | 0.0625 | 0.028438 |
| 26 | 3-JUL-03 | 9:30 | 1.25 | 0.31 | 0.512 | m | | 0.0775 | 0.03968 |
| 26 | 3-JUL-03 | 9:31 | 1.5 | 0.28 | 0.391 | m | | 0.07 | 0.02737 |
| 26 | 3-JUL-03 | 9:32 | 1.75 | 0.4 | 0.354 | m | | 0.1 | 0.0354 |
| 26 | 3-JUL-03 | 9:33 | 2 | 0.31 | 0.256 | m | | 0.0775 | 0.01984 |
| 26 | 3-JUL-03 | 9:34 | 2.25 | 0.33 | 0.493 | m | | 0.0825 | 0.040673 |
| 26 | 3-JUL-03 | 9:35 | 2.5 | 0.2 | 0 | m | | 0.025 | 0 |
| | | | | | | | | **0.734** | **0.253** |

**Discharge (Swoffer)** **0.25**

**Discharge (Calculated)** **0.253**

**MDLOTI ESTUARY**

**Location:** 1
**Mouth State:** Closed

| Section | Date | Time | Distance | Depth | Velocity | Unit | Comment | area | v.a |
|---|---|---|---|---|---|---|---|---|---|
| 28 | 4-JUL-03 | 10:09 | 0 | 0.31 | 0.212 | m | | 0.03875 | 0.00822 |
| 28 | 4-JUL-03 | 10:10 | 0.25 | 0.35 | 0.179 | m | | 0.0875 | 0.01566 |
| 28 | 4-JUL-03 | 10:11 | 0.5 | 0.36 | 0.393 | m | | 0.09 | 0.03537 |
| 28 | 4-JUL-03 | 10:12 | 0.75 | 0.25 | 0.443 | m | | 0.0625 | 0.02769 |
| 28 | 4-JUL-03 | 10:13 | 1 | 0.31 | 0.492 | m | | 0.11625 | 0.05720 |
| 28 | 4-JUL-03 | 10:15 | 1.5 | 0.4 | 0.623 | m | | 0.15 | 0.09345 |
| 28 | 4-JUL-03 | 10:16 | 1.75 | 0.37 | 0.328 | m | | 0.0925 | 0.03034 |
| 28 | 4-JUL-03 | 10:17 | 2 | 0.45 | 0.429 | m | | 0.05625 | 0.02413 |
| | | | | | | | | **0.694** | **0.292** |

**Discharge (Swoffer)** **0.26**

**Discharge (Calculated)** **0.292**

**MDLOTI ESTUARY**

**Location:** 1
**Mouth State:** Closed

| Section | Date | Time | Distance | Depth | Velocity | Unit | Comment | area | v.a |
|---|---|---|---|---|---|---|---|---|---|
| 30 | 5-JUL-03 | 10:50 | 0 | 0.3 | 0.245 | m | | 0.0375 | 0.00919 |
| 30 | 5-JUL-03 | 10:51 | 0.25 | 0.31 | 0.289 | m | | 0.0775 | 0.02240 |
| 30 | 5-JUL-03 | 10:52 | 0.5 | 0.38 | 0.367 | m | | 0.095 | 0.03487 |
| 30 | 5-JUL-03 | 10:53 | 0.75 | 0.31 | 0.342 | m | | 0.0775 | 0.02651 |
| 30 | 5-JUL-03 | 10:54 | 1 | 0.33 | 0.45 | m | | 0.12375 | 0.05569 |
| 30 | 5-JUL-03 | 10:56 | 1.5 | 0.32 | 0.429 | m | | 0.12 | 0.05148 |
| 30 | 5-JUL-03 | 10:57 | 1.75 | 0.35 | 0.426 | m | | 0.0875 | 0.03728 |
| 30 | 5-JUL-03 | 10:57 | 2 | 0.25 | 0 | m | | 0.03125 | 0 |
| | | | | | | | | **0.650** | **0.237** |

**Discharge (Swoffer)** **0.23**

**Discharge (Calculated)** **0.237**

**MDLOTI ESTUARY**

**Location:** 1
**Mouth State:** Closed

| Section | Date | Time | Distance | Depth | Velocity | Unit | Comment | area | v.a |
|---|---|---|---|---|---|---|---|---|---|
| 32 | 6-JUL-03 | 11:10 | 0 | 0.15 | 0 | m | | 0.01875 | 0 |
| 32 | 6-JUL-03 | 11:10 | 0.25 | 0.37 | 0.353 | m | | 0.0925 | 0.032653 |
| 32 | 6-JUL-03 | 11:11 | 0.5 | 0.41 | 0.436 | m | | 0.1025 | 0.04469 |
| 32 | 6-JUL-03 | 11:12 | 0.75 | 0.45 | 0.498 | m | | 0.1125 | 0.056025 |
| 32 | 6-JUL-03 | 11:13 | 1 | 0.44 | 0.529 | m | | 0.165 | 0.087285 |
| 32 | 6-JUL-03 | 11:14 | 1.5 | 0.37 | 0.774 | m | | 0.13875 | 0.107393 |
| 32 | 6-JUL-03 | 11:15 | 1.75 | 0.52 | 0.597 | m | | 0.13 | 0.07761 |
| 32 | 6-JUL-03 | 11:16 | 2 | 0.5 | 0.526 | m | | 0.125 | 0.06575 |
| 32 | 6-JUL-03 | 11:17 | 2.25 | 0.2 | 0 | m | | 0.025 | 0 |
| | | | | | | | | **0.910** | **0.471** |

**Discharge (Swoffer)** **0.47**

**Discharge (Calculated)** **0.471**

**MDLOTI ESTUARY**

**Location:** 1
**Mouth State:** Closed

| Section | Date | Time | Distance | Depth | Velocity | Unit | Comment | area | v.a |
|---|---|---|---|---|---|---|---|---|---|
| 34 | 7-JUL-03 | 12:32 | 0 | 0.15 | 0 | m | | 0.01875 | 0 |
| 34 | 7-JUL-03 | 12:33 | 0.25 | 0.36 | 0.413 | m | | 0.09 | 0.03717 |
| 34 | 7-JUL-03 | 12:34 | 0.5 | 0.38 | 0.477 | m | | 0.095 | 0.045315 |
| 34 | 7-JUL-03 | 12:35 | 0.75 | 0.3 | 0.58 | m | | 0.075 | 0.0435 |
| 34 | 7-JUL-03 | 12:36 | 1 | 0.26 | 0.71 | m | | 0.0975 | 0.069225 |
| 34 | 7-JUL-03 | 12:37 | 1.5 | 0.36 | 0.775 | m | | 0.135 | 0.104625 |
| 34 | 7-JUL-03 | 12:37 | 1.75 | 0.4 | 0.564 | m | | 0.1 | 0.0564 |
| 34 | 7-JUL-03 | 12:38 | 2 | 0.48 | 0.537 | m | | 0.12 | 0.06444 |
| 34 | 7-JUL-03 | 12:39 | 2.25 | 0.2 | 0 | m | | 0.025 | 0 |
| | | | | | | | | **0.756** | **0.421** |

**Discharge (Swoffer)** **0.42**

**Discharge (Calculated)** **0.421**

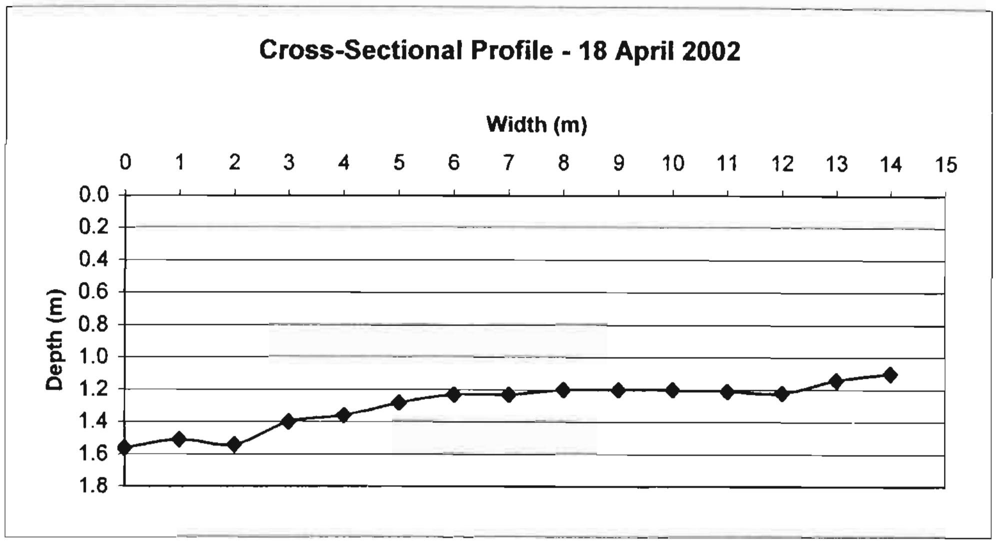
**MDLOTI ESTUARY**

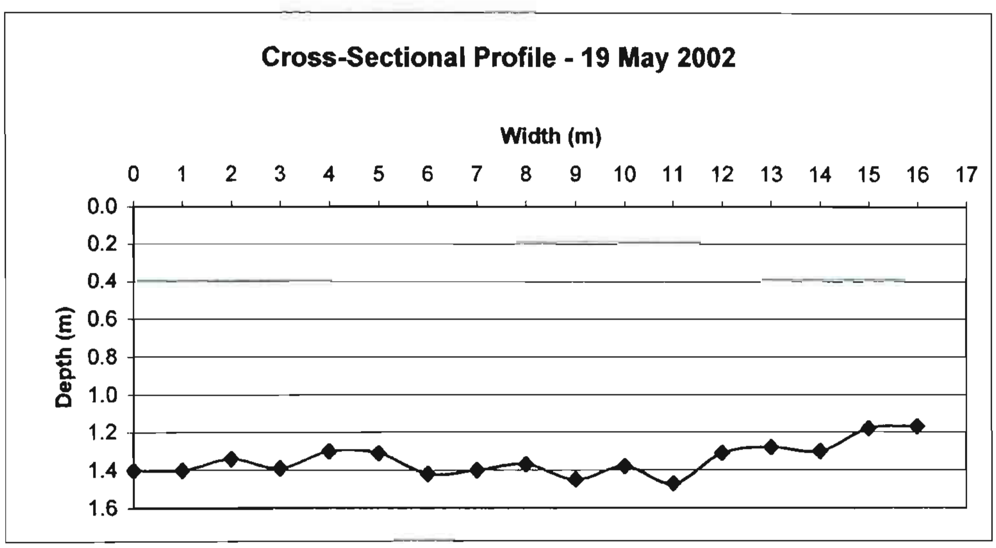
**Location:** 1
**Mouth State:** Closed

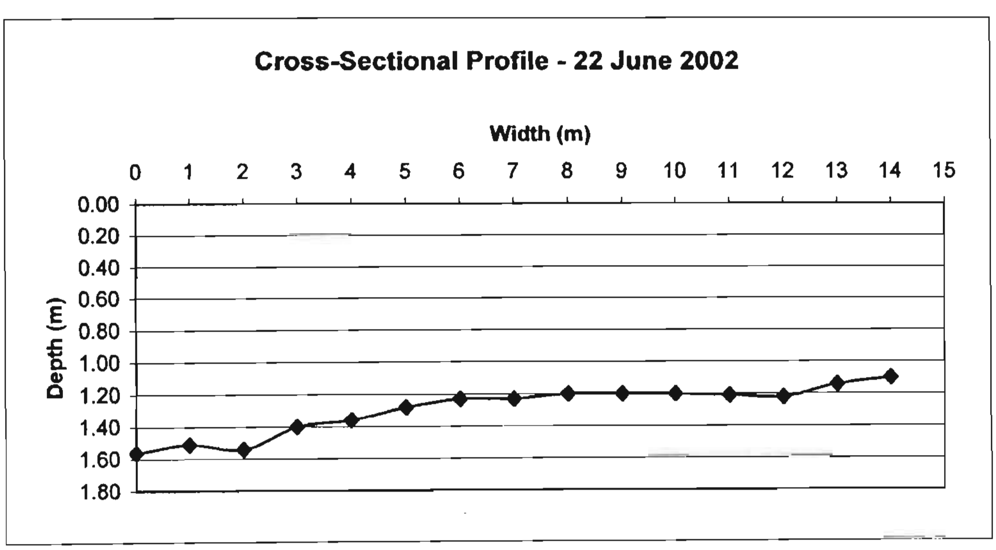
| Section | Date | Time | Distance | Depth | Velocity | Unit | Comment | area | v.a |
|---|---|---|---|---|---|---|---|---|---|
| 36 | 8-JUL-03 | 13:20 | 0 | 0.25 | 0 | m | | 0.03125 | 0 |
| 36 | 8-JUL-03 | 13:21 | 0.25 | 0.3 | 0.371 | m | | 0.075 | 0.027825 |
| 36 | 8-JUL-03 | 13:22 | 0.5 | 0.35 | 0.408 | m | | 0.0875 | 0.0357 |
| 36 | 8-JUL-03 | 13:22 | 0.75 | 0.25 | 0.515 | m | | 0.0625 | 0.032188 |
| 36 | 8-JUL-03 | 13:23 | 1 | 0.22 | 0.676 | m | | 0.0825 | 0.05577 |
| 36 | 8-JUL-03 | 13:24 | 1.5 | 0.33 | 0.715 | m | | 0.12375 | 0.088481 |
| 36 | 8-JUL-03 | 13:25 | 1.75 | 0.4 | 0.449 | m | | 0.1 | 0.0449 |
| 36 | 8-JUL-03 | 13:26 | 2 | 0.38 | 0.497 | m | | 0.095 | 0.047215 |
| 36 | 8-JUL-03 | 13:26 | 2.25 | 0.2 | 0 | m | | 0.025 | 0 |
| | | | | | | | | **0.683** | **0.332** |

**Discharge (Swoffer)** **0.33**

**Discharge (Calculated)** **0.332**


Cross-Sectional Profile - 18 April 2002
Width (m)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Depth (m)
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8


Cross-Sectional Profile - 19 May 2002
Width (m)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Depth (m)
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6


Cross-Sectional Profile - 22 June 2002
Width (m)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Depth (m)
0.00 0.20 0.40 0.60 0.80 1.00 1.20 1.40 1.60 1.80

**MHLANGA ESTUARY - Data obtained from digital photography.**
**Beam Height (b) = 930 mm**
**Column Height (H) = 2970 mm**
Height of Column above the water = h
Height of water above pile cap = H-h
Height below pc when empty = He

Height of pile cap above MSL = 1274

| Date | Time | $b_x$ (pixels) | $h_x$ (pixels) | $h_e$ (pixels) | $h=b*h_x/b_x$ (mm) | H-h (mm) | $H_e$ | Above MSL mm |
|---|---|---|---|---|---|---|---|---|
| 11-Apr-02 | | 92 | 130 | | 1314 | 1656 | | 2930 |
| May-02 | | 75 | 132 | | 1637 | 1333 | | 2607 |
| 22-Jun-02 | 12:18 | 21 | 48 | | 2126 | 844 | | 2118 |
| 14-Jul-02 | 13:43 | 81 | 295 | | 3387 | -417 | | 857 |
| 16-Aug-02 | 13:25 | 31 | 84 | | 2520 | 450 | | 1724 |
| 16-Aug-02 | 16:15 | 89 | 265 | | 2769 | 201 | | 1475 |
| 30-Aug-02 | 11:55 | 172 | 600 | | 3244 | -274 | | 1000 |
| 4-Sep-02 | 10:02 | 46 | 125 | | 2527 | 443 | | 1717 |
| 13-Sep-02 | | 38 | 69 | | 1689 | 1281 | | 2555 |
| 20-Sep-02 | 12:57 | 58 | 206 | | 3303 | -333 | | 941 |
| 27-Sep-02 | 12:15 | 29 | 52 | | 1668 | 1302 | | 2576 |
| 5-Oct-02 | 10:55 | 24 | 59 | | 2286 | 684 | | 1958 |
| 15-Oct-02 | 9:24 | 65 | 97 | | 1388 | 1582 | | 2856 |
| 31-Oct-02 | 10:00 | 121 | 220 | | 1691 | 1279 | | 2553 |
| 30-Dec-02 | 16:20 | 103 | 348 | | 3142 | -172 | | 1102 |
| 2-Jan-03 | 14:26 | 55 | 198 | | 3348 | -378 | | 896 |
| 8-Feb-03 | 15:56 | 81 | 232 | | 2664 | 306 | | 1580 |
| 14-Feb-03 | 11:55 | 82 | 230 | | 2609 | 361 | | 1635 |
| 19-Feb-03 | 12:07 | 55 | 156 | | 2638 | 332 | | 1606 |
| 7-Mar-03 | 7:35 | 121 | 243 | | 1868 | 1102 | | 2376 |
| 14-Mar-03 | 7:42 | 74 | 145 | | 1822 | 1148 | | 2422 |
| 21-Mar-03 | 14:53 | 131 | 504 | 66 | 3578 | -608 | | 666 |
| 25-Mar-03 | 10:42 | 67 | 201 | | 2790 | 180 | | 1454 |
| 2-Apr-03 | 16:18 | 48 | 125 | | 2422 | 548 | | 1822 |
| 16-Apr-03 | 12:30 | 282 | 438 | | 1444 | 1526 | | 2800 |
| 29-Apr-03 | 9:59 | 80 | 121 | | 1407 | 1563 | | 2837 |
| 7-May-03 | 12:19 | 138 | 213 | | 1435 | 1535 | | 2809 |
| 13-May-03 | 10:24 | 160 | 239 | | 1389 | 1581 | | 2855 |
| 23-May-03 | 10:33 | 139 | 496 | 66 | 3319 | -349 | | 925 |
| 24-May-03 | 9:49 | 24 | 86 | 9 | 3333 | -363 | | 912 |
| 26-May-03 | 11:37 | 48 | 162 | 11 | 3139 | -169 | | 1105 |
| 30-May-03 | 9.52 | 217 | 545 | | 2336 | 634 | | 1908 |
| 30-May-03 | 10:03 | 126 | 307 | | 2266 | 704 | | 1978 |
| 6-Jun-03 | 10:46 | 259 | 515 | | 1849 | 1121 | | 2395 |
| 14-Jun-03 | 8:25 | 215 | 386 | | 1670 | 1300 | | 2574 |
| 19-Jun-03 | 11:48 | 39 | 70 | | 1669 | 1301 | | 2575 |
| 25-Jun-03 | 7:52 | 55 | 93 | | 1573 | 1397 | | 2671 |
| 26-Jun-03 | 7:16 | 41 | 63 | | 1429 | 1541 | | 2815 |
| 27-Jun-03 | 9:14 | 33 | | 13 | | | -366 | 908 |
| 28-Jun-03 | 7:56 | 21 | 77 | | 3410 | -440 | | 834 |
| 28-Jun-03 | 9:53 | 130 | | 73 | | | -522 | 752 |
| 29-Jun-03 | 9:03 | 31 | | 9 | | | -270 | 1004 |
| 29-Jun-03 | 10:24 | 43 | | 19 | | | -411 | 863 |
| 29-Jun-03 | 15:18 | 183 | | 16 | | | -81 | 1193 |
| 30-Jun-03 | 10:29 | 36 | 105 | | 2713 | 258 | | 1532 |
| 1-Jul-03 | 10:52 | 69 | 164 | | 2210 | 760 | | 2034 |
| 2-Jul-03 | 10:45 | 36 | 82 | | 2118 | 852 | | 2126 |
| 3-Jul-03 | 11:19 | 29 | 69 | | 2213 | 757 | | 2031 |
| 4-Jul-03 | 11:53 | 57 | 137 | | 2235 | 735 | | 2009 |
| 5-Jul-03 | 12:57 | 105 | 227 | | 2011 | 959 | | 2233 |
| 6-Jul-03 | 13:08 | 54 | 115 | | 1981 | 989 | | 2263 |
| 7-Jul-03 | 13:06 | 286 | 577 | | 1876 | 1094 | | 2368 |
| 8-Jul-03 | 13:54 | 255 | 509 | | 1856 | 1114 | | 2388 |
| 15-Jul-03 | 11:35 | | | | | 1345 | | 2619 |
| 16-Jul-03 | 12:02 | 192 | 326 | | 1579 | 1391 | | 2665 |
| 18-Jul-03 | 9:04 | 160 | 264 | | 1535 | 1436 | | 2710 |
| 21-Jul-03 | 11:18 | 145 | 231 | | 1482 | 1488 | | 2762 |
| 26-Jul-03 | 15:28 | 351 | 537 | | 1423 | 1547 | | 2821 |

MIN = 666
MAX = 2930

**MDLOTI ESTUARY - Data obtained from digital photography**
**Beam Height (b) = 880 mm**
**Column Height (H) = 3640 mm** 3850
Height of Column above the water = h
Height of water above pile cap = H-h

Height of pile cap above MSL = 962

| Date | Time | $b_x$ (pixels) | $h_x$ (pixels) | $h=b*h_x/b_x$ (mm) | H-h (mm) | Above MSL mm |
|---|---|---|---|---|---|---|
| 18-May-02 | | 36 | 90 | 2200 | 1440 | 2402 |
| 22-Jun-02 | 8:22 | 9 | 17 | 1662 | 1978 | 2940 |
| 14-Jul-02 | 7:48 | 142 | 289 | 1791 | 1849 | 2811 |
| 16-Aug-02 | 11:18 | 12 | 37 | 2713 | 927 | 1889 |
| 30-Aug-02 | 11:02 | 16 | 56 | 3080 | 560 | 1522 |
| 4-Sep-02 | 9:29 | 26 | 113 | 3825 | -185 | 777 |
| 12-Sep-02 | | 31 | 91 | 2583 | 1057 | 2019 |
| 20-Sep-02 | 11:53 | 13 | 20 | 1354 | 2286 | 3248 |
| 5-Oct-02 | 10:06 | 20 | 47 | 2068 | 1572 | 2534 |
| 12-Oct-02 | 9:24 | 68 | 111 | 1436 | 2204 | 3166 |
| 15-Oct-02 | 11:28 | 20 | 30 | 1320 | 2320 | 3282 |
| 31-Oct-02 | 9:36 | 11 | 20 | 1600 | 2040 | 3002 |
| 8-Feb-03 | 15:34 | 30 | 78 | 2288 | 1352 | 2314 |
| 14-Feb-03 | 11:09 | 21 | 54 | 2263 | 1377 | 2339 |
| 19-Feb-03 | 9:23 | 41 | 117 | 2511 | 1129 | 2091 |
| 7-Mar-03 | 7:14 | 21 | 59 | 2472 | 1168 | 2130 |
| 14-Mar-03 | 7:20 | 21 | 48 | 2011 | 1629 | 2591 |
| 25-Mar-03 | 8:47 | 48 | 102 | 1870 | 1770 | 2732 |
| 2-Apr-03 | 15:33 | 22 | 46 | 1840 | 1800 | 2762 |
| 16-Apr-03 | 11:59 | 27 | 54 | 1760 | 1880 | 2842 |
| 29-Apr-03 | 9:44 | 85 | 215 | 2226 | 1414 | 2376 |
| 7-May-03 | 10:04 | 79 | 197 | 2194 | 1446 | 2408 |
| 13-May-03 | 10:07 | 136 | 327 | 2116 | 1524 | 2486 |
| 23-May-03 | 10:07 | 197 | 493 | 2202 | 1438 | 2400 |
| 30-May-03 | 9:24 | 133 | 324 | 2144 | 1496 | 2458 |
| 6-Jun-03 | 10.24 | 182 | 432 | 2089 | 1551 | 2513 |
| 14-Jun-03 | 12:40 | 194 | 437 | 1982 | 1658 | 2620 |
| 19-Jun-03 | 11:28 | 217 | 499 | 2024 | 1616 | 2578 |
| 25-Jun-03 | 9:31 | 257 | 571 | 1955 | 1685 | 2647 |
| 26-Jun-03 | 9:27 | 241 | 525 | 1917 | 1723 | 2685 |
| 27-Jun-03 | 10:28 | 233 | 517 | 1953 | 1687 | 2649 |
| 28-Jun-03 | 12:22 | 203 | 457 | 1981 | 1659 | 2621 |
| 29-Jun-03 | 10:47 | 147 | 346 | 2071 | 1569 | 2531 |
| 30-Jun-03 | 9:24 | 213 | 562 | 2322 | 1318 | 2280 |
| 1-Jul-03 | 9:22 | 260 | 568 | 1922 | 1718 | 2680 |
| 2-Jul-03 | 9:24 | 255 | 566 | 1953 | 1687 | 2649 |
| 3-Jul-03 | 9:54 | 202 | 554 | 2413 | 1227 | 2189 |
| 4-Jul-03 | 9:47 | 211 | 467 | 1948 | 1692 | 2654 |
| 5-Jul-03 | 11:15 | 238 | 560 | 2071 | 1569 | 2531 |
| 6-Jul-03 | 11:36 | 249 | 556 | 1965 | 1675 | 2637 |
| 7-Jul-03 | 12:56 | 214 | 471 | 1937 | 1703 | 2665 |
| 8-Jul-03 | 13:43 | 235 | 559 | 2093 | 1547 | 2509 |
| 15-Jul-03 | 9:35 | | | | 1593 | 2555 |
| 21-Jul-03 | 12:17 | 200 | 447 | 1967 | 1673 | 2635 |

MIN = 777
MAX = 3282

# APPENDIX G: WATER LEVEL DATA

| Dates (Inclusive) | | No. of days | State | Rainfall during period (mm) | Tidal Situation at the end of the period |
|---|---|---|---|---|---|
| From | To | | | | |
| 11-Nov-02 | 14-Nov-02 | 4 | Partly Open | 25.6 | 2 days after neap |
| 15-Nov-02 | 16-Nov-02 | 2 | Open | 6.4 | 4 days after neap |
| 17-Nov-02 | 20-Nov-02 | 4 | Closed | 0 | Spring |
| 21-Nov-02 | 30-Nov-02 | 10 | No data | 5 | n/a |
| 1-Dec-02 | 6-Dec-02 | 6 | Closed | 23.8 | 2 days after spring |
| 7-Dec-02 | 14-Dec-02 | 8 | Open | 17.2 | 2 days after neap |
| 15-Dec-02 | 16-Dec-02 | 2 | Partly Open | 0.4 | 4 days after neap |
| 17-Dec-02 | 20-Dec-02 | 4 | Closed | 13.8 | Spring |
| 21-Dec-02 | 30-Dec-02 | 10 | No data | 21.4 | n/a |
| 31-Dec-02 | 31-Dec-02 | 1 | Closed | 0 | 3 days after neap |
| 1-Jan-03 | 1-Jan-03 | 1 | Partly Open | 0 | 4 days after neap |
| 2-Jan-03 | 2-Jan-03 | 1 | Open | 0 | 5 days after neap |
| 3-Jan-03 | 8-Jan-03 | 6 | Closed | 35.6 | 4 days before spring |
| 9-Jan-03 | 15-Jan-03 | 7 | Open | 13.8 | 3 days after spring |
| 16-Jan-03 | 16-Jan-03 | 1 | Closed | 0.4 | 4 days after spring |
| 17-Jan-03 | 7-Feb-03 | 22 | Open | 51.2 | 3 days after spring |
| 8-Feb-03 | 8-Feb-03 | 1 | Closed | 0 | 4 days before neap |
| 9-Feb-03 | 9-Feb-03 | 45 | Partly Open | 0 | 3 days before neap |
| 10-Feb-03 | 11-Feb-03 | 2 | Closed | 0 | 1 day before neap |
| 12-Feb-03 | 17-Feb-03 | 6 | Partly Open | 0 | 2 days before spring |
| 18-Feb-03 | 26-Feb-03 | 9 | Closed | 15.6 | Neap |
| 27-Feb-03 | 28-Feb-03 | 2 | Open | 0 | 2 days after neap |
| 1-Mar-03 | 21-Mar-03 | 21 | Closed | 70 | 1 day after spring |
| 22-Mar-03 | 25-Mar-03 | 4 | Open | 1.8 | 1 day before neap |
| 26-Mar-03 | 27-Mar-03 | 2 | Closed | 0.2 | 1 day after neap |
| 28-Mar-03 | 28-Mar-03 | 1 | Open | 0 | 2 days after neap |
| 29-Mar-03 | 23-May-03 | 56 | Closed | 50 | Neap |
| 24-May-03 | 28-May-03 | 5 | Open | 0 | 5 days after neap |
| 29-May-03 | 25-Jun-03 | 28 | Closed | 21.8 | 2 days after neap |
| 26-Jun-03 | 29-Jun-03 | 4 | Open | 0.8 | 3 days before spring |
| 30-Jun-03 | 30-Jun-03 | 1 | Partly Open | 0 | 2 days before spring |
| 1-Jul-03 | 26-Jul-03 | 26 | Closed | 0.4 | 3 days after neap |
| 27-Jul-03 | 31-Jul-03 | 5** | Open | 0 | |

* the data only begins on the 1 March 2002, therefore the estuary may have been open for several days before.

** The data collected by KZN Wildlife was only available up to the 27 June 2003, the data up to the end of July 2003 was obtained from the water level monitor in conjunction with visual observations.

**The table represents the state of Mhlanga estuary relative to the rainfall and relevant tidal situation.**

| Dates (Inclusive) | | No. of days | State | Rainfall during period (mm) | Tidal Situation at the end of the period |
|---|---|---|---|---|---|
| From | To | | | | |
| 1-Mar-02 | 7-Mar-02 | 7* | Open | 26.8 | Neap |
| 8-Mar-02 | 10-Mar-02 | 3 | Partly Open | 3 | 3 days after neap |
| 11-Mar-02 | 10-Apr-02 | 31 | Closed | 25.8 | 5 days after neap |
| 11-Apr-02 | 12-Apr-02 | 2 | Open | 6 | 1 day before spring |
| 13-Apr-02 | 17-Apr-02 | 5 | Partly Open | 81.4 | 4 days after spring |
| 18-Apr-02 | 22-Apr-02 | 5 | Open | 0 | 1 day after neap |
| 23-Apr-02 | 23-Apr-02 | 1 | Partly Open | 0 | 2 days after neap |
| 24-Apr-02 | 26-Apr-02 | 3 | No data | 15.8 | n/a |
| 27-Apr-02 | 11-May-02 | 15 | Open | 9.4 | 2 days before spring |
| 12-May-02 | 20-May-02 | 9 | Closed | 0 | Neap |
| 21-May-02 | 22-May-02 | 2 | Open | 0 | 2 days after neap |
| 23-May-02 | 24-May-02 | 2 | Partly Open | 0 | 4 days after neap |
| 25-May-02 | 7-Jun-02 | 14 | Closed | 0.4 | 4 days after neap |
| 8-Jun-02 | 10-Jun-02 | 3 | Partly Open | 0 | 1 day before spring |
| 11-Jun-02 | 14-Jun-02 | 4 | Closed | 8.8 | 3 days after spring |
| 15-Jun-02 | 16-Jun-02 | 2 | Open | 0 | 5 days after spring |
| 17-Jun-02 | 20-Jun-02 | 4 | Partly Open | 0 | 2 days after neap |
| 21-Jun-02 | 2-Jul-02 | 12 | Closed | 0.2 | 1 day before neap |
| 3-Jul-02 | 6-Jul-02 | 4 | Open | 0 | 3 days after neap |
| 7-Jul-02 | 7-Jul-02 | 1 | Partly Open | 0 | 4 days after neap |
| 8-Jul-02 | 31-Jul-02 | 24 | Open | 158.4 | 3 days before neap |
| 1-Aug-02 | 3-Aug-02 | 3 | Partly Open | 0.2 | Neap |
| 4-Aug-02 | 14-Aug-02 | 11 | Open | 18.4 | 4 days after spring |
| 15-Aug-02 | 16-Aug-02 | 2 | Partly Open | 13.6 | 1 day before neap |
| 17-Aug-02 | 27-Aug-02 | 11 | Closed | 6.6 | 3 days after spring |
| 28-Aug-02 | 3-Sep-02 | 7 | Open | 8 | 2 days after neap |
| 4-Sep-02 | 4-Sep-02 | 1 | Partly Open | 2.2 | 3 days after neap |
| 5-Sep-02 | 9-Sep-02 | 5 | Closed | 16.2 | 1 day after spring |
| 10-Sep-02 | 10-Sep-02 | 1 | Open | 0 | 2 days after spring |
| 11-Sep-02 | 19-Sep-02 | 9 | Closed | 0.2 | 4 days after neap |
| 20-Sep-02 | 20-Sep-02 | 1 | Open | 0 | 5 days after neap |
| 21-Sep-02 | 22-Sep-02 | 2 | Closed | 2.8 | Spring |
| 23-Sep-02 | 28-Sep-02 | 6 | Partly Open | 5.2 | 2 days before neap |
| 29-Sep-02 | 1-Oct-02 | 3 | Closed | 11 | 1 day after neap |
| 2-Oct-02 | 5-Oct-02 | 4 | Partly Open | 0 | 5 days after neap |
| 6-Oct-02 | 20-Oct-02 | 15 | Closed | 8.8 | 1 day before spring |
| 21-Oct-02 | 22-Oct-02 | 2 | Partly Open | 0 | 1 day after spring |
| 23-Oct-02 | 3-Nov-02 | 12 | Closed | 20.2 | 5 days after neap |
| 4-Nov-02 | 4-Nov-02 | 1 | Partly Open | 0.2 | 1 day before spring |
| 5-Nov-02 | 5-Nov-02 | 1 | Open | 7.4 | Spring |
| 6-Nov-02 | 6-Nov-02 | 1 | Closed | 1.2 | 1 day after spring |
| 7-Nov-02 | 7-Nov-02 | 1 | Open | 0 | 2 days after spring |
| 8-Nov-02 | 8-Nov-02 | 1 | Closed | 0 | 3 days after spring |
| 9-Nov-02 | 10-Nov-02 | 2 | Open | 3.2 | 5 days after spring |

**The state of Mdloti estuary relative to the rainfall and relevant tidal situation of the time are present in tabular form.**

| **Dates (Inclusive)** | | **No. of days** | **State** | **Rainfall during period (mm)** | **Tidal Situation at the end of the period** |
|---|---|---|---|---|---|
| **From** | **To** | | | | |
| 14-Mar-02 | 23-Mar-02 | 10* | Open | 0.8 | Neap |
| 24-Mar-02 | 27-Mar-02 | 4 | Partly open | 13.2 | 4 days after neap |
| 28-Mar-02 | 10-Apr-02 | 14 | Closed | 11.8 | 4 days after neap |
| 11-Apr-02 | 12-Apr-02 | 2 | Open | 6 | 6 days after neap |
| 13-Apr-02 | 13-Apr-02 | 1 | Partly open | 0 | Spring |
| 14-Apr-02 | 15-Apr-02 | 2 | No data | 71.4 | n/a |
| 16-Apr-02 | 17-Apr-02 | 2 | Partly open | 10 | 4 days after spring |
| 18-Apr-02 | 23-Apr-02 | 6 | Open | 0 | 2 days after neap |
| 24-Apr-02 | 26-Apr-02 | 3 | Partly open | 15.8 | 5 days after neap |
| 27-Apr-02 | 4-May-02 | 8 | Open | 9.4 | 1 day before neap |
| 5-May-02 | 12-May-02 | 8 | No data | 0 | n/a |
| 13-May-02 | 31-May-02 | 19 | Closed | 0.2 | 5 days after spring |
| 1-Jun-02 | 1-Jun-02 | 1 | Partly open | 0.2 | 6 days after spring |
| 2-Jun-02 | 20-Jul-02 | 49 | Closed | 149.2 | 1 day after neap |
| 21-Jul-02 | 12-Aug-02 | 23 | Open | 34.2 | 1 day after spring |
| 13-Aug-02 | 15-Aug-02 | 3 | Partly open | 16.2 | 4 days after spring |
| 16-Aug-02 | 20-Aug-02 | 5 | Open | 1 | 3 days after neap |
| 21-Aug-02 | 28-Aug-02 | 8 | Closed | 13.6 | 4 days after spring |
| 29-Aug-02 | 11-Sep-02 | 14 | Open | 18.4 | 3 days after spring |
| 12-Sep-02 | 15-Sep-02 | 4 | Partly open | 0.2 | Neap |
| 16-Sep-02 | 21-Sep-02 | 6 | Closed | 0 | 1 day before spring |
| 22-Sep-02 | 26-Sep-02 | 5 | Open | 8 | 4 days after spring |
| 27-Sep-02 | 5-Oct-02 | 9 | Partly open | 11 | 2 days before spring |
| 6-Oct-02 | 6-Oct-02 | 1 | No data | 2.2 | n/a |
| 7-Oct-02 | 15-Oct-02 | 9 | Closed | 6.4 | neap |
| 16-Oct-02 | 30-Oct-02 | 15 | Open | 20.4 | 1 day after neap |
| 31-Oct-02 | 31-Oct-02 | 1 | Partly open | 0 | 2 days after neap |
| 1-Nov-02 | 14-Nov-02 | 14 | Closed | 37.6 | 2 days after neap |
| 15-Nov-02 | 29-Nov-02 | 15 | No data | 11.2 | n/a |
| 30-Nov-02 | 27-Dec-02 | 28 | Closed | 76.4 | Neap |
| 28-Dec-02 | 29-Dec-02 | 2 | Open | 0.4 | 2 days after neap |
| 30-Dec-02 | 13-Jan-03 | 15 | Partly open | 49.2 | 1 day after neap |
| 14-Jan-03 | 14-Jan-03 | 1 | Closed | 0.2 | 2 days after neap |
| 15-Jan-03 | 22-Jan-03 | 8 | Closed | 17.2 | 1 day after spring |
| 23-Jan-03 | 4-Feb-03 | 13 | Open | 34.4 | 1 day after spring |
| 5-Feb-03 | 8-Feb-03 | 4 | Partly open | 0 | 5 days after spring |
| 9-Feb-03 | 31-Jul-03 | 173** | closed | 160.6 | |

* the data only begins on the 14 March 2002, therefore the estuary may have been open for several days before.

** Data collected by KZN Wildlife is only available up to the end of July 2003.

# APPENDIX F: MOUTH STATE DATA

Motorola reserves the right to make changes without further notice to any products herein. Motorola makes no warranty, representation or guarantee regarding the suitability of its products for any particular purpose, nor does Motorola assume any liability arising out of the application or use of any product or circuit, and specifically disclaims any and all liability, including without limitation consequential or incidental damages. "Typical" parameters which may be provided in Motorola data sheets and/or specifications can and do vary in different applications and actual performance may vary over time. All operating parameters, including "Typicals" must be validated for each customer application by customer's technical experts. Motorola does not convey any license under its patent rights nor the rights of others. Motorola products are not designed, intended, or authorized for use as components in systems intended for surgical implant into the body, or other applications intended to support or sustain life, or for any other application in which the failure of the Motorola product could create a situation where personal injury or death may occur. Should Buyer purchase or use Motorola products for any such unintended or unauthorized application, Buyer shall indemnify and hold Motorola and its officers, employees, subsidiaries, affiliates, and distributors harmless against all claims, costs, damages, and expenses, and reasonable attorney fees arising out of, directly or indirectly, any claim of personal injury or death associated with such unintended or unauthorized use, even if such claim alleges that Motorola was negligent regarding the design or manufacture of the part. Motorola and Ⓜ are registered trademarks of Motorola, Inc. Motorola, Inc. is an Equal Opportunity/Affirmative Action Employer.

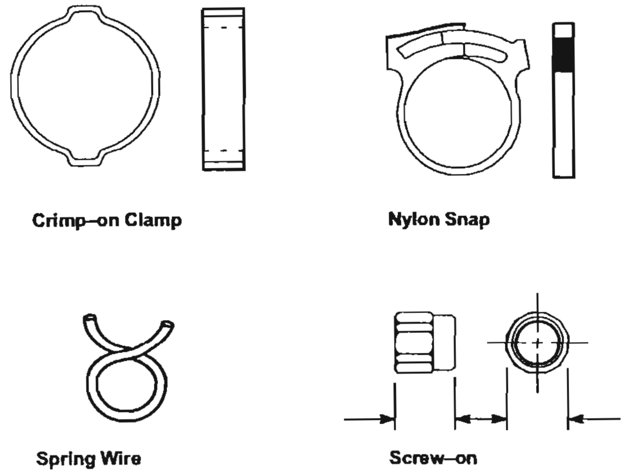



**Figure 4. Hose Clamps**

The two clamps most recommended by Motorola are the crimp–on clamp and the screw–on, Clippard reusable clamp. The crimp–on type clamp is offered from both Ryan Herco (#0929–007) and Clippard (#5000–2). Once crimped in place, it provides a very secure hold, but it is not easily removed and is not reusable. The Clippard, reusable hose clamp is a brass, self–threading clamp, which provides an equally strong grip as the crimp–on type just described. The drawback is the reusable clamp is considerably more expensive. The nylon snap is also reusable, however the size options do not match the necessary outside diameter. The spring wire clamp, common in the automotive industry, and known for its very low cost and ease of use, also has a size matching problem. Custom fit spring wire clamps may provide some cost savings in particular applications.

## SUPPLIER LIST

**Hoses**
Norton–Performance Plastics
Worldwide Headquarters
150 Dey Road, Wayne, NJ 07470–4599 USA
(201) 596–4700
Telex: 710–988–5834
USA
P.O. Box 3660, Akron, OH 44309–3660
USA
(216) 798–9240
FAX: (216) 798–0358

Clippard Instrument Laboratory, Inc.
7390 Colerain Rd.
Cincinnati, Ohio 45239, USA
(513) 521–4261
FAX: (513) 521–4464

Ryan Herco Products Corporation
P.O. Box 588
Burbank, CA 91503
1–800–423–2589
FAX: (818) 842–4488

**Spring Wire Clamps**
RotorClip, Inc.
187 Davidson Avenue
Somerset, NJ 08875–0461
1–800–631–5857 Ext. 255

**Rivets and Push–Pins**
ITW FasTex
195 Algonquin Road
Des Plaines, IL 60016
(708) 299–2222
FAX: (708) 390–8727

**Bolts**
Quality Screw and Nut Company
1331 Jarvis Avenue
Elk Grove Village, IL 60007
(312) 593–1600

**Crimp–on and Nylon Clamps**
Ryan Herco Products Corporation
P.O. Box 588
Burbank, CA 91503
1–800–423–2589
FAX: (818) 842–4488

**Crimp–on and Screw–on Clamps**
Clippard Instrument Laboratory, Inc.
7390 Colerain Rd.
Cincinnati, Ohio 45239, USA
(513) 521–4261
FAX: (513) 521–4464

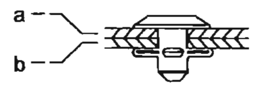
### Nylon Screws

Motorola recommends the use of #6–32 nylon screws as a hardware option. However, they should not be torqued excessively. The nylon screw will twist and deform under higher than recommended torque. These screws should be used with a nylon nut.

### Rivets

Rivets are excellent fasteners which are strong and very inexpensive. However, they are a permanent connection. Plastic rivets are recommended because metal rivets may damage the plastic package. When selecting a rivet size, the most important dimension, besides diameter, is the grip range. The grip range is the combined thickness of the sensor package and the thickness of the mounting surface. Package thicknesses are listed below.

| Port Style | Thickness, a | Grip Range = a + b |
|---|---|---|
| Single side port | 0.321″ (8.15 mm) | |
| Dual side port | 0.420″ (10.66 mm) | |
| Axial side port | 0.321″ (8.15 mm) | |
| Stovepipe port | (Does not apply) | |




### Push–Pins

Plastic push pins or ITW FasTex "Christmas Tree" pins are an excellent way to make a low cost and easily removable connection. However, these fasteners should not be used for permanent connections. Remember, the fastener should take all of the static and dynamic loads off the sensor leads. This type of fastener does not do this completely.

## HOSE APPLICATIONS

By using a hose, a sensor can be located in a convenient place away from the actual sensing location which could be a hazardous and difficult area to reach. There are many types of hoses on the market. They have different wall thicknesses, working pressures, working temperatures, material compositions, and media compatibilities. All of the hoses referenced here are 1/8″ inside diameter and 1/16″ wall thickness, which produces a 1/4″ outside diameter. Since all the port hose barbs are 1/8″, they require 1/8″ inside diameter hose. The intent is for use in air only and any questions about hoses for your specific application should be directed to the hose manufacturer. Four main types of hose are available:

- Vinyl
- Tygon
- Urethane
- Nylon

*Vinyl* hose is inexpensive and is best in applications with pressures under 50 psig and at room temperature. It is flexible and durable and should not crack or deteriorate with age. This type of hose should be used with a hose clamp such as those listed later in this application note. Two brands of vinyl h are:

| Hose | Wall Thickness | Max. Press. @ 70°F (24°C) | Max. Temp. (°F)/(°C |
|---|---|---|---|
| Clippard #3814–1 | 1/16″ | 105 | 100/(38 |
| Herco Clear #0500–037 | 1/16″ | 54 | 180/(82 |

*Tygon* tubing is slightly more expensive than vinyl, but i the most common brand, and it is also very flexible. It als recommended for use at room temperature and applicati below 50 psig. This tubing is also recommended applications where the hose may be removed and reattach several times. This tubing should also be used with a h clamp.

| Tubing | Wall Thickness | Max. Press. @ 73°F (25°C) | Max. Tem (°F)/(°C |
|---|---|---|---|
| Tygon B–44–3 | 1/16″ | 62 | 165/(74 |

*Urethane* tubing is the most expensive of the four typ described herein. It can be used at higher pressures (up to 1 psig) and temperatures up to 100°F (38°C). It is flexib although its flexibility is not as good as vinyl or Tyg Urethane tubing is very strong and it is not necessary to u a hose clamp, although it is recommended.

Two brands of urethane hose are:

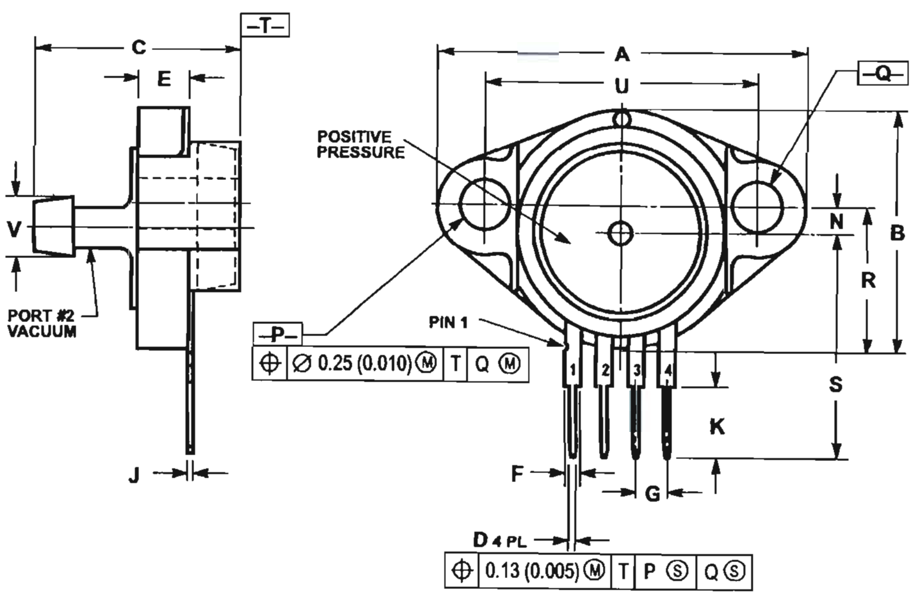
| Hose | Wall Thickness | Max. Press. @ 70°F (24°C) | Max. Temp. (°F)/(°C |
|---|---|---|---|
| Clippard #3814–6 | 1/16″ | 105 | 120/(49) |
| Herco Clear #0585–037 | 1/16″ | 105 | 225/(107 |

*Nylon* tubing does not work well with Motorola's sensors is typically used in high pressure applications with me fittings (such as compressed air).

## HOSE CLAMPS

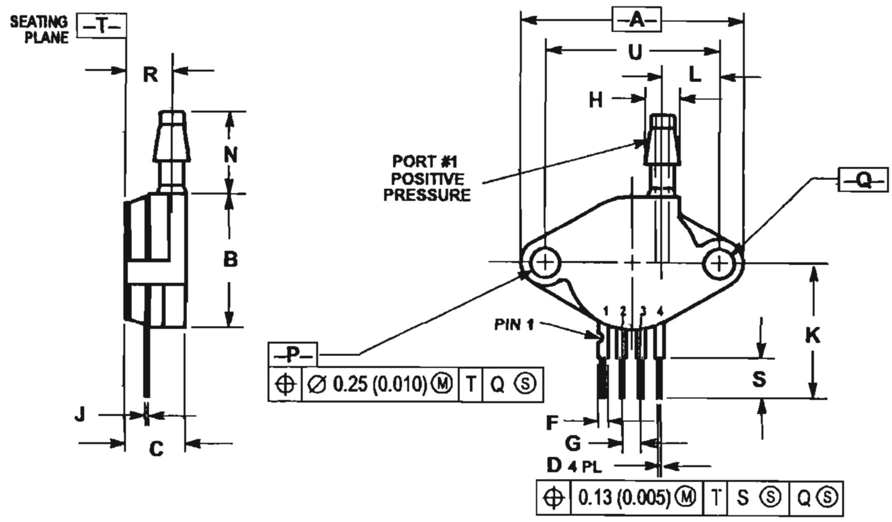
Hose clamps should be employed for use with all hos listed above. They provide a strong connection with the sens which prevents the hose from working itself off, and al reduces the chance of leakage. There are many types of ho clamps that can be used with the ported sensors. Here a some of the most common hose clamps used with hoses.

1/8" = 3,175mm
1/4" = 6,35 mm




NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

| DIM | INCHES MIN | INCHES MAX | MILLIMETERS MIN | MILLIMETERS MAX |
|---|---|---|---|---|
| A | 1.100 | 1.200 | 27.94 | 30.48 |
| B | 0.740 | 0.760 | 18.80 | 19.30 |
| C | 0.635 | 0.650 | 16.13 | 16.51 |
| D | 0.016 | 0.020 | 0.41 | 0.50 |
| E | 0.160 | 0.180 | 4.06 | 4.57 |
| F | 0.048 | 0.052 | 1.22 | 1.32 |
| G | 0.100 BSC | | 2.54 BSC | |
| J | 0.014 | 0.016 | 0.36 | 0.40 |
| K | 0.230 REF | | 5.84 REF | |
| N | 0.070 | 0.080 | 1.78 | 2.03 |
| P | 0.150 | 0.160 | 3.81 | 4.06 |
| Q | 0.150 | 0.160 | 3.81 | 4.06 |
| R | 0.445 | 0.460 | 11.30 | 11.68 |
| S | 0.685 | 0.715 | 17.40 | 18.16 |
| U | 0.840 | 0.860 | 21.33 | 21.84 |
| V | 0.185 | 0.195 | 4.69 | 4.95 |




NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1982.
2. CONTROLLING DIMENSION: INCH.

| DIM | INCHES MIN | INCHES MAX | MILLIMETERS MIN | MILLIMETERS MAX |
|---|---|---|---|---|
| A | 1.140 | 1.180 | 28.95 | 29.97 |
| B | 0.685 | 0.751 | 17.39 | 18.16 |
| C | 0.305 | 0.321 | 7.74 | 8.15 |
| D | 0.016 | 0.020 | 0.40 | 0.50 |
| F | 0.048 | 0.052 | 1.21 | 1.32 |
| G | 0.100 BSC | | 2.54 BSC | |
| H | 0.182 | 0.194 | 4.62 | 4.92 |
| J | 0.014 | 0.016 | 0.35 | 0.40 |
| K | 0.685 | 0.715 | 17.39 | 18.16 |
| L | 0.290 | 0.300 | 7.34 | 7.62 |
| N | 0.420 | 0.440 | 10.67 | 11.12 |
| P | 0.153 | 0.158 | 3.88 | 4.01 |
| Q | 0.153 | 0.158 | 3.88 | 4.01 |
| R | 0.231 | 0.250 | 5.86 | 6.35 |
| S | 0.230 REF | | 5.84 REF | |
| U | 0.910 BSC | | 23.11 BSC | |

**Figure 3. Case Outline Drawings**
**Top: Case 371D–02, Issue B**
**Bottom: Case 350–03, Issue H**

To mount any of the devices except Case 371–05/06 and 867E) to a flat surface such as a circuit board, the spacing and diameter for the mounting holes should be made according to *Figure 3*.

### Mounting Screws

Mounting screws are recommended for making a very secure, yet removable connection. The screws can be either metal or nylon, depending on the application. The holes are 0.155″ diameter which fits a #6 machine screw. The screw can be threaded directly into the base mounting surface or go through the base and use a flat washer and nut (on a circuit board) to secure to the device.

## MOUNTING TORQUE

The torque specifications are very important. The sensor package should not be over tightened because it can crack, causing the sensor to leak. The recommended torque specification for the sensor packages are as follows:

| Port Style | Torque Range |
|---|---|
| Single side port: | |
| port side down | 3–4 in–lb |
| port side up | 6–7 in–lb |
| Differential port (dual port) | 9–10 in–lb |
| Axial side port | 9–10 in–lb |

The torque range is based on installation at room temperature. Since the sensor thermoplastic material has a higher TCE (temperature coefficient of expansion) than common metals, the torque will increase as temperature increases. Therefore, if the device will be subjected to very low temperatures, the torque may need to be increased slightly. If a precision torque wrench is not available, these torques all work out to be roughly 1/2 of a turn past "finger tight" (contact) at room temperature.

Tightening beyond these recommendations may damage the package, or affect the performance of the device.

# AN151

# Mounting Techniques and Plumbing Options of Motorola's MPX Series Pressure Sensors

**Prepared by: Brian Pickard**
**Sensor Products Division**
**Semiconductor Products Sector**

## INTRODUCTION

Motorola offers a wide variety of ported, pressure sensing devices which incorporate a hose barb and mounting tabs. They were designed to give the widest range of design flexibility. The hose barbs are 1/8″ (≈3 mm) diameter and the tabs have #6 mounting holes. These sizes are very common and should make installation relatively simple. More importantly, and often overlooked, are the techniques used in mounting and adapting the ported pressure sensors. This application note provides some recommendations on types of fasteners for mounting, how to use them with Motorola sensors, and identifies some suppliers. This document also recommends a variety of hoses, hose clamps, and their respective suppliers.

This information applies to all Motorola MPX pressure sensors with ported packages, which includes the packages shown in Figure 1.

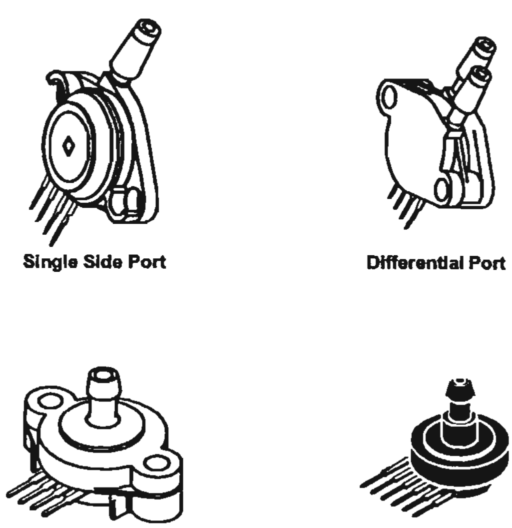



**Figure 1. MPX Pressure Sensors with Ported Packages**

A review of recommended mounting hardware, mounti torque, hose applications, and hose clamps is also provic for reference.

## MOUNTING HARDWARE

Mounting hardware is an integral part of package desi( Different applications will call for different types of hardwa When choosing mounting hardware, there are three import: factors:

- permanent versus removable
- application
- cost

The purpose of mounting hardware is not only to secure t sensor in place, but also to remove the stresses from t sensor leads. In addition, these stresses can be high if t hose is not properly secured to the sensor port. Screws, rive push–pins, and clips are a few types of hardware that can used. Refer to Figure 2.

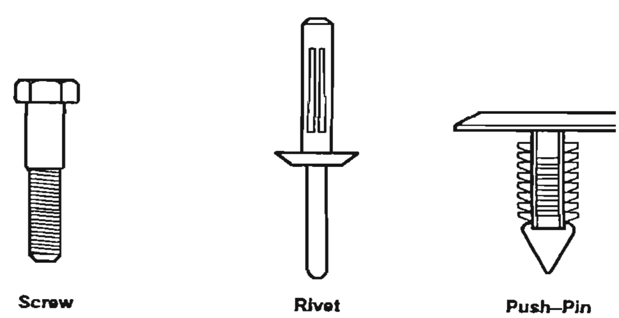



**Figure 2. Mounting Hardware**



© Motorola, Inc. 1997

# LOGGER ALARM UNIT (ACS-5000)

## FEATURES

### *Programmable delay*

The alarm unit can be programmed to wait for a specified length of time after the logger reports an alarm state. In this way, the unit can ignore short periods in an alarm state and it will only sound after a more prolonged, continuous alarm event. The delay resets itself each time the logger reports that it is no longer in an alarm state.
A free software tool is available as an add-on to the GLM Windows software. To use the tool, the alarm unit is connected directly to the PC using the standard PC to logger interface lead (CAB-0007). When the tool is run from the Tools menu, the user is guided by on-screen instructions to program the delay as required.

### *Test button*

The test button simulates an alarm condition while it is pressed, but without any delay. It has no other effect.

### *Clear Alarms Button*

If the logger is set with latched alarms, it will continue to report a previous alarm condition even when it is no longer in an alarm state. This will result in the alarm unit sounding continually. The Clear Alarms button resets the alarm *in the logger*, which will remain off until the next time it crosses back into the alarm state. Consequently the alarm unit is silenced.
The Clear Alarms button must be held down until a triple beep is heard.

### *Battery*

The alarm unit is powered by a single, 9-volt PP3 or equivalent alkaline battery. To change the battery, the case must be opened using a cross-headed screwdriver. To avoid damage, take care not to touch the electronics or trap any wires.
The unit gives a double beep on power-up.

### *Audible battery low warning*

When the battery voltage falls below about 6 Volts the unit emits three rapid high-pitched beeps once every minute.

### *Volt-Free Relay Contacts*

There is a built-in latching relay, which can be used to connect other devices to the alarm unit. Two sets of changeover contacts are available from a set of screw terminals inside the case. A label under the battery shows the arrangement of the terminals. A blanking plug in the side of the case allows cable access.
The relay operation reflects the state of the audible alarm (A small delay may be noticeable).
It is the user's responsibility to ensure that the relay contacts are used in a safe manner.

# TINYVIEW LOGGERS (TV-)

## FEATURES

***Minimum, Maximum or Actual Readings***

It is possible to record minimum, maximum or actual readings. For minimum and maximum readings, the recorded value at the end of each logging interval is calculated from readings taken during the interval. Therefore a minimum logging interval of 2 minutes is needed for these functions.

***Alarms***

TINYVIEW has two programmable alarms. Both use the LCD display to show an alarm state. Both are fully programmable for:

i. Alarm trip point
ii. Over or under value.
iii. Latching or non-latching.

These can be cleared via the Windows software without interrupting the logging.

***Display***

A clock face symbol on the display indicates that the logger is set for delayed start.

If it is set to start logging when a magnet is applied to the case, this is indicated by a block symbol, with arrows on the screen pointing to where the magnet must be applied.

An arrow on the display points to a graph symbol when the unit is logging.

Numerical reading: Actual temperature or Relative Humidity level. For temperature, an arrow pointing to the bottom of the display indicates the units used (degrees Centigrade or Fahrenheit). The display is updated every four seconds. (Later models: every second when logging in seconds mode)

Alarm status is shown by the presence of Lo1, Lo2, Hi1 and Hi2 indicators at the top of the LCD.

Word 'STOP': Logger in stop mode.

Display blank: In stop mode the logger turns the display off after 5 minutes to preserve battery life. When you connect to the logger in GLM the display turns on again.

Word 'CAL': Indicates that the logger is due or nearly due for calibration. This will only appear on calibrated units and will not stop the logger functioning. The word CAL will also appear on calibrated units for a few seconds each time the battery is inserted. Uncalibrated units will display 'BATT' instead.

***CARE OF UNIT***

See also 'General Information' section. Do not open the unit for any purpose other than to change the battery, particularly with RH units, as calibration may be affected.

***CALIBRATION***

For critical applications, TINYVIEW can be supplied with a NAMAS traceable calibration certificate. All calibrated units are fitted with a tamper-proof seal and re-calibration date label. To assist you in maintaining calibration, all TINYVIEWs that have been calibrated will warn you when re-calibration date falls due by showing the word 'CAL' on the display every few seconds. This calibration warning can only be cleared by returning the unit to your supplier for calibration cancellation or an approved Calibration Service, which also includes battery and O-ring replacement, re-sealing and dating.

The period for which a calibration is valid will depend upon the type of logger.

Please note that the Manufacturers Warranty is NOT extended by the Calibration Service.

***TWO CHANNEL LOGGERS***

Readings are displayed alternately on the screen. The two channels must share the same start/stop times and logging intervals.

# TINYTAG INTRINSICALLY SAFE LOGGERS (TGIS-)

## INTRODUCTION

TINYTAG IS loggers are clearly distinguishable from standard TINYTAGs by their red case and the distinctive community mark shown on the label.

Internally the units have a special circuit board with various safety components added for approval.

NOTE: any modification will invalidate the Intrinsically Safe approval.

TINYTAG Intrinsically Safe Dataloggers are approved for use in hazardous areas to the following standard:

**EEx ia IIC**
**T4 ($T_{amb}$=40°C) T3 ($T_{amb}$=85°C)**
**SCS Number: Ex 96D2069X**

With the following warnings:

i. Connection to the 3-pin socket (for serial communication to the host computer) may only be made when the TINYTAG IS logger is in the non-hazardous area and the installer shall ensure that the maximum voltage supplied does not exceed 125Vrms.
ii. Only SAFT LS14250 cells may be used. Do not change in the hazardous area.
iii. Static hazard - do not rub with a dry cloth.

TINYTAG IS loggers are approved over the operating temperature range of -20°C to +40°C (-4°F to +104°F) for a T4 environment and -20°C to +85°C (-4°F to +185°F) for a T3 environment.

NOTE: Although the functional temperature range of the loggers may be wider than the approved range, the IS approval is only valid while operating within the approved range.

Please refer to the Certificate of Conformity supplied with each TINYTAG IS logger for further details about the approval.

***Minimum, Maximum or Actual Readings***

It is possible to record minimum, maximum or actual readings. For minimum and maximum readings, the recorded value at the end of each interval is calculated from readings taken during the logging interval. Therefore a minimum logging interval of 2 minutes is needed for these functions.

***Alarms***

The logger has two programmable alarms. Both use a Red LED indicator to show an alarm state. Both are fully programmable for:

i. Alarm trip point
ii. Over or under value.
iii. Latching or non-latching.
iv. One or two flashes.

The alarms can be cleared via the Windows software without interrupting the logging.

***Red Alarm LED***

One or two flashes as defined by the user when setting the alarms. If both alarms are triggered together, the red LED flashes 4 times.

This LED is not normally used at any other time, however if both LEDs flash brightly and rapidly together, the unit will not work. Remove and refit the battery. If the problem persists, return the unit for repair.

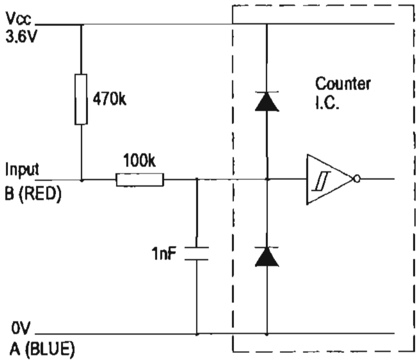
***Green Status LED***

Waiting delay start: 2 flashes every 4 sec
Logging (seconds): 1 flash every 3 sec
Logging (minutes): 1 flash every 4 sec
Storing a reading: 1 bright flash
Power Up: ON for several seconds
Note: Status indication may vary with very short logging intervals.

i) The maximum frequency input to guarantee no false readings is 50Hz although substantially higher frequencies may be allowed if very occasional false readings are acceptable (the higher the frequency the more false readings).
ii) The total number of counts, BEFORE the division, per LOGGING INTERVAL must not exceed 65535 counts otherwise the counter is reset to zero.
iii) In Seconds mode: The total number of counts per SECOND must not exceed 255 otherwise the counter is reset to zero.
iv) In Minutes mode: Total number of counts per ANY 4 SECOND period must not exceed 255 otherwise the counter is reset to zero.

***COUNT INTERFACE DETAILS***

***Input Circuit Diagram***




***Debounce***

A low pass filter on the input of TINYTAG RE-ED COUNT provides a basic level of input debounce for both digital and volt free switch inputs. If a volt free switch input is being used which requires further debounce this can be achieved by simply connecting an additional capacitor across the switch contacts (about 10nF should be sufficient). Note: Doing this will increase the minimum open time required. It is recommended that you test your circuit for switch bounce before using it. This can be done with the Current Reading option in GLM.

***Count Errors***

The first stored reading will always be zero. Readings which, after division, are greater than 255 will be stored as 255.
In most applications the only other significant error will be that due to rounding after the division:
Max Rounding Error = +/- Divisor/2
In applications using short logging intervals there will be an additional error due to the slight variations which can occur in the length of the logging intervals (although these will average out over multiple readings):
With PC connected, the maximum interval deviation is +/- 200ms (except while offloading, when it can be as much as +/- 4s).
Without PC connected it is +/- 20ms. (Note: The deviation will be greater than this during the first 3 seconds of the logging run.)

***TINYTAG PLUS RE-ED for OEMs (circuit board only)***

Please use the edge connector for all terminations, rather than soldering directly to the PCB.
See individual datasheets for PCB dimensions and layout of the edge connector.
Pins are numbered to suit a standard 20-way IDC female edge connector. Pins 1,2,19 and 20 are not used.

**General Electrical Characteristics.**

| Pin | Signal | Description | Min | Typ | Max |
|---|---|---|---|---|---|
| 3 | VBAT | O/P Supply* (using on-board battery) | | 3.6V | 3.67V |
| 3 | VBAT | O/P Supply current available* (using on-board battery) | | 5mA | |
| 3 | VBAT | I/P Logger power requirement (if no battery fitted) | 3.2V | 3.6V | 5.5V |
| 3 | VBAT | I/P Logger Current (if no on-board battery fitted) | | | 5mA (Peak) |
| 5 | GLED | O/P Green LED anode (See Tinytag Plus section,Status indicator) | VBAT, via series 560 ohms | | |
| 6 | RLED | O/P Red LED anode (See Tinytag Plus section, Alarm indicator) | VBAT, via series 560 ohms | | |
| 7 | TX-B | O/P Transmit RS232 data | | | |
| 9 | RX-A | I/P Receive RS232 data | | | |
| 10 | SENSE | O/P goes high from 150ms before reading (NOT TGPR-1200) | VBAT, via series 100k | | |
| 12 | VREF | O/P Reference when SENSE line is high (NOT TGPR-1200) | | 2.50V | |
| 12 | VREF | O/P Current available (NOT TGPR-1200) | | | 125uA |
| 17 | GND | Signal and power Ground | | | |
| 18 | IN | Signal Input. See specific datasheets and previous pages for electrical characteristics. | | | |

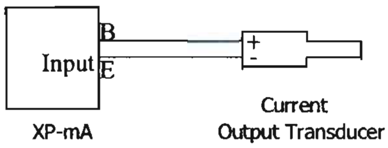
DO NOT CONNECT TO ANY OTHER PAD.

*Based on Saft LS14250 battery at 20°C (68°F). The current available improves with higher temperatures.

All output signals are Tri-state or passive when not in the active high state.
These specifications are subject to change without prior notice.

***Application Note*** (TGPR-0805 only)

When using a two-wire current output transducer with an XP TINYTAG RE-ED - mA, the negative supply of the transducer is also the current output and should be connected to the input of the XP.




***TINYTAG PLUS RE-ED Voltage loggers (TGPR-0700, -0704, -0705 only)***

***Selecting Volt I/P Ranges***

TINYTAG RE-ED - VOLT loggers are factory set with a range of 0 to 2500mV. Ranges of 10V and 25V can be selected on the internal switch (the O-ring may need to be replaced when the lid is removed). Re-educator software is required to change the range look-up table. Note: The applied voltage (relative to ground connection) must be no less than 0V or greater than 3.5, 14 or 35V for the 2.5, 10 and 25V ranges respectively.

Voltages outside of these ranges may permanently damage the unit. If 'input' is left unconnected on the 2.5V range, the input will float. On the other ranges it will pull down to 0V.

***TINYTAG PLUS RE-ED Count loggers (TGPR-1200, -1201 only)***

***Introduction***

TINYTAG RE-ED COUNT is designed to count pulses generated by an external circuit or a volt free switch. At the end of each logging interval the number of pulses counted during that interval is divided by a user programmable constant (from 1 to 256) and recorded as an 8 bit value. In this way count rates of over 65,000 per interval can be logged.

NOTE: Unlike TINYTAG loggers that record readings at discrete points in time e.g. temperature, TINYTAG RE-ED COUNT loggers record readings over time so the reading taken depends on the logging interval selected. This gives rise to some extra points which need to be considered:

- The property units are specified as 'per interval' - e.g. if one pulse from a flow meter represents one litre of liquid, then the units will be 'litres/interval'. Because these units are general, it is a good idea to state the specific interval being used as part of the Title, e.g. 'Water Flow per hour', in this way the interval will be clearly shown when the data is presented.

- The Current Reading becomes meaningless to some extent as the interval between readings is not user defined (it is about one second). Also, no division is applied to Current Readings, regardless of any that has been set. The Current Reading is however a useful test tool, and so has been left available except while logging.

- The alarms and data statistics are of limited use with TINYTAG RE-ED COUNT although, by setting an alarm condition as greater than zero, a total count may be calculated from the statistics using the following formula:

$$\text{Total counts} = \text{Area in alarm condition} \times \frac{\text{1 hour}}{\text{logging interval}}$$

NOTE: Depending on what property is being recorded by a counting logger, the data collected may be transient in nature. If this is the case it is important that no data points are omitted when plotting the data (unlike, say temperature, where on a large dataset every other point or so may be plotted to speed up the drawing process without any loss of visible detail). GLM gives an option to always plot all of the data points.

When using Re-Educator with TINYTAG RE-ED COUNT remember to:

i) Include 'per interval' in the property units e.g. People/interval.

ii) Ensure that any algorithms that may be used take account of the input division that is set.

iii) Delete any algorithms that apply to a different input division.

***COUNT INPUT SPECIFICATION***

***Digital***

Low level: -0.5V to 1V
High level: 2.5V to 10V
Min pulse width: 150µs (@5V)
Min pulse separation: 150µs (@5V)
Input impedance: >100kohms
Max input frequency: 50Hz (subject to restrictions below)
Edge detection: High to Low transition.

***Volt Free Switch***

Switch type: Normally open contacts with minimal bounce.
Min closed time: 150µs
Min open time: 500µs
Max input frequency: 50Hz (subject to restrictions below)
Edge detection: Open to Closed transition.

***Frequency and Count Restrictions***

In order to get reliable data from TINYTAG RE-ED COUNT it is very important that the following restrictions are adhered to:

# TINYTAG PLUS RE-EDUCATABLE LOGGERS (TGPR-)

## FEATURES

***Minimum, Maximum or Actual Readings, LED Indicators:*** As for Tinytag Plus.

***XP - External Power Supply (TGPR- 0705, -0805, 1002 only)***

XP TINYTAG PLUS RE-ED has a 12V battery pack inside as standard, which enables a wide range of commercially available sensors and transducers to be used without the need for an additional power supply. This power is switched on only when readings are taken (allowing 8 seconds for the sensor to stabilise) which greatly extends battery life. This battery also powers the status and alarm LEDs further increasing the life of the XP TINYTAG PLUS RE-ED's separate internal lithium battery supply.

NOTE: whenever the XP is linked to the host computer, the external supply line is active.

## RE-EDUCATOR SOFTWARE

The re-educator software runs in the Windows environment and allows the replacement of:

- Data conversion tables
- Property names and units
- Overall logger name

With TINYTAG RE-ED COUNT it also allows setting the input division (See the COUNT section of this manual for details). It does not allow the replacement of serial numbers or modification of existing data. For further details see the Re-educator software manual.

## ADDITIONAL INFORMATION

***HARDWARE CONNECTOR WIRING***

(For OEM users all connections should be made via the PCB edge connector as detailed in the separate section.)

***(TGPR-0804, -1001, -1201)***

| Name | Colour | Pin |
|---|---|---|
| Input | Red | B |
| Ground | Blue | A |

***(TGPR-0704, -0705, -0805, -1002)***

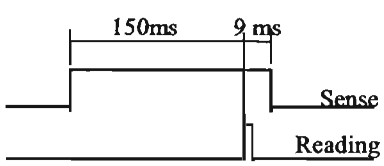
| Name | Colour | Pin |
|---|---|---|
| Input | Yellow | E |
| Ground | Black | D |
| Sense (TGPR-0704 only) | White | C |
| External Power (XPs only) | Green | B |
| 2.5V ref | Red | A |

***Line details***

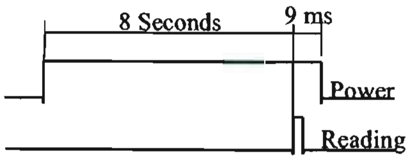
Input: On Volt and mV units this is the (dc) input voltage to be measured. On mA units it is the current input. On count units it can either be connected via a switch to Ground or used as a digital input (See TINYTAG RE-ED COUNT section for detailed specification). On all units this pin must not be held negative with respect to ground.

Ground: Common power supply ground (where applicable) and voltage signal ground.

Sense: (not XP, or mV/mA except OEM) A trigger signal which can be used to switch the power to external circuitry during a reading. Power goes high (3.5V), 150ms before the A/D takes a reading. A 100k resistor is fitted in series with the sense line to protect it from overload.




Power: This line is available in XP units only. 12 Volt power output used to power external circuitry during a reading. Power goes high (12V), 8 seconds before the A/D takes a reading, to allow external circuitry to stabilise. Max. recommended load current: 50mA with a voltage drop of 0.4V. Current is internally limited to 80mA.




2.5V ref.: Reference signal during reading (FSD for 2.5V range). The Maximum load that can be applied is 20K to GND.

- The property units are specified as 'mm per interval'. Because these units are general, it is a good idea to state the specific interval being used as part of the Title, e.g. 'Summer Rain mm/day', in this way the interval will be clearly shown when the data is presented.

- The Current Reading option is meaningless.

- The alarms and data statistics are of limited use with TINYTAG PLUS RAINFALL although, by setting an alarm condition as greater than zero, the total rainfall for a period may be calculated from the statistics using the following formula:

$$\text{Total Rainfall} = \text{Area in alarm condition} \times \frac{1\ \text{hour}}{\text{logging interval}}$$

NOTE: Because a plot of rainfall can be transient in nature, it is important that no data points are omitted when plotting the data (unlike, say temperature, where on a large dataset every other point or so may be plotted to speed up the drawing process without any loss of visible detail). In GLM there is an option to always plot all of the data points.

***Rainfall Logger Errors***

The first stored reading will always be zero.

Because the error is 'per interval' it is cumulative over multiple readings. For this reason short logging intervals - especially when combined with low rainfalls - should be avoided in order to minimise error.

With very heavy rainfall additional errors may be encountered due to raindrops splashing over the side of the gauge.

***-TINYTAG PLUS LEAF WETNESS LOGGER TGP-0903***

The Leaf Wetness Logger is aimed at agricultural/ horticultural users who need to determine the proportion of time for which leaves are wet. The Leaf Wetness Logger uses an artificial leaf type of sensor manufactured by Campbell Scientific (Model 237). The sensor consists of a circuit board with interlaced gold- plated copper fingers. Condensation on the sensor lowers the resistance between the fingers, which is measured by the logger. The resistance of the sensor varies from over 3 Meg Ω when dry to about 1kΩ when submersed in water. Droplets small enough not to touch two fingers simultaneously do not affect the sensor resistance. For this reason, this type of sensor is often coated with flat latex paint to spread the water droplets. The colour and type of paint affects sensor performance. Only the raw sensor is supplied since individual modifications vary depending on the application.

The following scientific paper details the effect of paint colour and sensor angle on the response of the leaf wetness sensor:

Gillespie, T.J. and Kidd, G.E. 1978. 'Sensing duration of leaf moisture retention using electrical impedance grids' Can. J. Plant Sci. 58:179-187.

NOTE: The sensor's resistance is artificially reduced by contaminants such as fingerprints and smudges. Before painting or calibrating the sensor, wash it with alcohol to remove possible contaminants.

***Leaf Wetness: Units of Measurement***

Because the measured resistance of the grid will depend not only on the wetness, but also on many other different factors such as coatings on the grid and impurities in the water (pure water does not conduct electricity), it is not possible to calibrate the logger with an absolute scale of wetness. For this reason the Leaf Wetness Logger is calibrated in arbitrary units of percent wetness based on the resistance of the grid as follows:

| Wetness | 0% | 10% | 20% | 30% | 40% | 50% | 60% | 70% | 80% | 90% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Grid Resistance (kΩ) | 8200 | 2200 | 1160 | 720 | 478 | 326 | 221 | 144 | 86 | 40 | 3 |

***Leaf wetness Logger Accuracy***

The variation in percent wetness for a given 'leaf' resistance (i.e. interchangeability between loggers) is ± 2% wetness.

Due to the high resistances that must be measured, the Leaf Wetness Logger may be susceptible to additional errors due to noise if electrical machinery is operated nearby.

***Wet/Dry Transition Point***

Before the fraction of time wet or dry can be calculated, the wet/dry transition point must be found.

A sharp change in resistance occurs in the wet/dry transition on the un-coated sensor, while the coated sensors have a poorly defined transition. The resistance of the un-coated sensor at the wet/dry transition is normally between 50kΩ and 200kΩ. The coated sensor transition normally occurs from 20kΩ to above 1MΩ.

***Leaf Wetness Sensor Calibration***

For best results, the leaf wetness sensor should be field calibrated, since the transition point will vary for different areas and vegetation. Set the logger with a short logging interval (say 1 minute) and place the sensor among the vegetation whose wetness is to be monitored. Then observe the vegetation until it reaches the desired wetness by natural means and note the time. The logger can then be offloaded and the transition point found.

***Tip for using Leaf Wetness Loggers with GLM software:***

Once the wet/dry transition point has been found, set an alarm for readings over this level. GLM will then calculate the total time spent in the wet state for you.

# TINYTAG TRANSIT, ULTRA & PLUS LOGGERS (TG-, TGU2K-,TGU-,TGP-)

## FEATURES

***Minimum, Maximum or Actual Readings***

It is possible to record minimum, maximum or actual readings. For minimum and maximum readings, the recorded value at the end of each logging interval is calculated from readings taken during the interval. Therefore a logging interval of at least 2 minutes is needed for these functions.

***LED Indicators***

These loggers have a red alarm indicator and a green status indicator. In Tinytag Transit loggers they shine through the base of the case, while in other loggers there are coloured lenses on the outside of the box.

***Red Alarm Indicator***

The logger has two programmable alarms. Both are fully programmable for:

i. Alarm trip point
ii. Over or under value.
iii. Latching or non-latching.
iv. One or two flashes.

If both alarms are triggered the red LED flashes 4 times.

The alarms can be cleared via the Windows software without interrupting the logging.

When the unit stops logging, the red LED gives one bright, half-second flash.

This LED is not normally used at any other time, however if both LEDs flash brightly and rapidly together, the unit will not work. Remove and refit the battery. If the problem persists, return the unit for repair.

***Green Status Indicator***

Waiting delay start: 2 flashes every 4 sec

Logging (seconds): 1 flash every 3 sec

Logging (minutes): 1 flash every 4 sec

Storing a reading: 1 bright flash

Power Up: On for several seconds

Note: Status indication may vary with very short logging intervals. While in alarm condition, LED indicators override logging indication.

***CARE OF UNIT***

See also 'General Information' section. Tinytag Transit and Tinytag Ultra only give limited resistance against ingress of moisture. When used outdoors they must be placed with the base facing downwards. To open a Tinytag Transit case, grip the lid in one hand and the hanging tab in the other, and gently ease apart the two halves of the container. To open a Tinytag Ultra, gently ease apart the tabs at the sides of the container to release the lid.

***TWO CHANNEL LOGGERS***

Two channel loggers behave the same way as single channel ones, but the two channels must share the same start times, logging intervals and stop times.

## TINYTAG LOGGERS - ADDITIONAL INFORMATION

***-TINYTAG PLUS SHOCK LOGGERS TGP-0605, TGP-0610***

The SHOCK logger records the maximum acceleration that it experiences during each logging interval, but not its direction. The maximum survivable shock for all models is 300g. (2940 m/s$^2$)

To achieve the stated accuracy, the permitted operating temperature range is -40°C to +70°C (-40°F to 158°F). TNYTAG PLUS loggers are designed to operate up to +85°C (185°F), however accuracy is not guaranteed.

***-TINYTAG PLUS VIBRATION LOGGER TGP-0650***

the VIBRATION logger records perturbation levels at discrete time intervals. The frequency response of the unit is 20Hz to 1kHz. The logger is less sensitive to vibrations outside this frequency range.

To achieve the stated accuracy, the permitted operating temperature range is -40°C to +70°C (-40°F to 158°F). TNYTAG PLUS loggers are designed to operate up to +85°C (185°F), however accuracy is not guaranteed.

***-TINYTAG PLUS RAINFALL LOGGER TGP-0901***

***Introduction***

TINYTAG PLUS RAINFALL is a counting logger that has been integrated with a simple rain gauge. Rain collected over a 5000mm$^2$ area passes through the gauge forming into drops of known volume. These drops are then counted and the rainfall in mm/interval calculated and stored. NOTE: because the rain gauge senses the drops by measuring their conductivity, it may not function in areas where the rain is exceptionally pure, as pure water does not conduct electricity.

Unlike TINYTAG loggers that record readings at discrete points in time e.g. temperature, TINYTAG PLUS RAINFALL loggers record readings over time so the reading taken depends on the logging interval selected. This gives rise to some extra points which need to be considered:

# TINYTALK LOGGERS (TK-)

***Green Status LED***

Waiting delay start: 2 flashes every 4 sec
Logging: 1 flash every 3 sec
Storing a reading: 1 short, bright flash
When logger stops: 1 half-second bright flash
Power Up: On for several seconds

***CARE OF UNIT***

See also 'General Information' section. To remove the unit from its container, gently squeeze the sides of the canister.

## TINYTALK VOLT LOGGER

***Selecting Volt I/P Ranges***

TINYTALK - VOLT is factory set with a range of 0 to 2500mV. Ranges of 10V and 25V can be selected on the internal switch. Re-educator software is required to change the range look-up table, property names and units and overall logger name. It does not allow the replacement of serial numbers or modification of existing data. For further details see the Re-educator software manual.

***Connector Wiring***

| Name | Colour | Pin |
|---|---|---|
| Input | Yellow | Ring |
| Ground | Black | Outer |
| Sense | White | Tip |

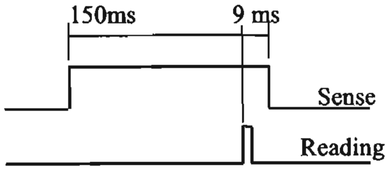
***Line details***

Input: This is the (dc) input voltage to be measured.

Note: The applied voltage (relative to ground connection) must be no less than 0V or greater than 3.5, 14 or 35V for the 2.5, 10 and 25V ranges respectively. Voltages outside of these ranges may permanently damage the unit. If 'input' is left unconnected on the 2.5V range, the input will float. On the other ranges it will pull down to 0V.

Ground: Voltage signal ground.

Sense: A trigger signal that can be used to switch the power to external circuitry during a reading. Power goes high (3.5V), 150ms before the A/D takes a reading. A 100k resistor is fitted in series with the sense line to protect it from overload.



## Introduction

The 'Getting Started' guide supplied with every logger provides the basic information needed to launch and offload loggers. It also contains guarantee information.
This manual gives the user a guide to the features and correct use of the products in the Gemini range. For full details of the specification for your particular product, please see the datasheet for that product.
For more detailed information on how to use the host software, please refer to the on-screen Help within the software.

## General Information

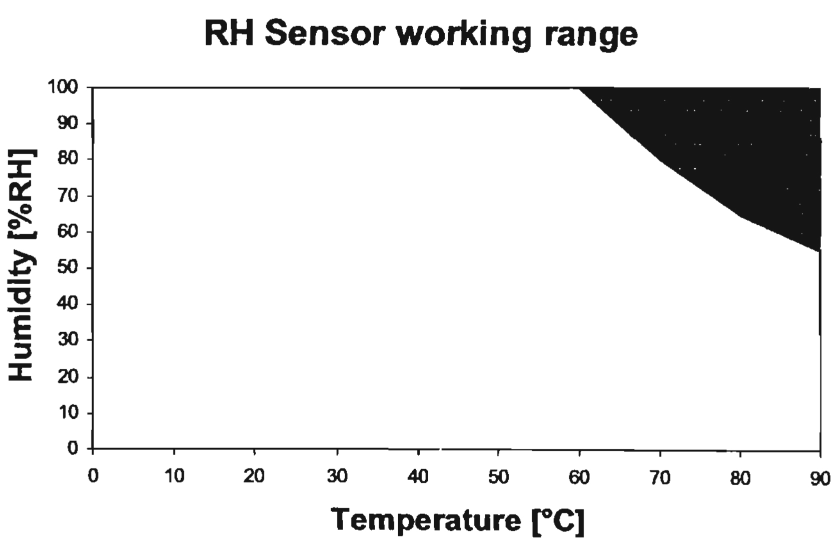
### CARE OF UNIT

Care must be taken to ensure that no dirt or moisture gets into the logger or any connectors. Moisture will cause the unit to stop recording and can lead to corrosion. Protection ratings of all loggers are only valid when lids and connectors are all securely fitted. In some models, the orientation of the case also affects the level of protection against ingress of moisture and dirt. Where any logger has been used in cold conditions, allow it to warm to room temperature prior to opening or removing connector caps, to prevent condensation forming inside. Should Tinytalk, Tinytag Transit or Tinytag Ultra electronics accidentally get wet, remove the battery immediately, wash the unit in fresh water (avoiding the RH sensor, where fitted) and dry completely before re-installing the battery. Care should be taken when handling the unit once out of the container, since it may be damaged by static electricity.

***Battery Life***

The life of the battery varies considerably depending on the logger type and how it is used. To maximise battery life, use longer logging intervals (in minutes mode) if possible, and do not leave the logger connected to the host computer for long periods. Disable any alarms when not in use. Low temperatures also reduce battery life.

### RH LOGGERS: Sensor Working Range




Note: If wetted the sensor may take up to 30 minutes to recover. For high humidity or applications with significant temperature changes, it is advisable to use Tinytag Plus RH data logger, Part No. TGP-0304, which has an IP68 waterproof case.

*Gemini Data Loggers*

**Data Logger Manual**

9800-4401 Issue 2: 8th Jan 2001

E&OE

⚠ WARNING

Please be sure to read the Warnings Section in the Getting Started Guide before using your data logger.

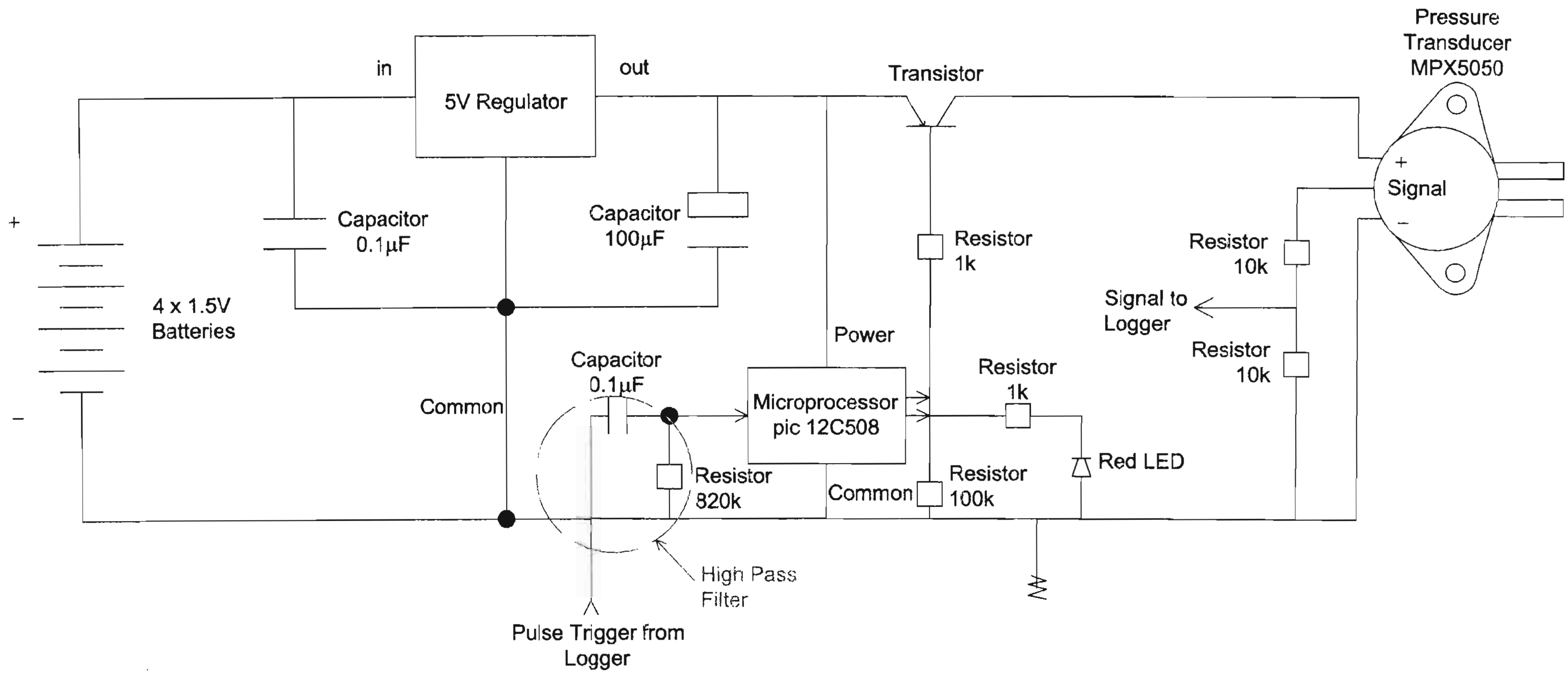
## Contents

# APPENDIX E: MANUFACTURER'S SPECIFICATIONS

GEMINI DATA LOGGERS
MOTOROLA PRESSURE TRANSDUCER

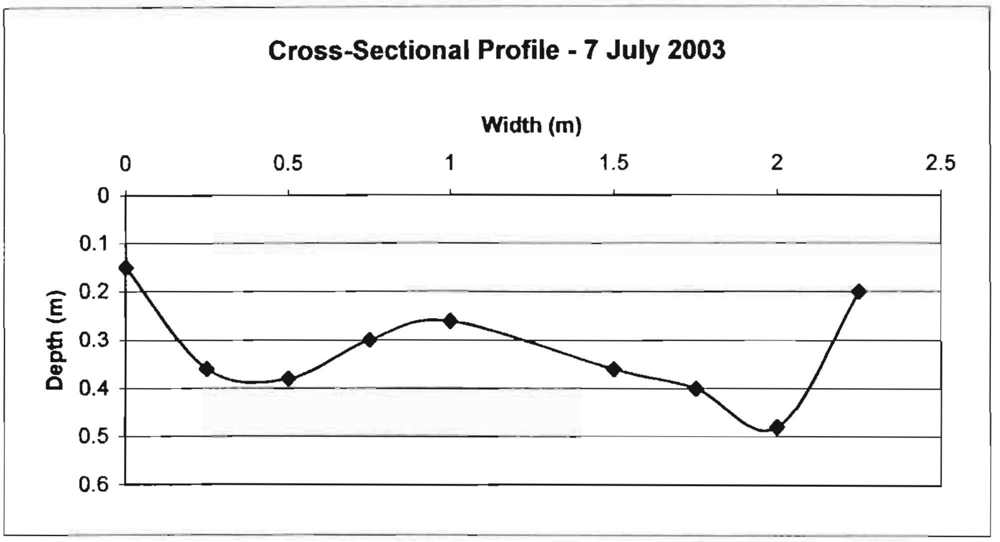
**Parts List for Tiny Talk Timer Interfaces**

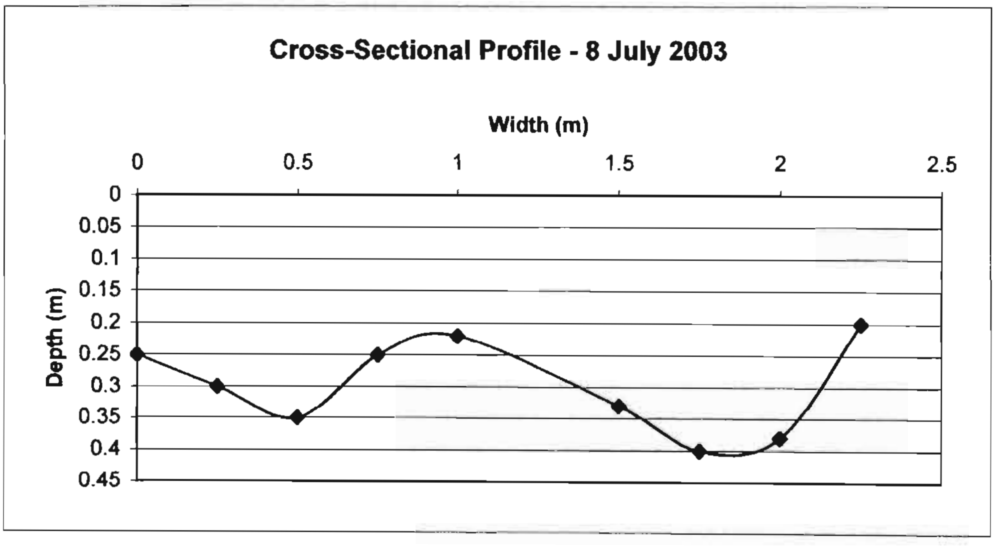
| Component Details | Supplier | Cost / Item | QTY | Cost |
|---|---|---|---|---|
| Single sided PCB | UNP Electronics Centre | R 5.00 | 1 | R 5.00 |
| pic12C508A-04SM UCB 160 | Avnett Kopp | R 7.49 | 1 | R 7.49 |
| LM 2936M-5.0 Low Drop out 5V regulator (SMD) | Arrow Altec | R 8.96 | 1 | R 8.96 |
| 32.768KHz XTL | Electrocomp Components | R 0.98 | 1 | R 0.98 |
| 100n 0805 SM chip capacitor | Electrocomp Components | R 0.15 | 2 | R 0.30 |
| 15p 0805 SM chip capacitor | Electrocomp Components | R 0.04 | 2 | R 0.08 |
| 100k 0805 SM resistor | Electrocomp Components | R 0.03 | 1 | R 0.03 |
| 10k 0805 SM resistor 1% | Electrocomp Components | R 0.04 | 2 | R 0.08 |
| 1k 0805 SM resistor | Electrocomp Components | R 0.03 | 2 | R 0.06 |
| 100uF 16V radial capacitor | Electrocomp Components | R 0.16 | 1 | R 0.16 |
| BC807-40 SOT23 Transistor | Electrocomp Components | R 0.20 | 1 | R 0.20 |
| 100m Blue 0.4mm Panel Wire | A1 Radio | R 50.00 | 1 | R 50.00 |
| 100m Red 0.4mm Panel Wire | A1 Radio | R 50.00 | 1 | R 50.00 |
| 100m Black 0.4mm Panel Wire | A1 Radio | R 50.00 | 1 | R 50.00 |
| MPX5100DP Transducer | Avnett Kopp | R 160.00 | 1 | R 160.00 |
| | | | | |
| **Total cost** | | | | **R 333.34** |

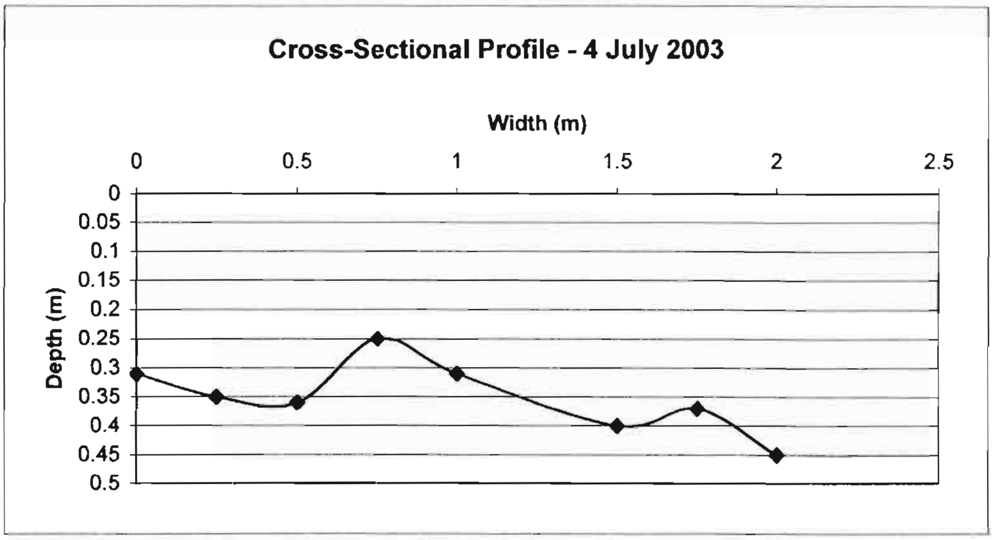


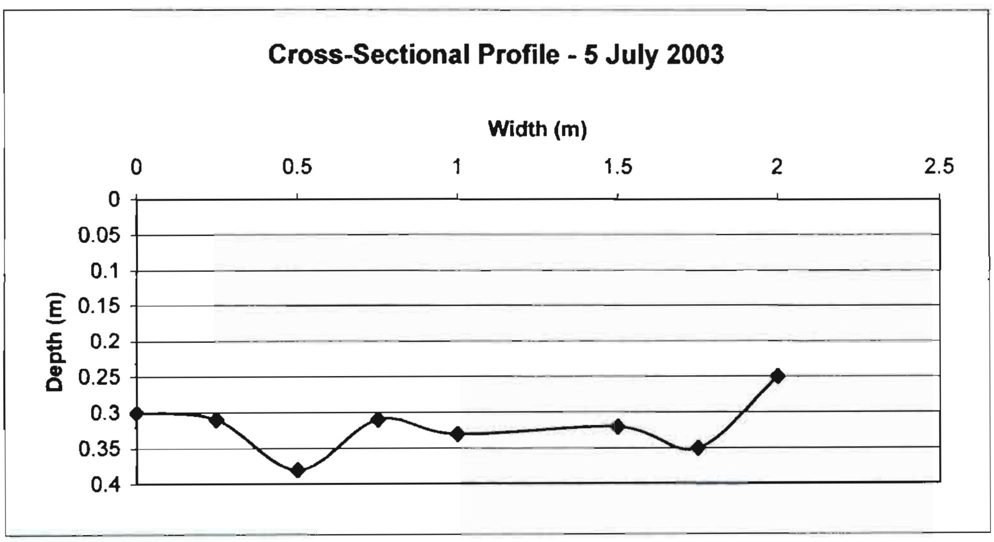

Logger Timer Circuit

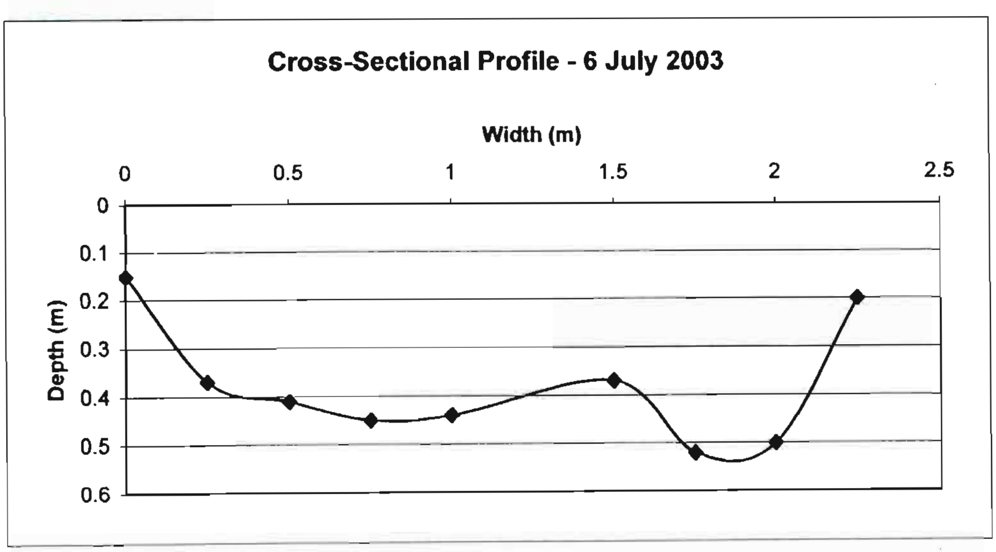
# APPENDIX D: CIRCUIT DIAGRAM AND COSTING FOR THE WATER LEVEL MONITORS

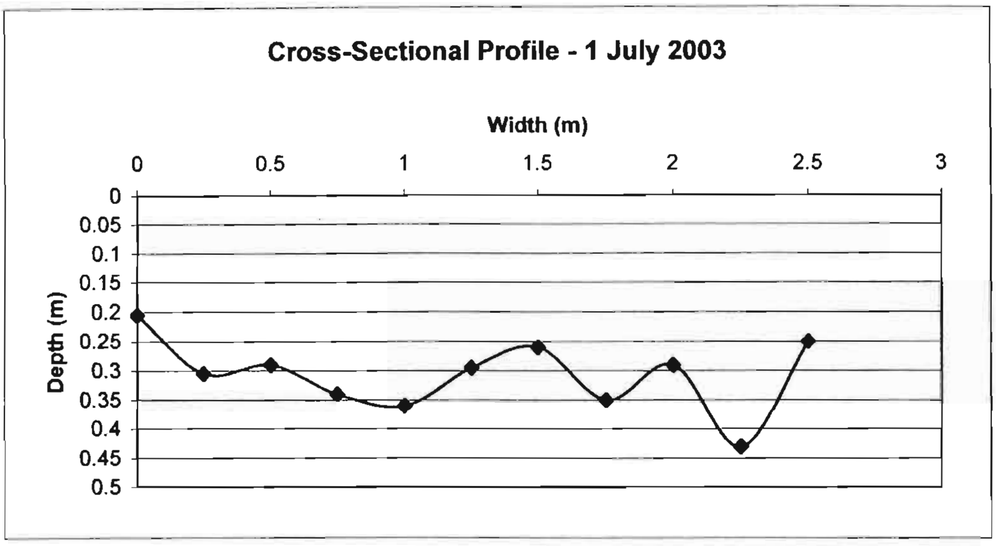

Cross-Sectional Profile - 7 July 2003
Width (m)
0
0.5
1
1.5
2
2.5
Depth (m)
0
0.1
0.2
0.3
0.4
0.5
0.6

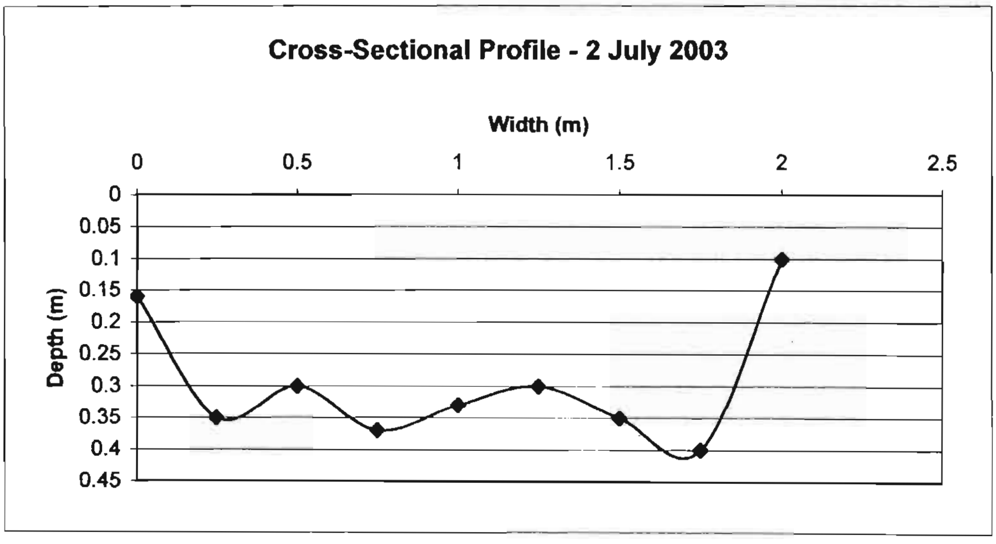

Cross-Sectional Profile - 8 July 2003
Width (m)
0
0.5
1
1.5
2
2.5
Depth (m)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45

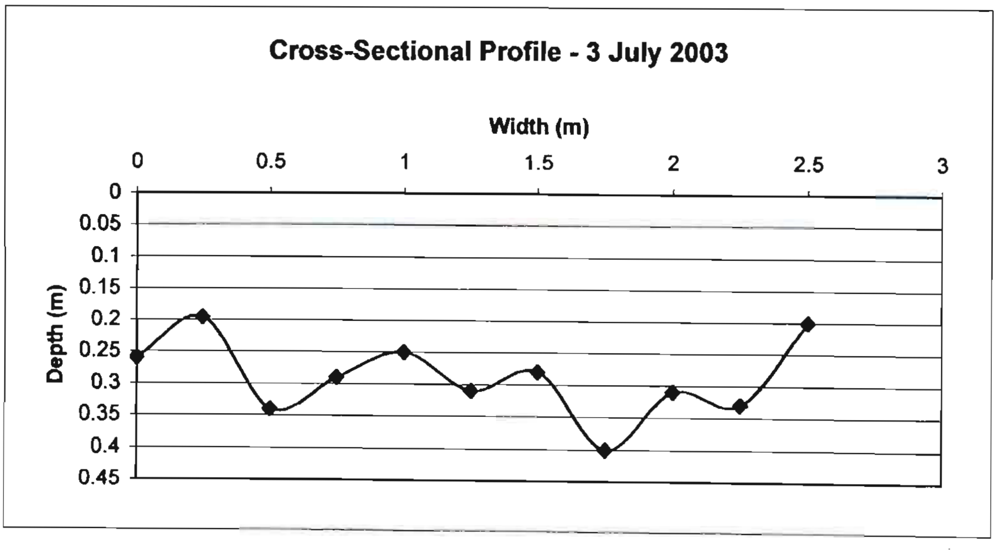

Cross-Sectional Profile - 4 July 2003
Width (m)
0
0.5
1
1.5
2
2.5
Depth (m)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5

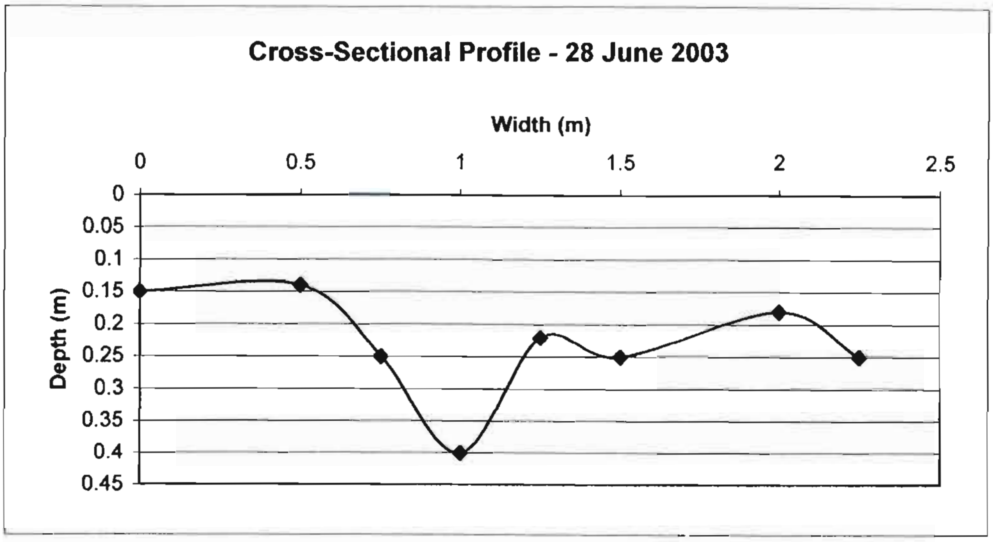

Cross-Sectional Profile - 5 July 2003
Width (m)
0
0.5
1
1.5
2
2.5
Depth (m)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4


Cross-Sectional Profile - 6 July 2003
Width (m)
0
0.5
1
1.5
2
2.5
Depth (m)
0
0.1
0.2
0.3
0.4
0.5
0.6

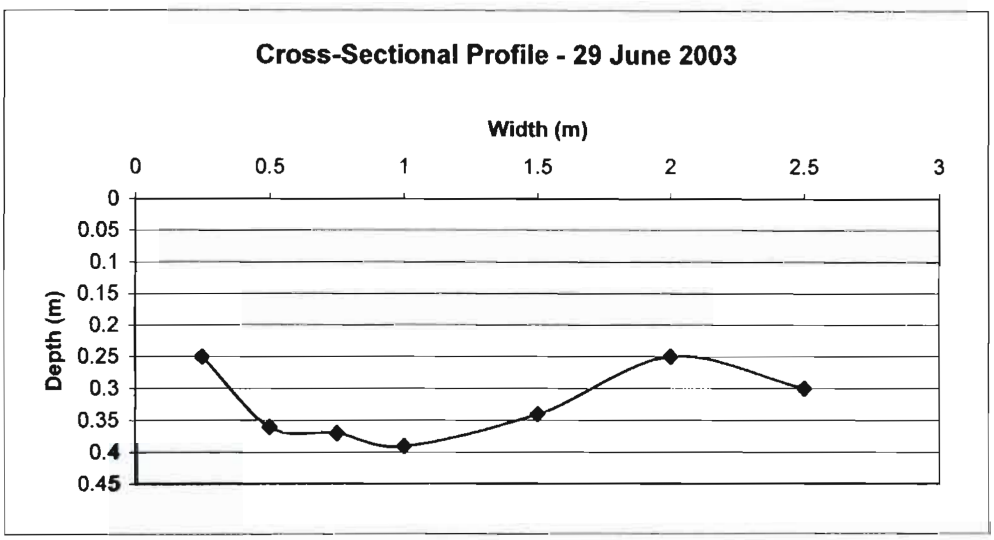

Cross-Sectional Profile - 1 July 2003
Width (m)
0
0.5
1
1.5
2
2.5
3
Depth (m)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5


Cross-Sectional Profile - 2 July 2003
Width (m)
0
0.5
1
1.5
2
2.5
Depth (m)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45

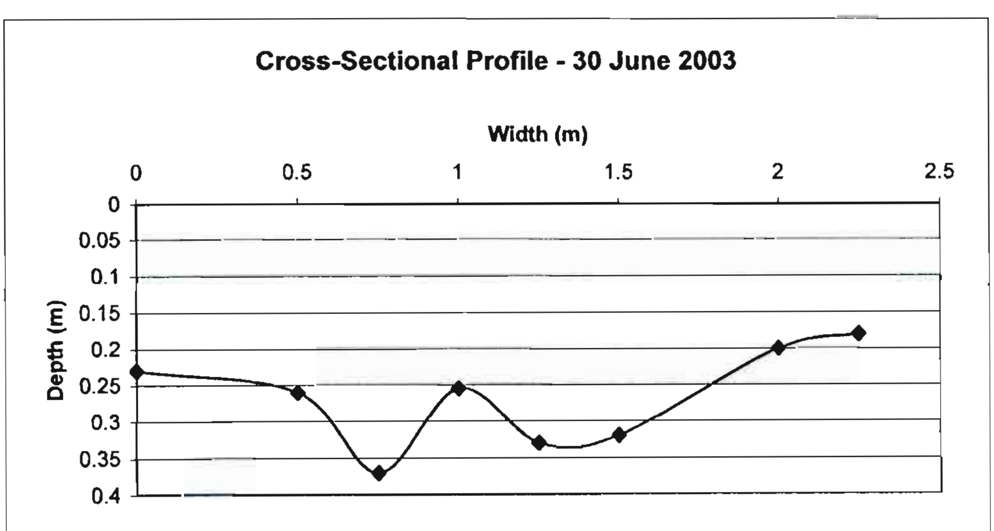

Cross-Sectional Profile - 3 July 2003
Width (m)
0
0.5
1
1.5
2
2.5
3
Depth (m)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45



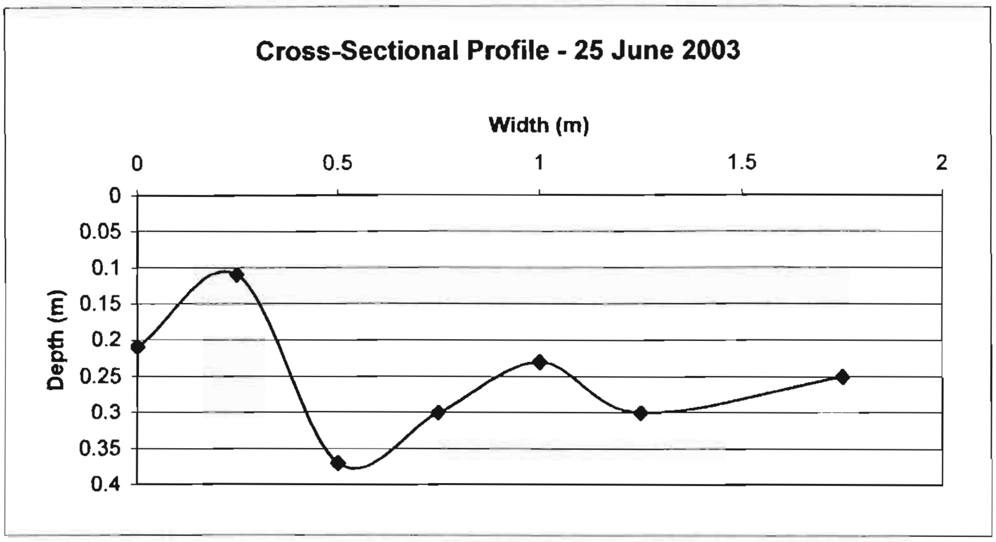
Cross-Sectional Profile - 28 June 2003
Width (m)
0
0.5
1
1.5
2
2.5
Depth (m)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45

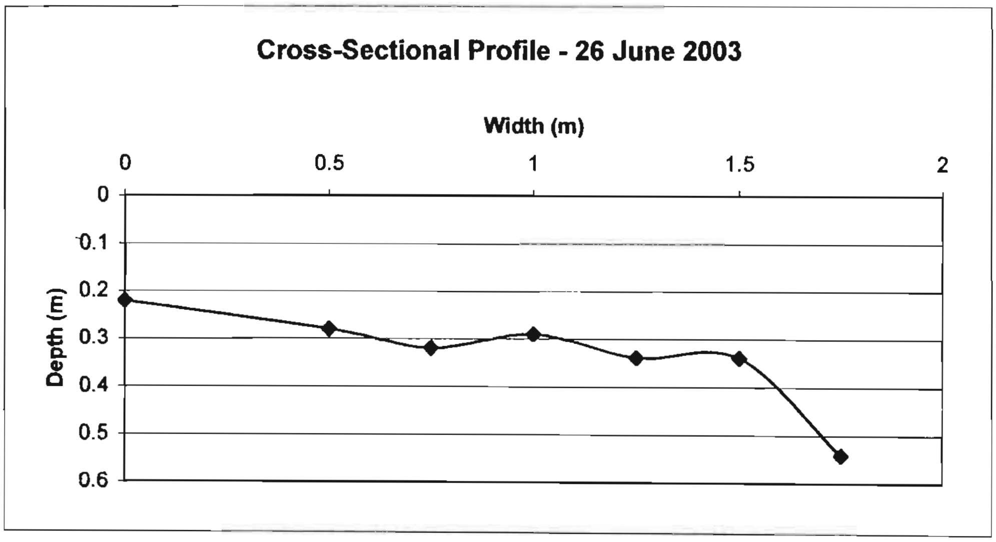



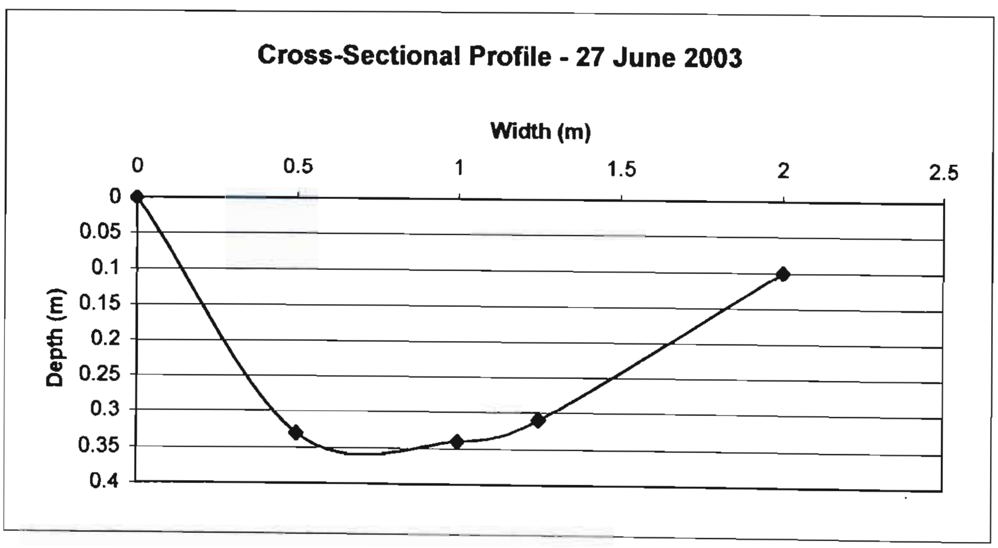
Cross-Sectional Profile - 29 June 2003
Width (m)
0
0.5
1
1.5
2
2.5
3
Depth (m)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45

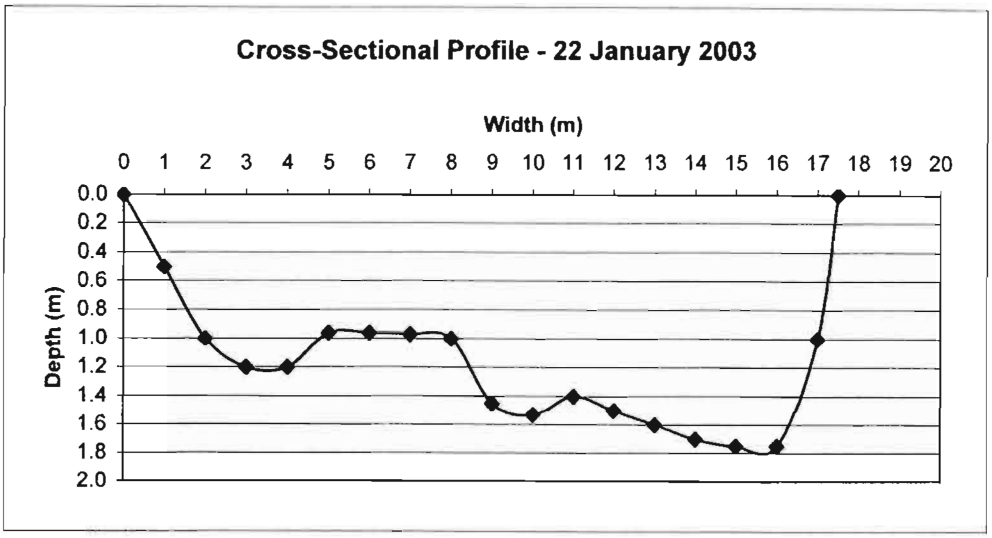



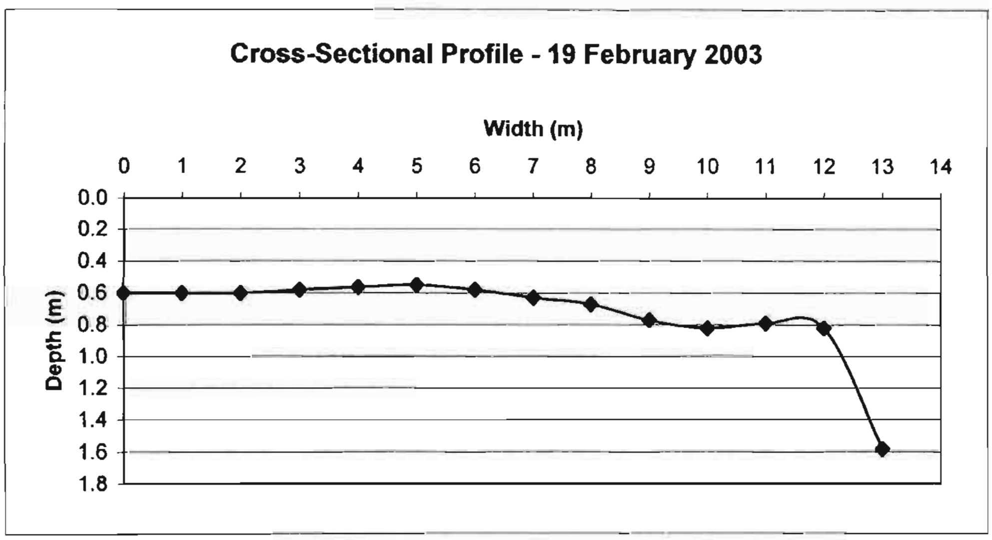
Cross-Sectional Profile - 30 June 2003
Width (m)
0
0.5
1
1.5
2
2.5
Depth (m)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4

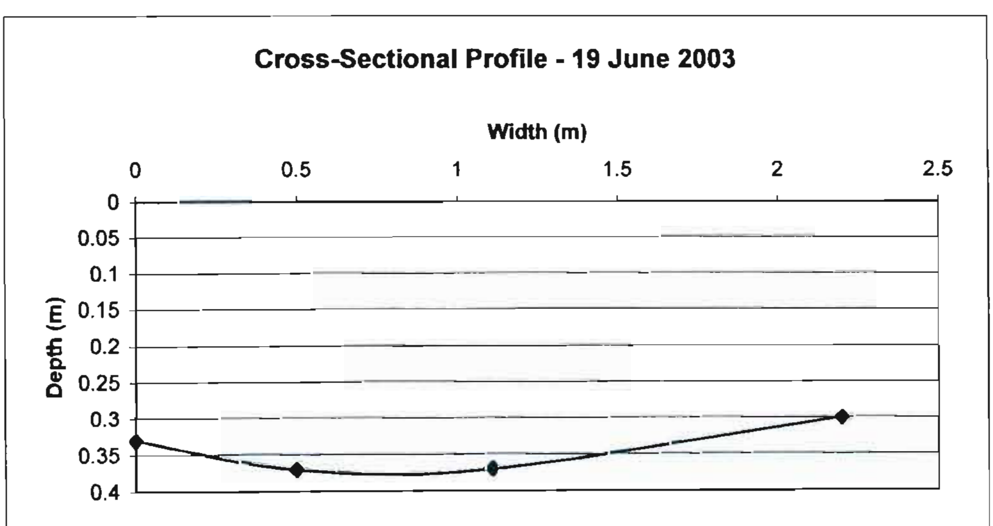

Cross-Sectional Profile - 25 June 2003
Width (m)
0
0.5
1
1.5
2
Depth (m)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4

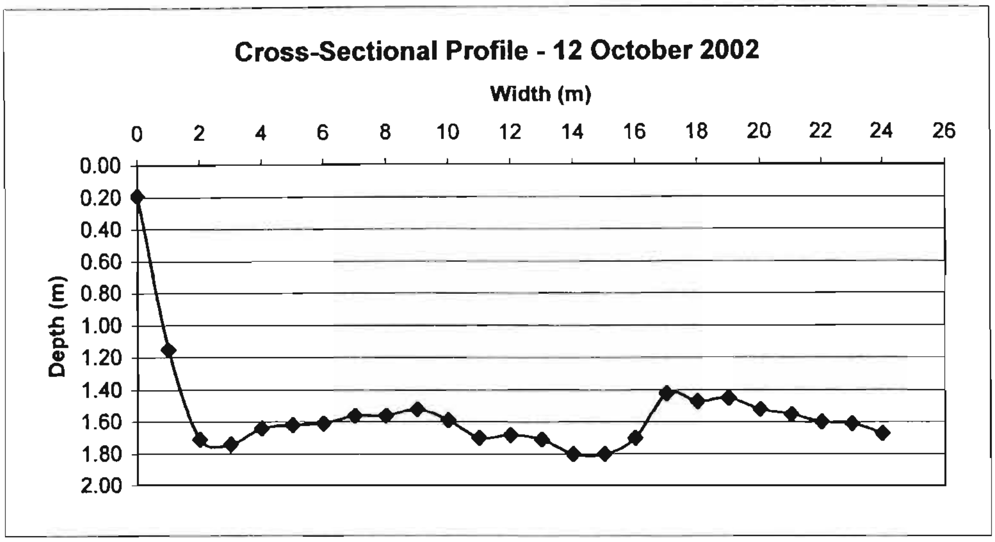

Cross-Sectional Profile - 26 June 2003
Width (m)
0
0.5
1
1.5
2
Depth (m)
0
0.1
0.2
0.3
0.4
0.5
0.6

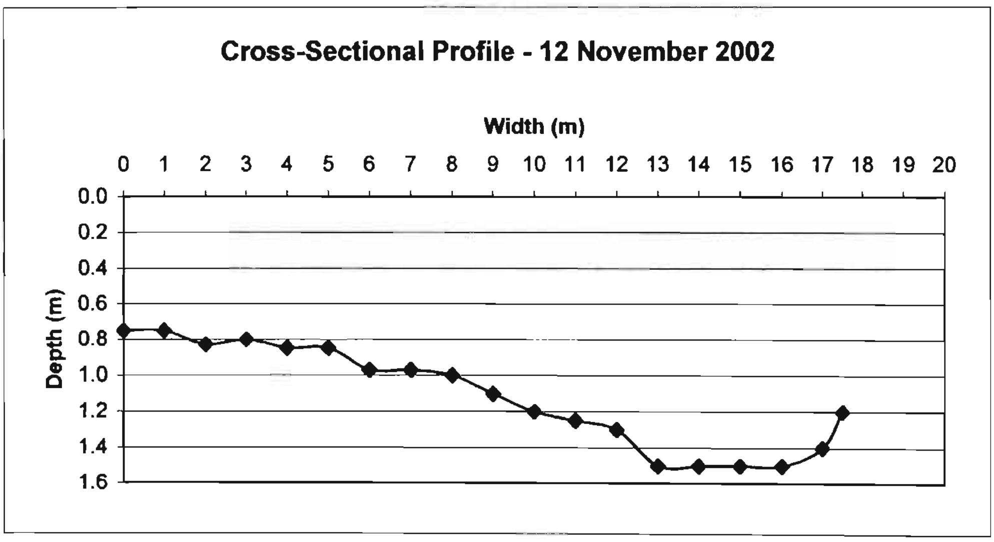

Cross-Sectional Profile - 27 June 2003
Width (m)
0
0.5
1
1.5
2
2.5
Depth (m)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4

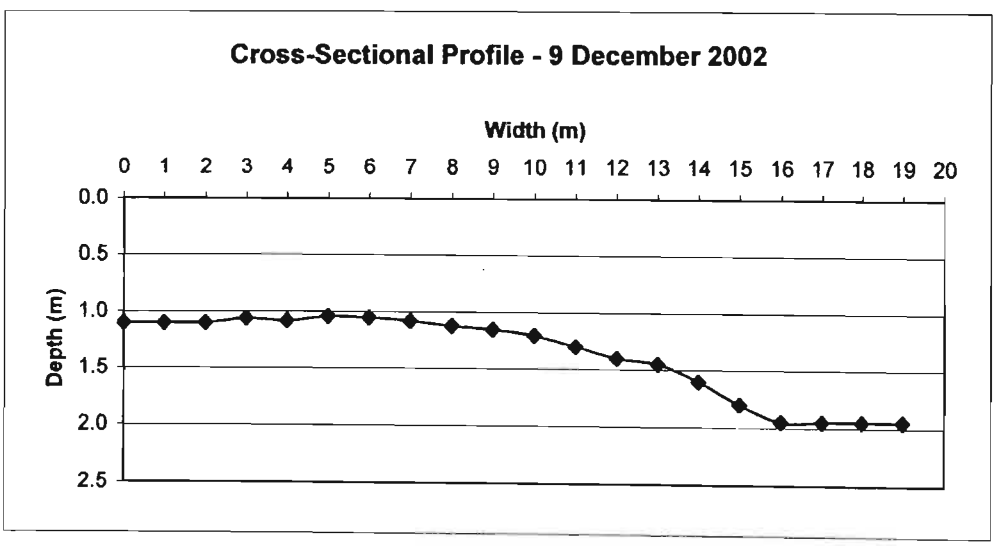

Cross-Sectional Profile - 22 January 2003
Width (m)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (m)
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0

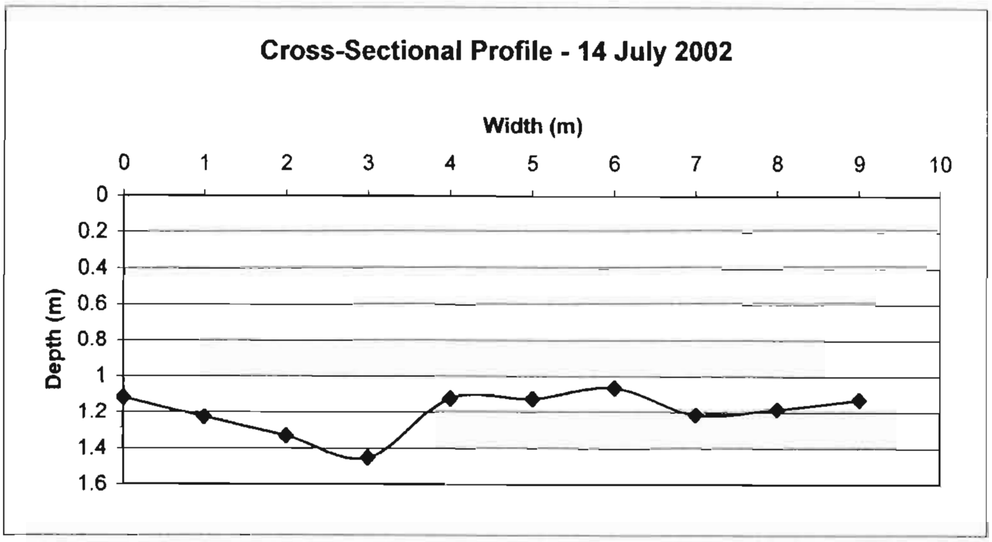

Cross-Sectional Profile - 19 February 2003
Width (m)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Depth (m)
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8

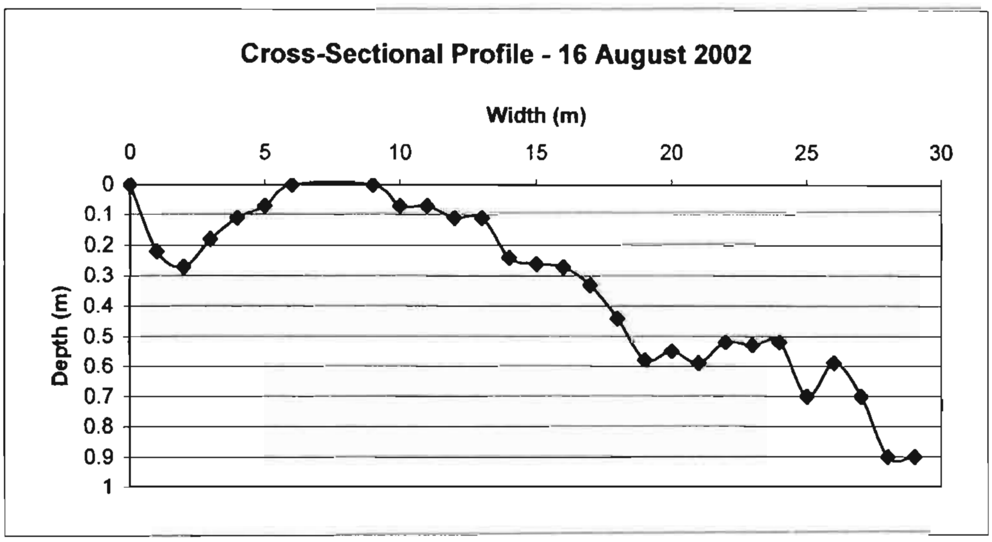

Cross-Sectional Profile - 19 June 2003
Width (m)
0 0.5 1 1.5 2 2.5
Depth (m)
0 0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4

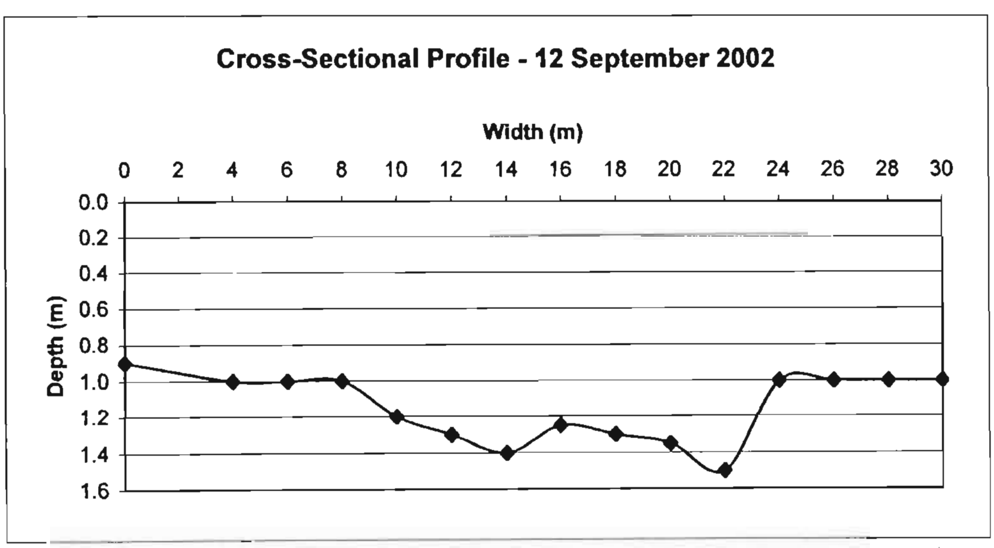

Cross-Sectional Profile - 12 October 2002
Width (m)
0 2 4 6 8 10 12 14 16 18 20 22 24 26
Depth (m)
0.00 0.20 0.40 0.60 0.80 1.00 1.20 1.40 1.60 1.80 2.00


Cross-Sectional Profile - 12 November 2002
Width (m)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (m)
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6


Cross-Sectional Profile - 9 December 2002
Width (m)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (m)
0.0 0.5 1.0 1.5 2.0 2.5


Cross-Sectional Profile - 14 July 2002
Width (m)
Depth (m)


Cross-Sectional Profile - 16 August 2002
Width (m)
Depth (m)


Cross-Sectional Profile - 12 September 2002
Width (m)
Depth (m)

**EXAMPLE OF DATA RETRIEVED FROM WATER LEVEL MONITORS AND PROCESSED**

Mhlanga Estuary

Calibration constant (c)= 2.24 (Processed data = ΔWL+ΔP+Measured)

| Date & time | Voltage (mV) | Change in Voltage (ΔV) | Change in water level =ΔV*c (mm) | Change in Pressure (mm) | Photos (mm) | Measured (mm) | Processed data (mm) |
|---|---|---|---|---|---|---|---|
| 30/05/03 11:00 | 1010 | 0 | 0 | 0 | 1908 | 1884 | 1884.0 |
| 30/05/03 12:00 | 1000 | -10 | -22.4 | 9.185 | | | 1870.8 |
| 30/05/03 13:00 | 990 | -20 | -44.8 | 22.453 | | | 1861.7 |
| 30/05/03 14:00 | 990 | -20 | -44.8 | 25.514 | | | 1864.7 |
| 30/05/03 15:00 | 990 | -20 | -44.8 | 27.555 | | | 1866.8 |
| 30/05/03 16:00 | 990 | -20 | -44.8 | 27.555 | | | 1866.8 |
| 30/05/03 17:00 | 1000 | -10 | -22.4 | 18.370 | | | 1880.0 |
| 30/05/03 18:00 | 1000 | -10 | -22.4 | 13.267 | | | 1874.9 |
| 30/05/03 19:00 | 1010 | 0 | 0 | 3.062 | | | 1887.1 |
| 30/05/03 20:00 | 1010 | 0 | 0 | 1.021 | | | 1885.0 |
| 30/05/03 21:00 | 1010 | 0 | 0 | 0.000 | | | 1884.0 |
| 30/05/03 22:00 | 1020 | 10 | 22.4 | -4.082 | | | 1902.3 |
| 30/05/03 23:00 | 1020 | 10 | 22.4 | -4.082 | | | 1902.3 |
| 31/05/03 00:00 | 1020 | 10 | 22.4 | 0.000 | | | 1906.4 |
| 31/05/03 01:00 | 1020 | 10 | 22.4 | -3.062 | | | 1903.3 |
| 31/05/03 02:00 | 1020 | 10 | 22.4 | 1.021 | | | 1907.4 |
| 31/05/03 03:00 | 1020 | 10 | 22.4 | 2.041 | | | 1908.4 |
| 31/05/03 04:00 | 1020 | 10 | 22.4 | 6.123 | | | 1912.5 |
| 31/05/03 05:00 | 1020 | 10 | 22.4 | 8.165 | | | 1914.6 |
| 31/05/03 06:00 | 1030 | 20 | 44.8 | 4.082 | | | 1932.9 |
| 31/05/03 07:00 | 1030 | 20 | 44.8 | 0.000 | | | 1928.8 |
| 31/05/03 08:00 | 1040 | 30 | 67.2 | -4.082 | | | 1947.1 |
| 31/05/03 09:00 | 1040 | 30 | 67.2 | -9.185 | | | 1942.0 |
| 31/05/03 10:00 | 1040 | 30 | 67.2 | -7.144 | | | 1944.1 |
| 31/05/03 11:00 | 1040 | 30 | 67.2 | 5.103 | | | 1956.3 |
| 31/05/03 12:00 | 1030 | 20 | 44.8 | 12.247 | | | 1941.0 |
| 31/05/03 13:00 | 1030 | 20 | 44.8 | 19.391 | | | 1948.2 |
| 31/05/03 14:00 | 1030 | 20 | 44.8 | 23.473 | | | 1952.3 |
| 31/05/03 15:00 | 1030 | 20 | 44.8 | 25.514 | | | 1954.3 |
| 31/05/03 16:00 | 1020 | 10 | 22.4 | 23.473 | | | 1929.9 |
| 31/05/03 17:00 | 1030 | 20 | 44.8 | 22.453 | | | 1951.3 |
| 31/05/03 18:00 | 1030 | 20 | 44.8 | 18.370 | | | 1947.2 |
| 31/05/03 19:00 | 1040 | 30 | 67.2 | 16.329 | | | 1967.5 |
| 31/05/03 20:00 | 1040 | 30 | 67.2 | 7.144 | | | 1958.3 |
| 31/05/03 21:00 | 1040 | 30 | 67.2 | 8.165 | | | 1959.4 |
| 31/05/03 22:00 | 1050 | 40 | 89.6 | 7.144 | | | 1980.7 |
| 31/05/03 23:00 | 1050 | 40 | 89.6 | 12.247 | | | 1985.8 |
| 01/06/03 00:00 | 1050 | 40 | 89.6 | 10.937 | | | 1984.5 |
| 01/06/03 01:00 | 1050 | 40 | 89.6 | 12.978 | | | 1986.6 |
| 01/06/03 02:00 | 1050 | 40 | 89.6 | 17.061 | | | 1990.7 |
| 01/06/03 03:00 | 1050 | 40 | 89.6 | 17.061 | | | 1990.7 |
| 01/06/03 04:00 | 1050 | 40 | 89.6 | 24.206 | | | 1997.8 |
| 01/06/03 05:00 | 1050 | 40 | 89.6 | 23.185 | | | 1996.8 |
| 01/06/03 06:00 | 1050 | 40 | 89.6 | 17.061 | | | 1990.7 |
| 01/06/03 07:00 | 1050 | 40 | 89.6 | 18.082 | | | 1991.7 |
| 01/06/03 08:00 | 1060 | 50 | 112 | 15.020 | | | 2011.0 |
| 01/06/03 09:00 | 1060 | 50 | 112 | 16.041 | | | 2012.0 |
| 01/06/03 10:00 | 1060 | 50 | 112 | 20.123 | | | 2016.1 |
| 01/06/03 11:00 | 1060 | 50 | 112 | 30.330 | | | 2026.3 |
| 01/06/03 12:00 | 1050 | 40 | 89.6 | 40.537 | | | 2014.1 |
| 01/06/03 13:00 | 1040 | 30 | 67.2 | 46.662 | | | 1997.9 |
| 01/06/03 14:00 | 1030 | 20 | 44.8 | 60.951 | | | 1989.8 |
| 01/06/03 15:00 | 1020 | 10 | 22.4 | 66.055 | | | 1972.5 |
| 01/06/03 16:00 | 1020 | 10 | 22.4 | 69.117 | | | 1975.5 |
| 01/06/03 17:00 | 1030 | 20 | 44.8 | 67.076 | | | 1995.9 |
| 01/06/03 18:00 | 1040 | 30 | 67.2 | 60.951 | | | 2012.2 |
| 01/06/03 19:00 | 1040 | 30 | 67.2 | 57.889 | | | 2009.1 |
| 01/06/03 20:00 | 1040 | 30 | 67.2 | 59.931 | | | 2011.1 |
| 01/06/03 21:00 | 1040 | 30 | 67.2 | 62.993 | | | 2014.2 |
| 01/06/03 22:00 | 1040 | 30 | 67.2 | 62.993 | | | 2014.2 |
| 01/06/03 23:00 | 1050 | 40 | 89.6 | 69.117 | | | 2042.7 |

**APPENDIX H: SALINITY DATA**

**Summary of salinity data recorded at Mhlanga Estuary.**

| Date | Time | Estuary State | Tidal Situation | Salinity profile | Salinity Range (ppt) |
|---|---|---|---|---|---|
| 20 Mar 02 | 10:40 | Closed (day 10) | 3 days before neap | Vertical stratification | 1.1-27.7 |
| 19 Apr 02 | 12:30 | Open (day 2) | 1 day before neap (low) | Longitudinal stratification | 0.3-1.8 |
| 21 May 02 | 13:30 | Open (day 1) | 1 day after neap (high) | Vertical stratification | 1.1-20.9 |
| 19 Jun 02 | 14:30 | Partially open (day 3) | 1 day after neap (mid) | Vertical stratification | 0.6-21.3 |
| 18 Jul 02 | 12:00 | Open (day 11) | 1 day after neap (high) | Vertical stratification | 0.5-26.2 |
| 16 Aug 02 | 12:30 | Partially open (day 2) | 1 day before neap (mid) | Fresh intrusion at head, saline at mouth | 0.2-20.4 |
| 13 Sept 02 | 12:50 | Closed (day 3) | 2 days before neap | Vertical stratification | 2.5-28.3 |
| 15 Oct 02 | 14:30 | Closed (day 10) | 1 day after neap | Dominated by brackish water | 0.9-22 |
| 13 Nov 02 | 12:40 | Partially open (day 3) | 1 day after neap (high) | Some vertical stratification | 1.5-19.4 |
| 10 Dec 02 | 14:20 | Open (day 4) | 2 days before neap (low) | Longitudinal stratification | 0.3-25.2 |
| 23 Jan 03 | 13:00 | Open (day 7) | 3 days before neap (low) | Fresh | 0.1-0.2 |
| 10 Feb 03 | 10:00 | Closed (day 1) | neap | Slight Vertical stratification | 0.8-9.9 |

**Notes:**

**Tidal situation given was taken from Hopper 2003, and is the estimated tide for Durban.**

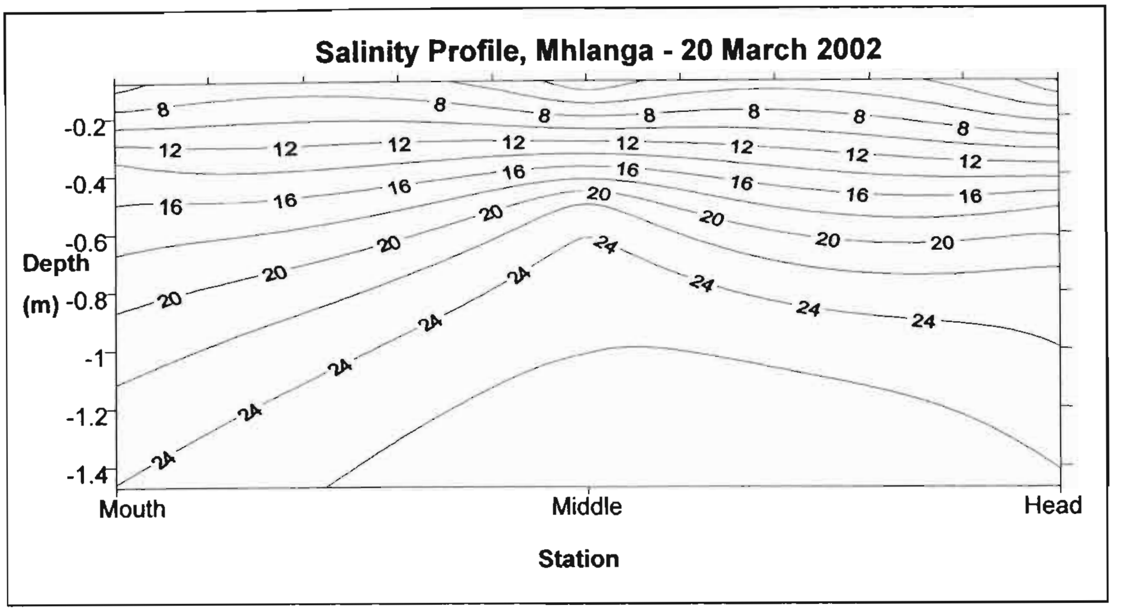
**Summary of salinity data recorded at Mdloti Estuary.**

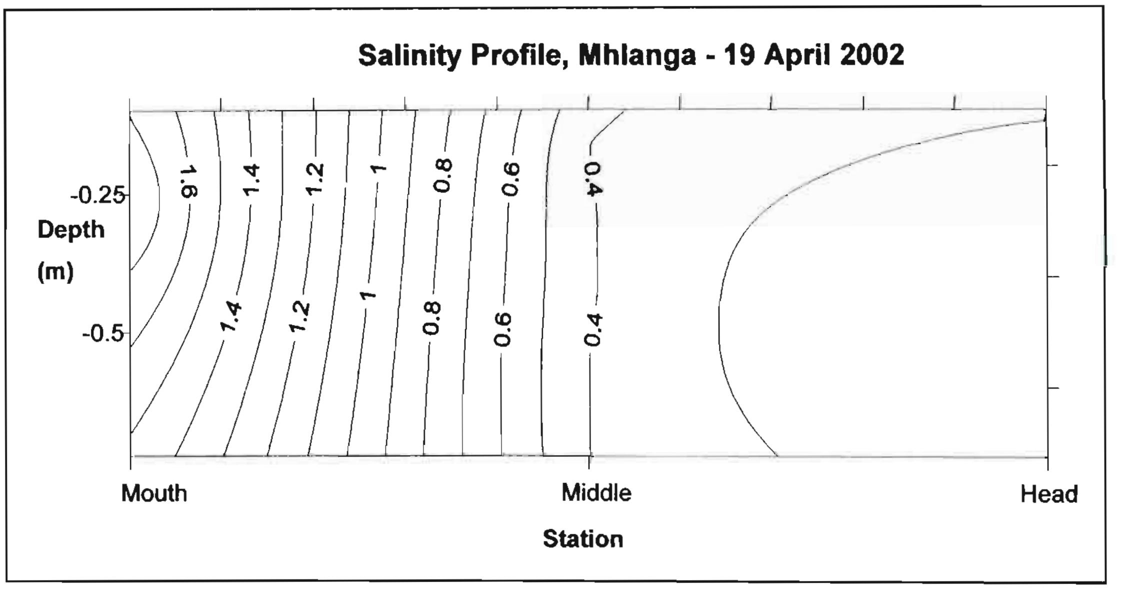
| Date | Time | Estuary State | Tidal Situation | Salinity profile | Salinity Range (ppt) |
|---|---|---|---|---|---|
| 19 Mar 02 | 10:40* | Open * | 4 days before neap | | 1.6-16 |
| 18 Apr 02 | 10:50 | Open (day 1) | 2 days before neap (low) | Slight longitudinal stratification | 0-1 |
| 22 May 02 | 12:40 | Closed * | 2 days after neap | Mixed – Low salinity | 1.2-2.4 |
| 20 Jun 02 | 13:45 | Closed (day 19) | 2 days after neap | Mixed - Fresh | 0.3-0.4 |
| 17 Jul 02 | 11:00-13:00 | Closed (day 46) | Neap | Fresh, salinity increase towards mouth | 0.2-0.3 |
| 15 Aug 02 | 11:30 | Partially Open (day 3) | 2 days before neap (mid) | Slight vertical stratification | 0.2-1.7 |
| 12 Sept 02 | 12:00 | Partially Open (day 1) | 3 days before neap (low) | Increased salinity with depth | 5.7-20.4 |
| 16 Oct 02 | 13:00 | Open (day 1) | 2 days after neap (high) | none | 1-23.9 |
| 13 Nov 02 | 13:50 | Closed (day 13) | 1 day after neap | Low salinity, highest salinity at mouth | 0.5-0.9 |
| 9 Dec 02 | 16:30 | Closed * | 3 days before neap | Fresh, salinity increase towards mouth | 0.1-0.3 |
| 22 Jan 03 | 12:10 | Open (day 1) | 4 days before neap (low) | Fresh. (Flooding event) | 0.1-0.3 |
| 19 Feb 03 | 11:00 | Closed (day 11) | 6 days before neap | Highest salinity in bottom layers near mouth | 1.1-8.4 |

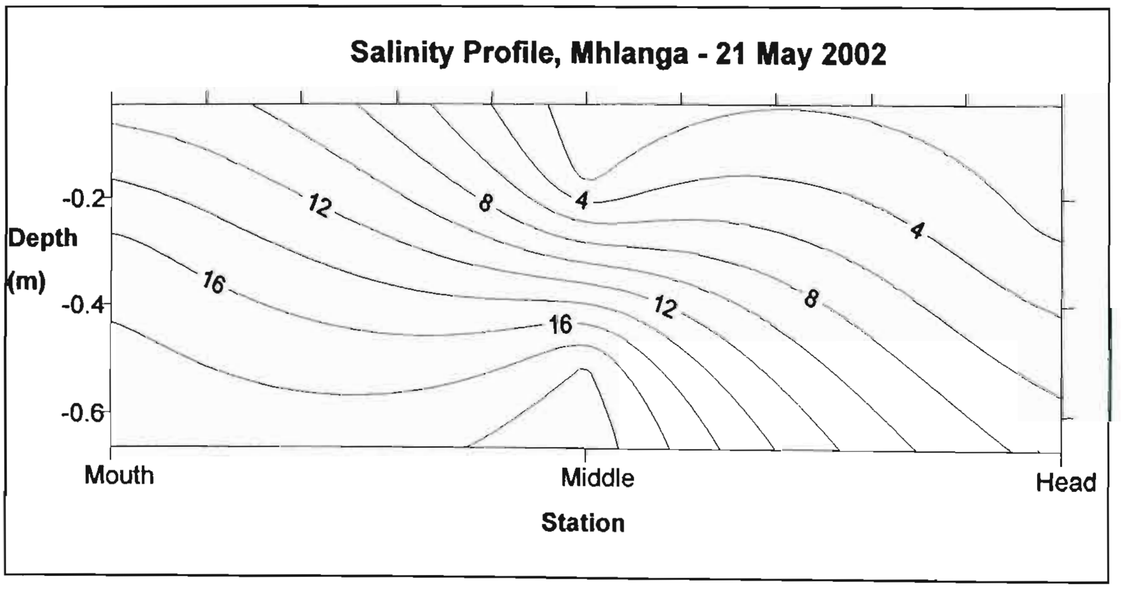
**Notes:**

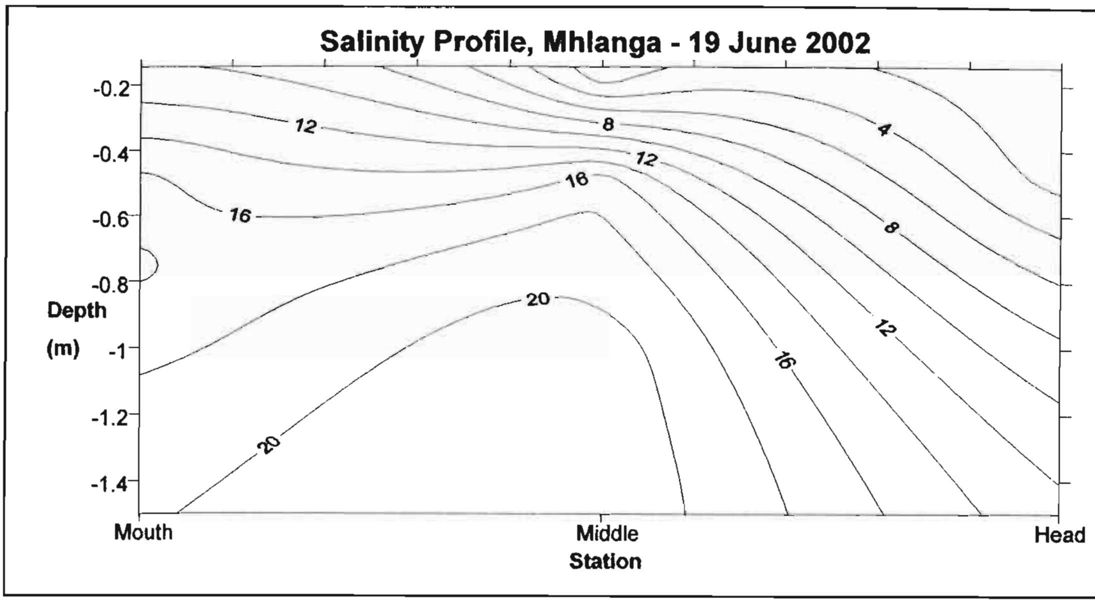
**Tidal situation given was taken from Hopper 2003, and is the estimated tide for Durban.**

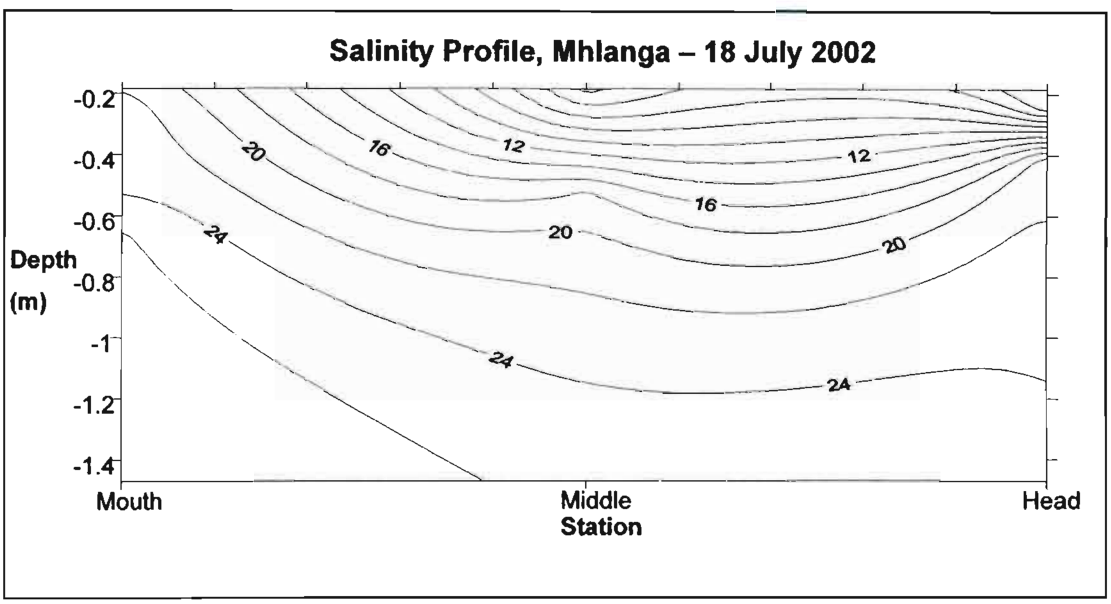
***Data missing**

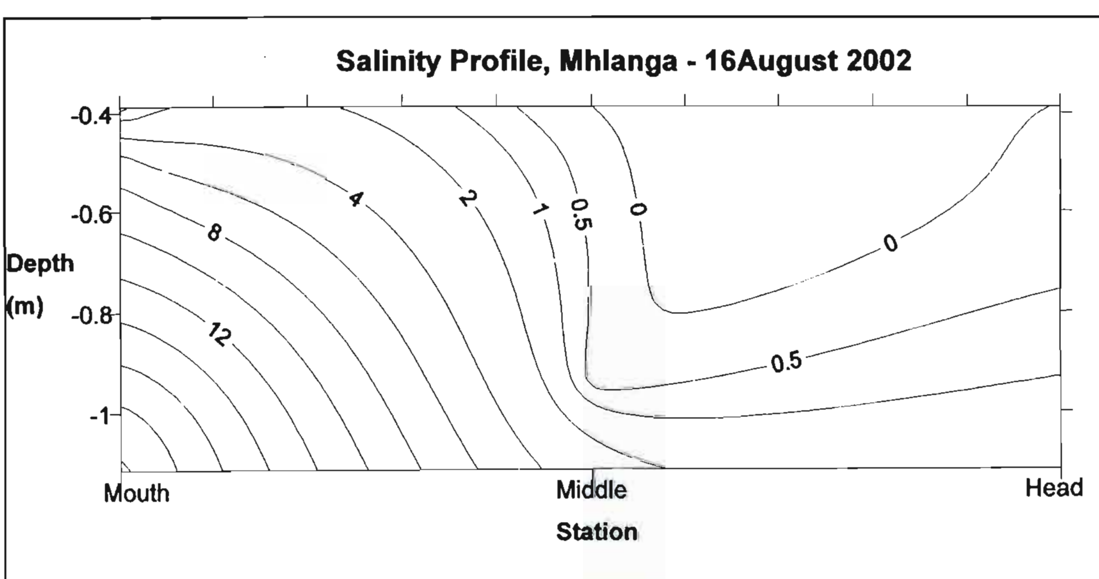

Salinity Profile, Mhlanga - 20 March 2002
Depth (m)
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
8
12
16
20
24
Mouth
Middle
Head
Station

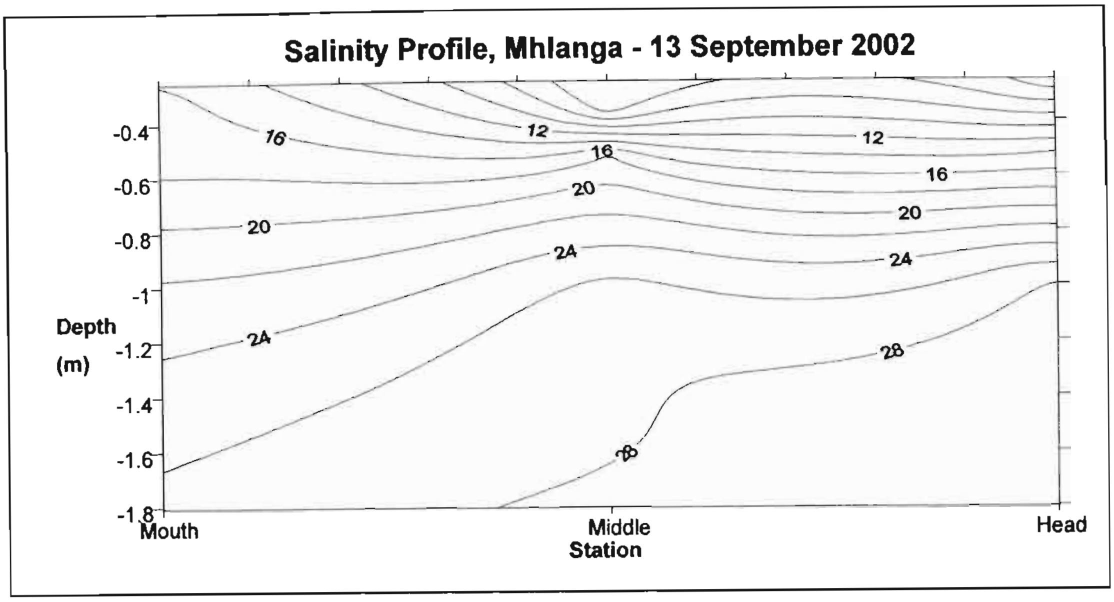

Salinity Profile, Mhlanga - 19 April 2002
Depth (m)
-0.25
-0.5
1.6
1.4
1.2
1
0.8
0.6
0.4
Mouth
Middle
Head
Station

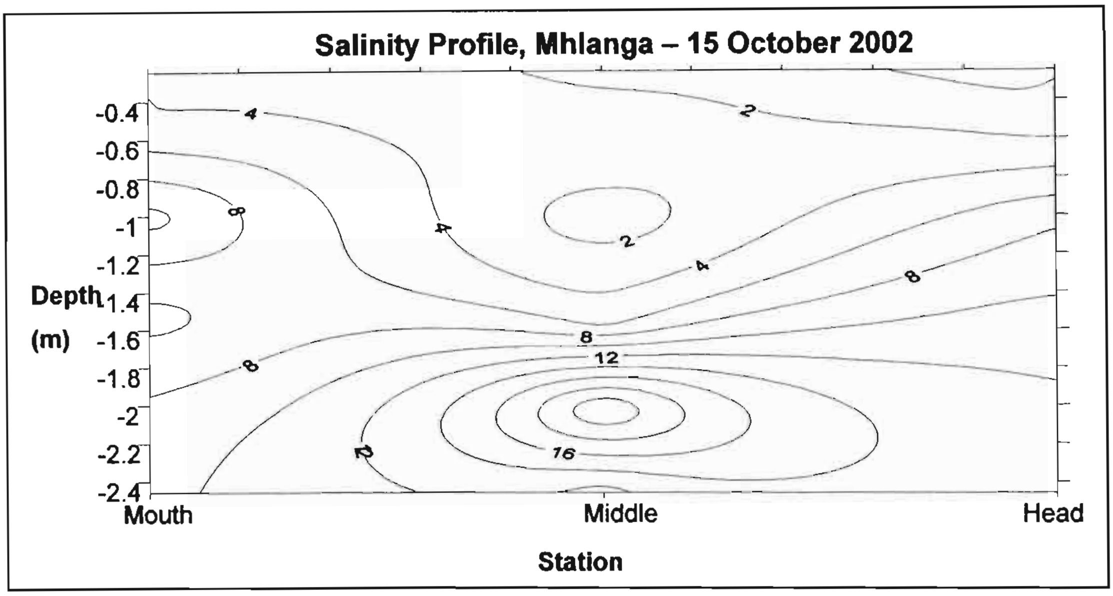

Salinity Profile, Mhlanga - 21 May 2002
Depth (m)
-0.2
-0.4
-0.6
4
8
12
16
Mouth
Middle
Head
Station

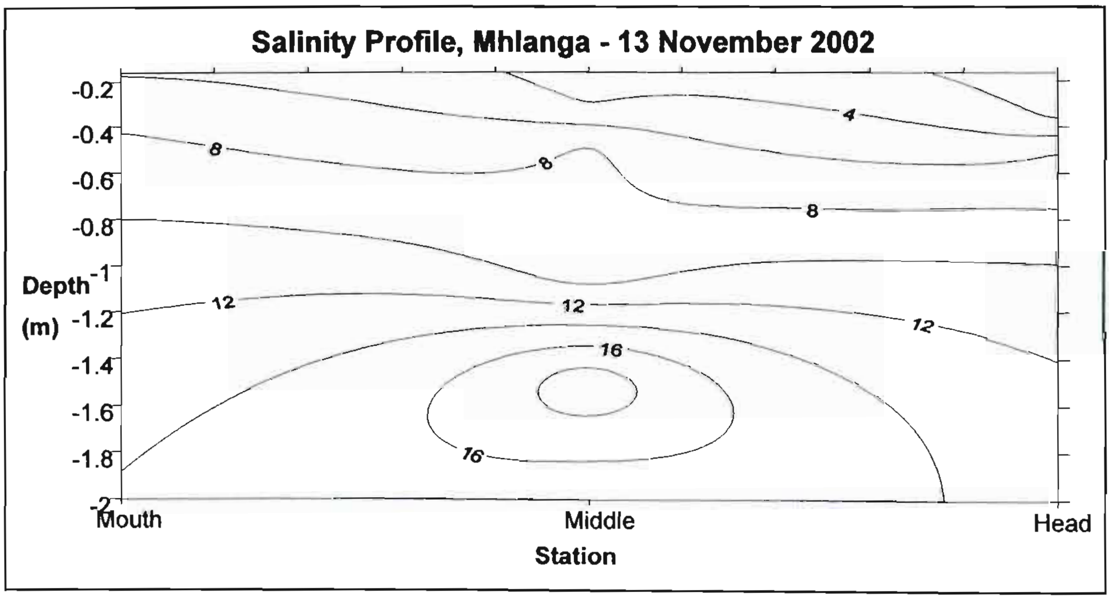

Salinity Profile, Mhlanga - 19 June 2002
Depth
(m)
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
12
8
4
12
16
16
8
20
12
16
20
Mouth
Middle
Head
Station

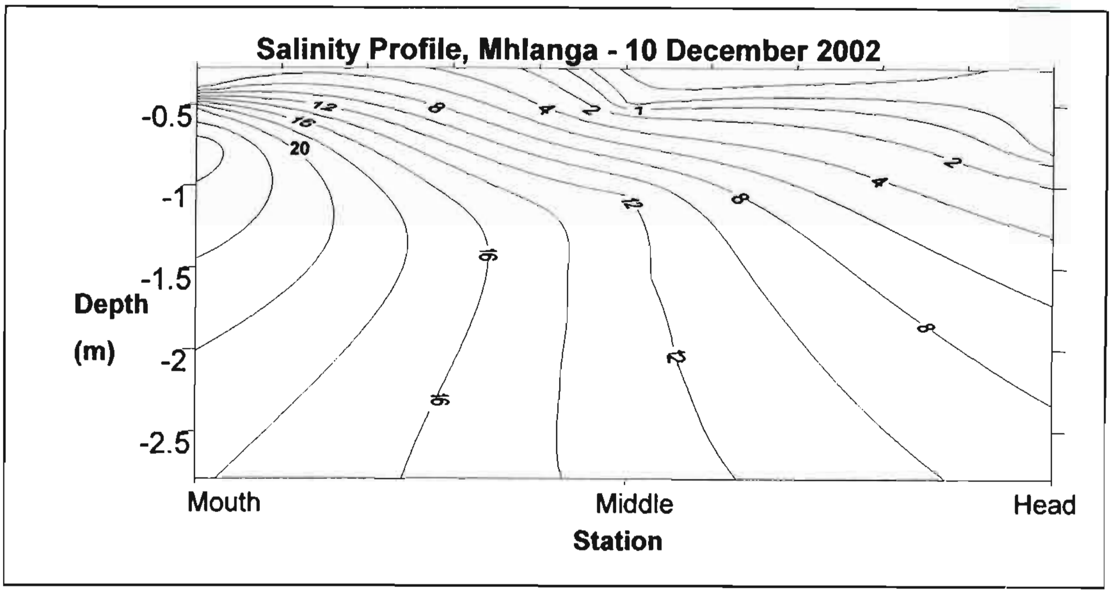

Salinity Profile, Mhlanga – 18 July 2002
Depth
(m)
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
20
16
12
12
16
20
20
24
24
24
Mouth
Middle
Head
Station

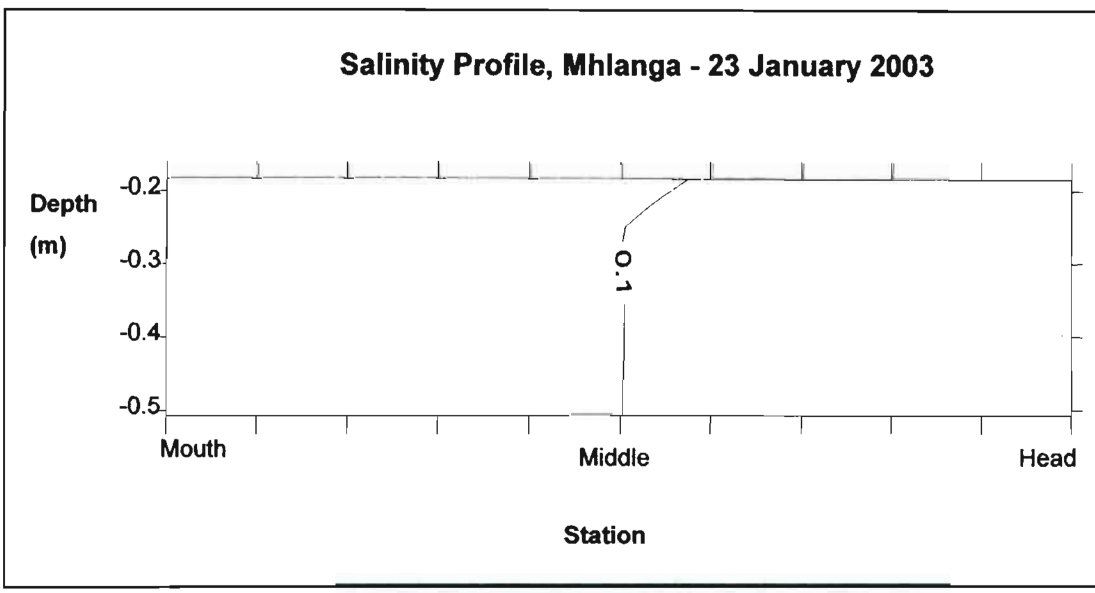

Salinity Profile, Mhlanga - 16August 2002
Depth
(m)
-0.4
-0.6
-0.8
-1
4
2
1
0.5
0
8
0
12
0.5
Mouth
Middle
Head
Station

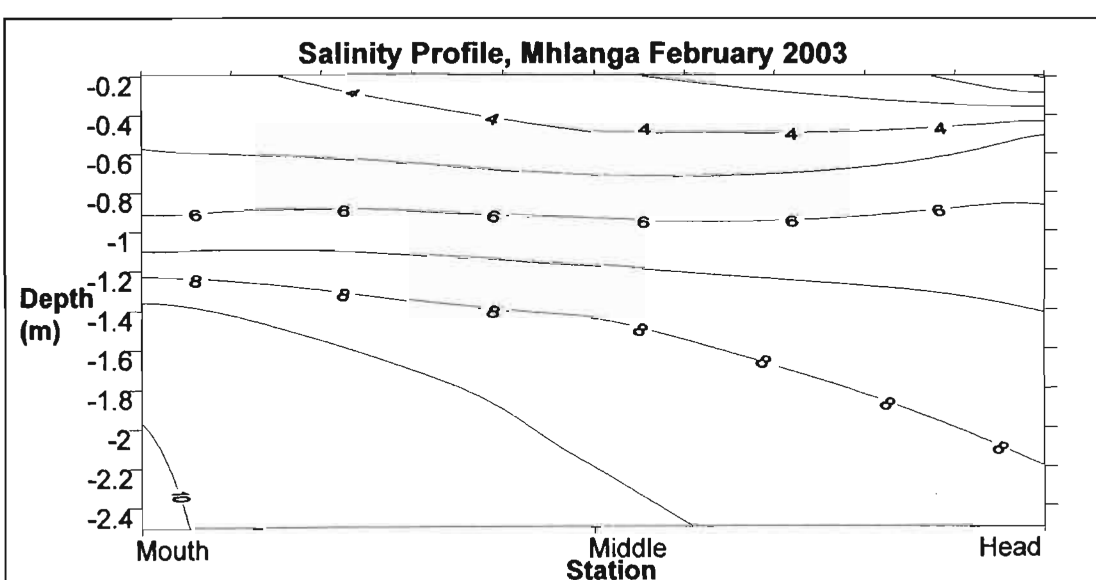

Salinity Profile, Mhlanga - 13 September 2002
Depth (m)
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
16
12
16
20
24
28
Mouth
Middle
Head
Station

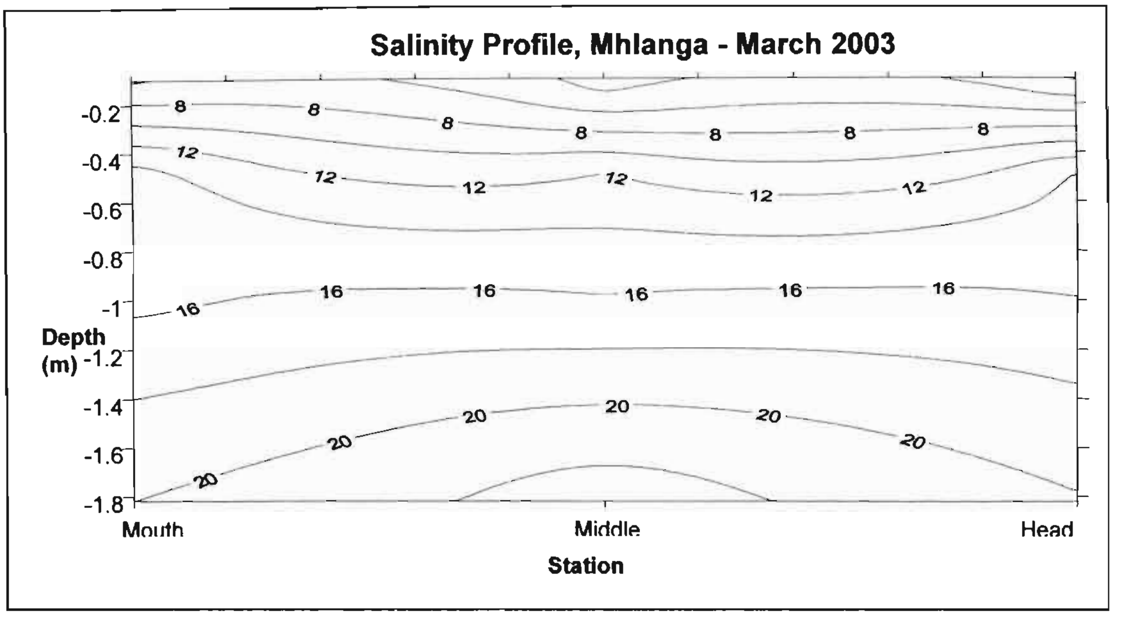

Salinity Profile, Mhlanga – 15 October 2002
Depth (m)
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
-2
-2.2
-2.4
2
4
8
12
16
Mouth
Middle
Head
Station


Salinity Profile, Mhlanga - 13 November 2002
Depth (m)
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
-2
4
8
12
16
Mouth
Middle
Head
Station


Salinity Profile, Mhlanga - 10 December 2002
Depth (m)
-0.5
-1
-1.5
-2
-2.5
12
8
4
2
1
16
20
2
4
12
8
16
16
12
8
Mouth
Middle
Head
Station


Salinity Profile, Mhlanga - 23 January 2003
Depth (m)
-0.2
-0.3
-0.4
-0.5
0.1
Mouth
Middle
Head
Station


Salinity Profile, Mhlanga February 2003
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
-2
-2.2
-2.4
Depth (m)
4
6
8
10
Mouth
Middle
Head
Station



Salinity Profile, Mhlanga - March 2003
Depth (m)
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
8
12
16
20
Mouth
Middle
Head
Station