UNIVERSITY OF KWAZULU-NATAL

School of Civil Engineering, Surveying & Construction

FINAL REPORT

EVALUATION OF THE SHORT-TERM LINK BETWEEN THE MFOLOZI ESTUARY AND ST LUCIA LAKE

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Glossary of Terms and Abbreviations

Back Channel	Man-made link between the St Lucia and Umfolozi estuaries
BCWL	Back Channel Weir Level
BC Weir	Back Channel Weir
Breaching level	Level in the Estuary above which the mouth will breach
C_dQ_o	Characteristic Flow Scale for the Mouth (m^3/s)
CPI	Current Precipitation Index (mm)
DRDEU	Daily Rainfall Data Extraction Utility
EMWL	Estuary Mean Water Level (m)
EMSL	Estuary Mean Sea Level (same as EMWL)
EKZN Wildlife	Ezemvelo KwaZulu-Natal Wildlife
FDC	Flow Duration Curve
g	acceleration due to gravity (9.81 m/s^2)
GMSL	Geodetic Mean Sea Level (m)
H	Water depth above the crest of a Broad Crested Weir (m)
HRU	Hydrological Research Unit
HWS	High Spring Tide Water Level (m)
HWSE	High Spring Tide Water Level in the Estuary when open (m)
LWS	Low Spring Tide Water Level (m)
m	Exponent
MFBL	Umfolozi Breaching Level (m)
MSL	Mean Sea Level (m)
Pan factor	Factor that relates Pan Evaporation to Actual Open Pan Evaporation
"Present inflows"	After abstractions, damming and afforestation
R	Rainfall (mm)
STBL	St Lucia Breaching Level (m)
Threshold flow	Flow below which the combined mouth would close
Q	Flow (m^3/s)
V	Lake Volume (m^3)
V_B	Lake Volume at the Breaching Level (m^3)
V_C	Critical Lake Volume (m^3)
"Virgin inflows"	Prior to significant anthropogenic influence
V_o	Lake Volume when Mouth Discharge is Zero (m^3)
Weather SA	Weather South Africa
ρ	Memory coefficient

Executive Summary

Lake St Lucia has been subjected to many artificial changes over the past century. These include:

- a decrease in inflows from its main feeder catchments (particularly the Mkuze river) due to abstractions
- the artificial separation of the Umfolozi mouth from the St Lucia mouth in 1952 - ostensibly to address the perceived threat of siltation from silt-laden Umfolozi waters
- the artificial maintenance of an open mouth between 1952 – 2002 by dredging and other measures (such as the construction of groynes in the late 60's)
- Since 2002, the management strategy has been to cease the artificial manipulation of the St Lucia mouth state and allow the system to close during drought periods, while continuing to keep the Umfolozi mouth separate
- Most recently a "back-channel" has been used to allow a limited link with the Umfolozi that diverts some fresh-water into the closed St Lucia system. This strategy is similar to that of a "link canal" that was previously explored, and unsuccessfully implemented in the 70's. In terms of mouth management, the management strategy remains to keep the Umfolozi mouth separated to prevent silt influxes into St Lucia when the Umfolozi floods. In practice the strategy is to maintain a weak point in the spit near Maphelane so that the Umfolozi will breach and form a separate mouth when it floods.

A series of modelled scenarios are presented, focusing on the management strategy of maintaining a separate Umfolozi mouth while allowing a managed flow of water via the back-channel into St Lucia to maintain the ecosystem during drought periods.

Firstly, long-term simulations have been used to illustrate the consequences of the artificial changes that have been implemented in the past and continue to be part of the current management strategy. The key result of these simulations is the conclusion that the separation of the Umfolozi and St Lucia mouths is by far the most significant anthropogenic intervention in terms of long-term impacts on the functioning of the St Lucia system. The addition of $5Mm^3$ per month of fresh water from the Umfolozi to the St Lucia via the back-channel can restore *virgin* fresh water inflows into the system, but has no significant effect on the mouth state of the St Lucia system. This indicates the importance of re-establishing a combined mouth so that the Umfolozi can resume its historical role of providing a more stable mouth state for the system.

Secondly, short-term simulations, using forecast rainfall, are used to predict the state of the system for the next nine months. They suggest that below average or even average rainfall will result in hypersaline conditions and very low water levels. Above average rainfall will see water levels increasing slowly and salinities dropping. The supply of additional freshwater via the back-channel (if the Umfolozi mouth is closed) can significantly reduce or delay the onset of hypersaline conditions (and associated low water levels) in the lake. However this strategy is only likely to be effective during the periods of low flow in the Umfolozi (typically from June through September) - the onset of spring rains will generally lead to a rapid rise in water levels in the Umfolozi basin with subsequent breaching of the berm. Preliminary hydraulic analysis of the back-channel has led to recommendations for the heights of the required key control points, in particular a crest height of the "weir" controlling the back-channel flows, and the breaching level for the Umfolozi estuary.

In summary our primary recommendations are:

1. The back-channel link should be maintained essentially as it is, with some adjustment of the control point elevations if required, since its effects are beneficial to the system in its current state.
2. The management strategy should move away from persistent intervention towards a new strategy of non-intervention, but with detailed monitoring. This includes allowing the re-establishment of the historical configuration of a combined Umfolozi/St Lucia mouth. The monitoring program and future research should focus on the uncertain issues concerning siltation and mouth dynamics.

1 Background

Extensive scientific research has been carried out on St Lucia, most of which has been focused on biological components of the system. The hydrology and physical dynamics of the system has received much less research attention, the most significant of which has been the work at the Hydrological Research Unit (HRU – University of Witwatersrand) reported by Hutchison and Pitman (1977), Hutchison and Midgley (1978). The HRU study used a water balance model to simulate the functioning of the system and to investigate the efficacy of various management options to mitigate the effects of extreme hypersaline conditions that occur during drought conditions. These measures included the importing of fresh water using various forms of link canal, which was a preferred option. It should however be noted that the HRU modelling did not include any attempt to predict the mouth state of the system: it was simply specified based on available historical observations.

Figure 1.1 Lake St Lucia with insert showing magnified view of the mouth region (Google Earth, 2005)

Lake St Lucia receives a mean annual rainfall of 890 mm (Hutchison and Pitman, 1973) and loses on average 1470mm to evaporation per annum. The surface area of the lake is roughly 300 km^2 (at average water levels) with an average depth of 1m. The high surface area to volume ratio, makes the system vulnerable to evaporative losses during drought conditions when catchment inflows reduce. The total supply of freshwater to the lake is estimated to be about 600Mm^3 per annum on average, and the total loss due to evaporation about 400Mm^3 (Hutchison, 1976). However, these values are highly variable, depending on erratic wet and dry cycles. Episodic floods contribute an immense quantity of fresh water, much of which is lost to the sea when the mouth opens. These floods act to periodically "reset" the system by flushing out salt and accumulated sediments.

Figure 1.2 Aerial view of the St Lucia/Mfolozi mouth region (Google Earth, 2008)

It is widely believed that the extensive accumulation of sediments at the mouth by the early 1950s was caused by the canalization of the Umfolozi swamps (starting in 1911) which in turn increased the silt loadings in the Mfolozi (Taylor, 2006). It should however be noted that the area experienced a prolonged drought starting in the mid 40s (one of the longest on record) which persisted until floods in 1956. In 1952 a separate Umfolozi mouth was dredged open to address the siltation issue and to protect sugarcane farms in the Umfolozi floodplain from flooding (Taylor, 2006). We note that while there appears to be a widely held perception that Umfolozi silts have been deposited into the main St Lucia lake basin there is no scientific evidence yet linking the two. After 1952, the management strategy was, and still is, to keep the two mouths separate. Management actions were also directed at maintaining a sea-estuary link and the St Lucia mouth was kept open during drought conditions. In the 1970s extensive dredging operations took place in the Narrows to increase flows. The perception seems to have been that the removal of accumulated sediment from the Narrows would cause the St Lucia mouth to stay mostly open. A sand trap was also constructed at the estuary mouth to inhibit marine sediments from closing the mouth. The management strategy of maintaining an open mouth was changed in 2002 and the mouth was allowed to close in July 2002.

In the past, when St Lucia formed a combined mouth with the Umfolozi, a narrow north extending spit developed from the Maphelane bluff due to the prevailing littoral transport patterns. An aerial photograph of the combined Umfolozi and St Lucia mouth taken in the 1930s is shown in Figure 1.3. Note the constricted mouth with a well-developed flood delta. Large floods in the Umfolozi would generally destroy this spit and the Umfolozi would discharge out to sea. Littoral transport would then re-build the spit and the mouths would recombine. When the combined mouth was closed, fresh water from the Umfolozi would have flowed into St Lucia replenishing water lost due to evaporation thus diluting salinities.

Figure 1.3 An aerial photograph illustrating the combined St Lucia and Umfolozi mouth in the 1930s (provided by Taylor, 2007)

The current drought cycle has had a severe impact on St Lucia. The mouth has remained continuously closed with extreme hypersaline conditions (and desiccation) developing in the upper reaches of the lake. Although the system has been extensively researched in the past, we believe that the re-current management crises, particularly concerning issues of mouth manipulation and catchment management, indicate a need for further research to develop our understanding of the physical and biological dynamics of this system with the aim of providing improved tools for the ongoing management of this key resource. The conservation of this wetland system relies on the implementation of appropriate management decisions informed by models based on scientific research.

Key management questions include: should the mouth be kept open artificially or be allowed to remain closed during drought conditions (Taylor *et al.*, 2006); and should the Umfolozi mouth be linked back into the St Lucia system (Taylor, 2006) as in the past (refer to Figure1.3)?

1.1 Objectives

The brief of this study was to investigate the following:

- The importance, or not, of fresh water supplied via the back-channel for the maintenance of the St Lucia ecosystem. This must consider cases where the Umfolozi mouth is open or closed, with the St Lucia mouth closed, and cases where the Umfolozi mouth is open or closed, with St Lucia mouth open.
- St Lucia water levels and salinity states (via modelling and the development of scenarios) for the next nine months, with and without fresh water from the

Umfolozi/Umsunduze via the back-channel, with and without "average" spring rain, indicating probabilities of outcomes of salinity levels becoming intolerable.

- Probabilities attached to the flow of fresh water from the Umfolozi/Umsunduze for the next 9 months, taking cognisance that should the Umfolozi come down in flood, the Umfolozi mouth will have to be breached near Maphelane, and water will no longer flow down the back-channel into the St Lucia system.
  - The probability that even a minor flood in the Umfolozi River will force the opening of the Umfolozi mouth to the sea.
  - The quantity of water that is likely to be available to flow into St Lucia
  - The evaporative losses that can be expected in St Lucia over this time period and how much of this evaporative loss will be offset by the inflowing Umfolozi/Umsunduze water.
- The deepening or widening of the back-channel to allow increased fresh water flow from the Umfolozi/Umsunduze rivers into St Lucia, with provision for the rapid closing of the Back-channel in the event that the Umfolozi river comes down in flood.

1.2 Outline of the Report

The following chapters included in this report are outlined as follows:

- Chapter Two presents the methodology. The various parameters included in the water balance model are introduced.
- Chapter Three presents the results of the various simulations. A validation of the model is included and the objectives of the report are investigated. A sensitivity analysis of key parameters is also included.
- Chapter Four presents the conclusions of the study followed by
- Recommendations regarding management strategies and for further research are considered in Chapter Five.

2 Methodology

The freshwater inputs to the St Lucia Lake system comprise 1) rainfall, 2) river inflow mainly from the Mkuze, Hluhluwe, Mzinene and Nyalazi Rivers and 3) groundwater seepage along the Eastern Shores. The mouth state is a major driver of the functioning of the system. Closed mouth conditions allow fresh water to accumulate, but losses due to evaporation exceed the inputs during dry periods. Open mouth conditions on the other hand allow the inflow of seawater thereby modulating the water level in the lake. Water levels and salinities are key influences on the biological functioning of the system.

The water balance model developed for the study is similar to the model developed by Hutchison and Midgley (1978), but incorporates the mouth dynamics. The various components of the model are introduced in the following section. Due to the lack of measured river flows, inflows were simulated using the Pitman (1973) model, and a method based on flow duration curves (Smakhtin and Masse, 2000). The model was validated using measured monthly salinities provided by EKZN Wildlife. In order to estimate what may ensue in the next nine months, rainfall data was forecast for different scenarios and the corresponding flows simulated. A sensitivity analysis was performed to assess the effects of uncertain parameters on the modelling results.

2.1 Water Balance Model of the Lake System

The water balance model includes the ability to simulate the intermittent closing and breaching of the mouth. The model operates according to a monthly time step. Mouth state, average salinities and average water levels can be simulated to test various management strategies.

For simplicity, the model represents St Lucia Lake as one unified basin. Simulated salinities and water levels are therefore averaged over the whole lake system. Data inputs for the model include monthly rainfall, evaporation, river inflows, mouth discharge and Umfolozi flows. A few key parameters must be specified for the model and will be discussed in the following sections.

2.1.1 Volume, surface area and water level relationship for the St Lucia basin

The morphology of the lake was analysed by Hutchison (1974) based on a bathymetric survey carried out in the 70's. The analysis yielded relationships between water level, surface area and volume. The same relationships were used for the present model, but it is recognized that significant changes may have occurred. This input data can and should be updated as soon as new measurements become available.

2.1.2 Freshwater inflows

The model has been set-up to use simulated inflows for both "*virgin*" and "*present*" conditions as defined by Hutchison and Pitman (1977). *Virgin* conditions refer to a state prior to significant anthropogenic influence. *Present* conditions include the effects of abstractions, dams and afforestation. Hutchison and Pitman (1977) suggested that these have led to a roughly 20 % reduction of fresh water inflows into the lake (a total reduction of 60Mm^3 of fresh water, or 5Mm^3 per month). Changes since the 1970s are not known and require further investigation.

Flow gauges of the rivers that feed Lake St Lucia are located some distance from the lake and provide relatively limited or incomplete/unreliable data. Therefore, Hutchinson and Pitman (1973) used the rainfall-runoff model developed by Pitman (1973) to simulated monthly inflow from each of the surrounding catchments for the period 1918 to 1971. In order to extend this information, observed rainfall data from the same surrounding fifty-seven weather stations were extracted from the Daily Rainfall Data Extraction Utility (DRDEU, developed by Kunz, 2004). These were supplemented with recent data provided by Weather SA.

Average monthly evaporation data given by Hutchison (1976) was adopted unchanged for the present model.

A method based on flow duration curves (FDCs) and following Smakhtin and Masse (2000), was used to extend the Pitman simulated inflows to the present. A Current Precipitation Index (CPI) was computed from the rainfall data using Equation 2.1, namely

$CPI_t = \rho \, CPI_{t-1} + R_t$ **Equation 2.1**

where ρ is a memory coefficient ($\rho < 1$) and R_t is the current monthly rainfall. The CPI is a proxy indicator of catchment wetness. The duration curve for the CPI was then used to infer the corresponding flow from the FDC by matching their exceedance probabilities (refer Figure 2.1). The value of ρ was chosen to produce the best correlation with the target flows (ρ = 0.7 for the Lake catchment and ρ = 0.6 for the Mfolozi catchment).

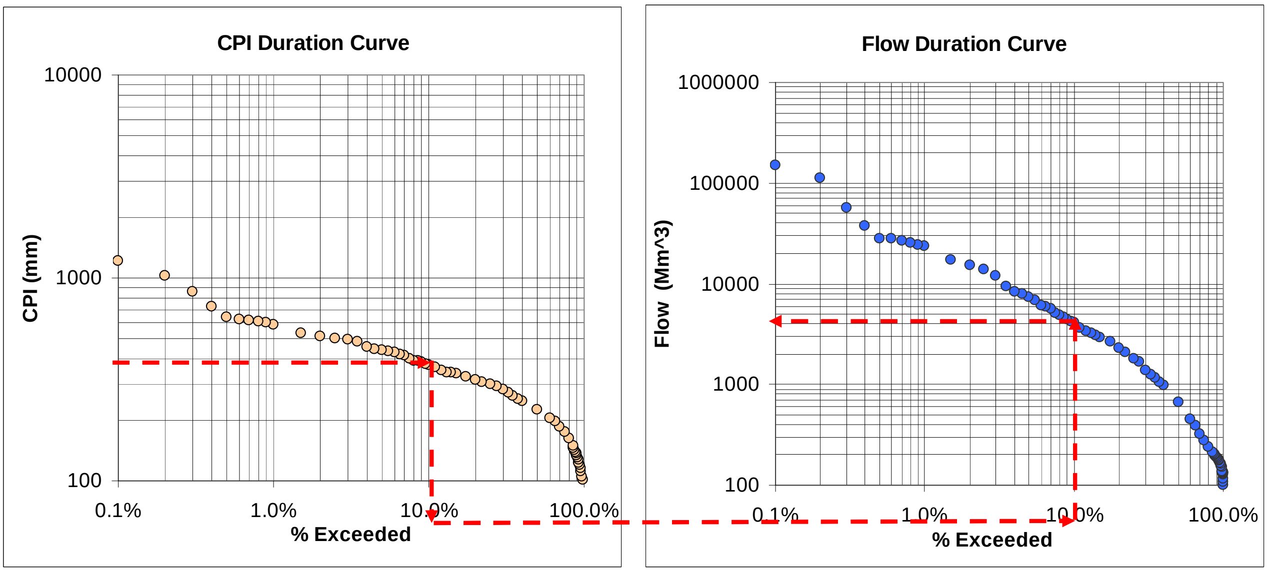

Figure 2.1 Flow and CPI duration curves used to simulate flow into the St Lucia Lake.

Figure 2.2 compares the FDCs of the inflows simulated by Hutchison and Pitman (1973) with those simulated using the method described above. It can be seen that the flow duration characteristics are accurately preserved by this technique.

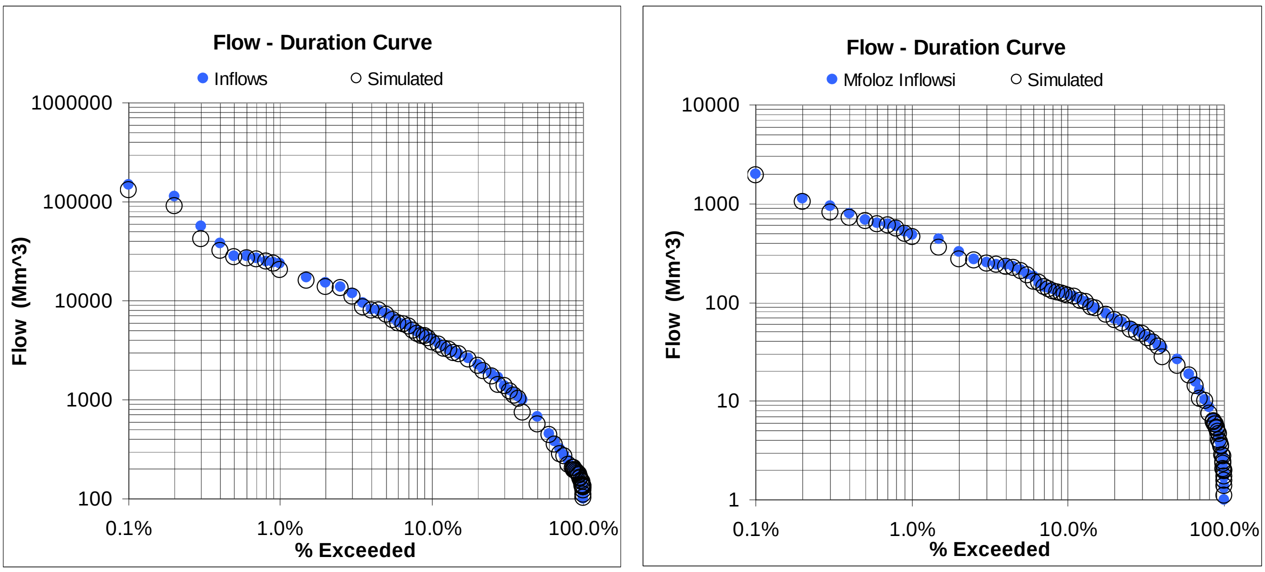

Figure 2.2 Comparison of the FDCs of the inflows simulated by Hutchison and Pitman (1973) and the inflows simulated using the FDC method.

2.1.3 Linkage to the Umfolozi

The model is designed to simulate various degrees of linkage between St Lucia and the Umfolozi. These range from completely separated systems to one where the mouths are combined. With the systems fully separated, the water in the Umfolozi plays no role in the water balance of St Lucia, and also has no influence on its mouth state. With the systems sharing a common combined mouth, the Umfolozi can contribute both to the water balance and the mouth state of the system. Details of the mouth state model are given in section 2.1.5. When a combined mouth closes, the model assumes that fresh water from the Umfolozi can flow into St Lucia, diluting salinities and increasing water levels. When a combined mouth is open, the model assumes that fresh water from the Umfolozi is mainly lost to the sea through tidal exchange flows. The facility to add a source for imported fresh water with specified flow rates, has been included in the model e.g. to simulate the effects of the back-channel.

2.1.4 Estuary mouth inflows and outflows

The inflows and outflows through the estuary mouth (when it is open) are pivotal in modulating the salt and water balance of the lake and also govern the mouth state of the system. Therefore in order to simulate the salinity and water level of the lake accurately, it is important that the exchange of flows between the lake and the sea are modelled. Hutchison and Midgley (1978) reported a relationship between lake water levels and average mouth discharges. This relationship was based on some (limited) tidal prism measurements and on simulations using a one-dimensional tidal propagation model. For the present study a weir-type equation was fitted to the reported mouth outflows and used to relate these outflows to lake volumes V, whence

$$Q = [C_d.Q_o].\,(V/V_o - 1)^m \qquad \text{for } V \geq V_o \qquad \textbf{Equation 2.2}$$

In this equation $[C_d.Q_o]$ is a characteristic flow scale for the mouth that, together with the exponent m, is chosen to best fit the predicted mouth discharges. The volume V_o is the lake volume when discharges are zero - V_o corresponds approximately to the volume when the lake water level is at the average level during open mouth conditions (i.e. estuary mean water level or EMWL). When lake volumes are less than V_o (water levels below about EMWL) there is a nett inflow from the sea into the lake, which is assumed to be independent of water levels and equal to 14Mm^3 per month. This inflow volume is based on measurements of the tidal prism reported by Hutchison (1976). More recent measurements of tidal exchange flows by Chrystal and Stretch (2008), carried out after the breaching event in 2007, have confirmed that the nett inflows at low lake water levels are in the range 500000 to 1000000 m^3 per day, depending on the tidal amplitude: this corresponds to 15 – 30 Mm^3 per month. The inflow rate at low lake levels is an adjustable parameter in the model.

2.1.5 Mouth state model

As already noted, the link with the sea via the estuary is pivotal in modulating the salt and water balance of the estuary e.g. the closure of the mouth in June/July 2002 followed by ongoing drought conditions ultimately lead to very low water levels and hypersaline conditions. The modelling of the mouth state allows us to simulate water levels and salinities under various mouth management strategies, and is a key new feature of the present water balance model.

Three key parameters are assumed to control the mouth state. They are the volume (or water level) at which the mouth will breach and the volume (or water level) below which the mouth closes. In addition, if the Umfolozi/St Lucia has a combined mouth, the Umfolozi flow rates are assumed to provide another mechanism for modulating the state of the combined mouth. The determination of the mouth state is summarized in Table 1.

Table 1 Mouth state model

If the St Lucia mouth is:	It will remain so if:	Otherwise it:
• Open • Closed	• The volume in the lake exceeds a specified critical level, V_C • The volume of the lake remains below the specified breaching level, V_B	• Closes • Opens
If the combined mouths are: • Open • Closed	They will remain so if: • The Umfolozi flow rates or lake volume are above a specified critical flow rate or volume respectively • The volume of the lake remains below the specified breaching level, V_B	Otherwise it: • Closes • Opens

Data concerning the mouth state under natural conditions is scarce. Due to the lack of measured data, estimates of the mouth model parameters were based on comparing predicted mouth states with recorded historical observations for the period 1918 to 1952. The threshold flow in the Umfolozi to maintain an open combined mouth was thus estimated to be about 4 Mm^3 per month and the threshold lake volume at closure of the mouth was estimated to be about 300 Mm^3 (with a corresponding lake level of -0.1m below EMWL). The threshold volume in the lake at which the mouth would breach naturally was assumed to be about 1175 Mm^3, which corresponds to a water level of +2m EMWL (2.25m above actual MSL). The effects of artificially breaching the system at lower water levels, or of other natural breaching levels can (and were) investigated by simply changing the relevant parameter.

2.1.6 Additional fresh water inputs via the back-channel

The model is configured to incorporate additional fresh water inflow via the back-channel or another source. For the present study, the fresh water link used in the simulations was assumed constant throughout the year, but variable flows can be accommodated if required. During open mouth conditions the model allows for a specified dilution of the sea water inflows where the mouth inflows are assumed to mix with fresh water from the source while outflows will flush the fresh water out to sea.

2.1.7 Salinity and water levels

Since the lake is represented as one unified basin, during extreme drought periods when water levels decrease drastically and different parts of the lake start to be isolated, the model will not accurately represent the actual situation.

Salinities are modelled using a salt balance which incorporates increases in salt loading when there are inflows from the sea (when the mouth is open and water levels are low, $V < V_o$), as well as the flushing effect of outflows via the mouth when water levels are higher ($V > V_o$).

2.1.8 Back-channel analysis

A detailed analysis of the functioning of the back-channel requires coupled water balance models for both the Umfolozi and the St Lucia basins that can simulate the Umfolozi estuary functioning under various scenarios. To build this model requires a bathymetric survey of the Umfolozi basin in order to establish its water-level/surface-area/volume relationship. Since this is not currently available, changes in water levels were simply inferred from.

Water level change = (Inflow volume)/(surface area of basin) **Equation 2.3**

where the surface area was assumed to be approximately 1.2km^2 (Lindsay *et al.*, 1995).

The back channel discharges into St Lucia were assumed to be controlled by a broad crested weir at the downstream end, where critical conditions give the corresponding maximum flow that is possible:

$$Q = 0.385 \times SQRT(gH)\ H\ B$$ **Equation 2.4**

where, g is gravity (9.81m/s^2), H is the water level relative to the crest of the weir and B is the width of the weir. Friction losses in the back channel were estimated with a uniform flow model.

2.1.9 Data Forecasting

In order to predict what may happen in the next nine months, a statistical analysis of the monthly rainfall data of the lake and the Umfolozi catchment was performed. Monthly mean, median, minimum, maximum, 75th, 25th and 10th percentiles were calculated. A rainfall forecast option for the next nine months was incorporated into the model where the user is able to select average monthly rainfall, below average monthly rainfall (e.g. 25th percentile) or above average monthly rainfall (e.g. 75th percentile).

2.1.10 Sensitivity Analysis

In order to give an indication of the sensitivity of the model to the parameters, a sensitivity analysis was performed. The breaching level was originally set at a threshold volume of 1175 Mm^3 (corresponding to a water level of 2 m EMWL). The effect of changing the breaching level to 1 m and 3 m EMWL was investigated as the breaching level is an important parameter that will influence inundation of adjacent agricultural lands. The sensitivity of the system was evaluated by comparing changes in the average salinity, water level and percentage mouth closure. The sensitivity analysis was performed both with and without a separate Umfolozi mouth.

2.2 General Approach of this study

The general approach in this study was to use long-term simulations to provide a broad perspective of the functioning of the lake. By simulating the functioning of this system over roughly a century, the long-term consequences of different management options and scenarios can be illustrated. These simulations are supplemented by short-term predictions for the next nine months. It is important to note that in order to relate the results of the long-term model simulations to the current state of the system (which is essentially a consequence of the management interventions that have taken place recently) requires that the system be "reset" by a significant flood event. We estimate that under current conditions, this would occur if the system experienced a flood with a return period of 10 years or more. Another important point to make regarding the resetting of the system is that if the St Lucia Estuary were to breach under natural conditions (i.e. from a water level of about +2mEMWL), a peak outflow through the mouth of about 1000Mm^3 per month (i.e. 380m^3/s) could occur. These outflows are of a similar magnitude to those of a very large flood (return period of 50 years or more) and would result in massive scouring of accumulated sediment built up in the mouth and narrows. Without the large flows of a natural breach such as this, sediment could continue to accumulate in the narrows and mouth. These natural breaching events, which have been prevented by artificial manipulation of the mouth state, would probably have played a significant role in the maintenance of the system prior to human intervention.

3 Simulation Results

The simulation results of the water balance model are presented in this chapter. The chapter begins with the validation of the model using measured and simulated salinities. Results of long-term simulations are presented in order to give the overall behaviour of the system under various management scenarios. Short-term simulations of the future are then presented to give an educated guess at what may happen in the next few months. The sensitivity of the model to certain key parameters is also discussed.

3.1 Validation of the Model

Salinities of North Lake, False Bay and South Lake have been measured by EKZN Wildlife since 1958 and are shown in Figure 3.1. The dashed line represents the salinity of sea water (35 ppt). Lake salinities vary spatially - the salinity gradient between the northern and southern parts of the lake are shown in Figure 3.1. Note that a positive gradient indicates increasing salinities from South to North and vice versa. During drought periods hypersaline conditions are associated with a significant increase in the salinity gradient. During wet periods there is typically a negative salinity gradient (up to about 24ppt).

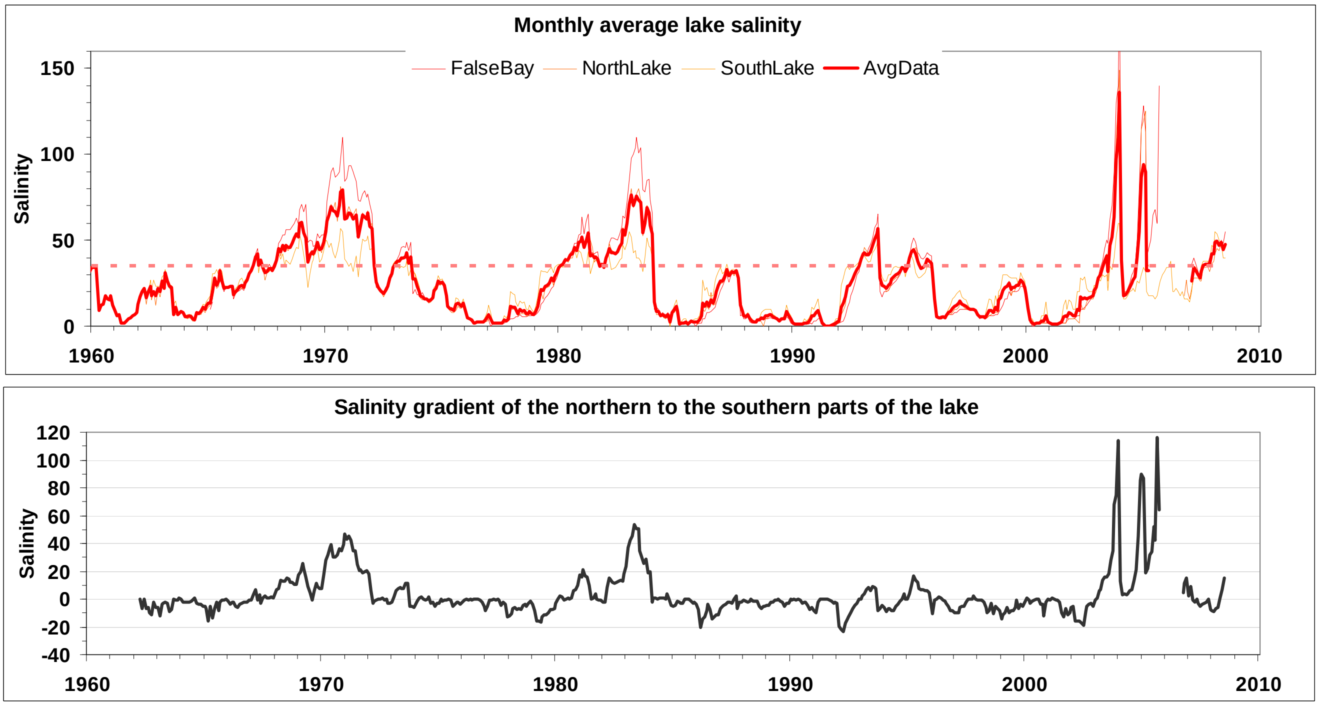

Figure 3.1 Measured monthly average lake salinities and salinity gradient between the northern and southern parts of the lake (courtesy of Ricky Taylor and Caroline Fox).

To validate the model, monthly lake salinities from 1950 until July 2008 were simulated under permanently open mouth conditions and compared to measured monthly average salinities (see Figure 3.2). The model represents the lake as one unified basin and therefore simulates average lake salinities and does not account for spatial variability. Measured monthly average salinities are also included in Figure 3.2 for comparison. It is important to note that the management strategy at the time (from 1955 until 2002) was to artificially keep the mouth open. The Umfolozi mouth has been separated since 1952. Monthly average lake salinities were simulated for both *present* and *virgin* inflow conditions (see section 2.1.2).

Notice how simulated salinities clearly mimic the measured salinities, increasing in the drier cycles and decreasing during the wetter cycles. These trends are caused by the increase in salt loading during dry periods as seawater flows into the system to modulate water levels and vice versa in wet periods. Since the lake is represented as one unified basin, the simulated average salinities deviate substantially from the mean in different parts of the lake during drought periods. The discrepancy in salinities after 2002 is due to the fact that the mouth was closed from mid June 2002 until March 2007 and then again from September 2007 until present (August 2008). Salinities during this period are better represented when the mouth dynamics are included (see below). Notice how *virgin* salinities are consistently lower then *present* salinities indicating the effect of the reduced fresh water inflows on the water and salinity balance. Adding a constant 5Mm³/mth of additional fresh water to the *present* inflows makes the modelled salinities for that case correspond nearly perfectly with those of the *virgin* case.

Overall, the agreement between the measured and modelled average lake salinities is excellent and provides confidence in the basic input data that drives the water balance model. Note that for the simulations shown here, there are no adjustable model parameters, since the mouth state is fixed at open.

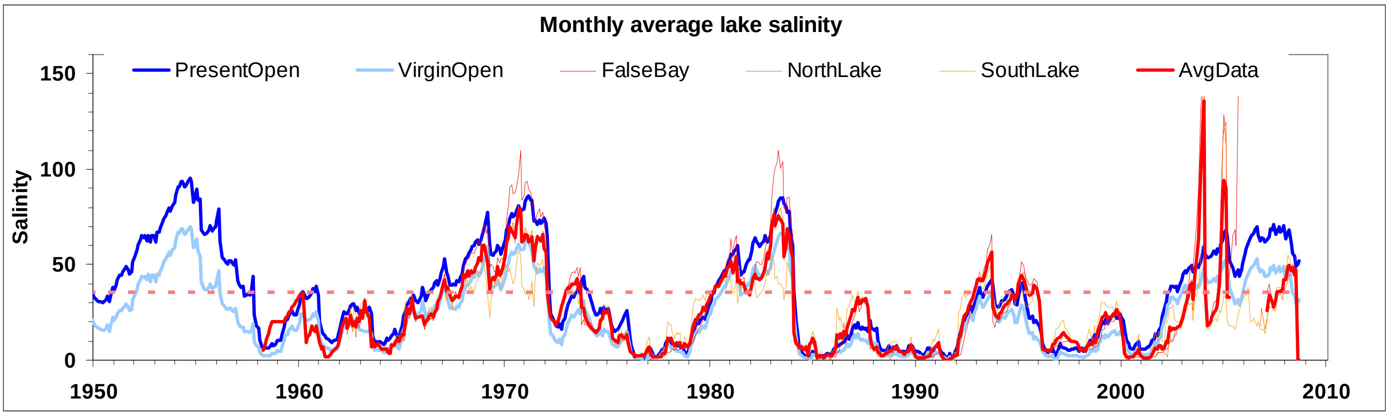

Figure 3.2 Simulated and measured monthly average lake salinities.

Figure 3.3 shows simulated versus measured monthly averaged lake salinities but without artificial manipulation of the mouth state i.e. the mouth state model was used to predict the natural state of the mouth as shown in Figure 3.3. Note how predicted salinities are generally significantly lower during dry periods when compared to the actual lake salinities that occurred with the mouth artificially maintained in a permanently open state.

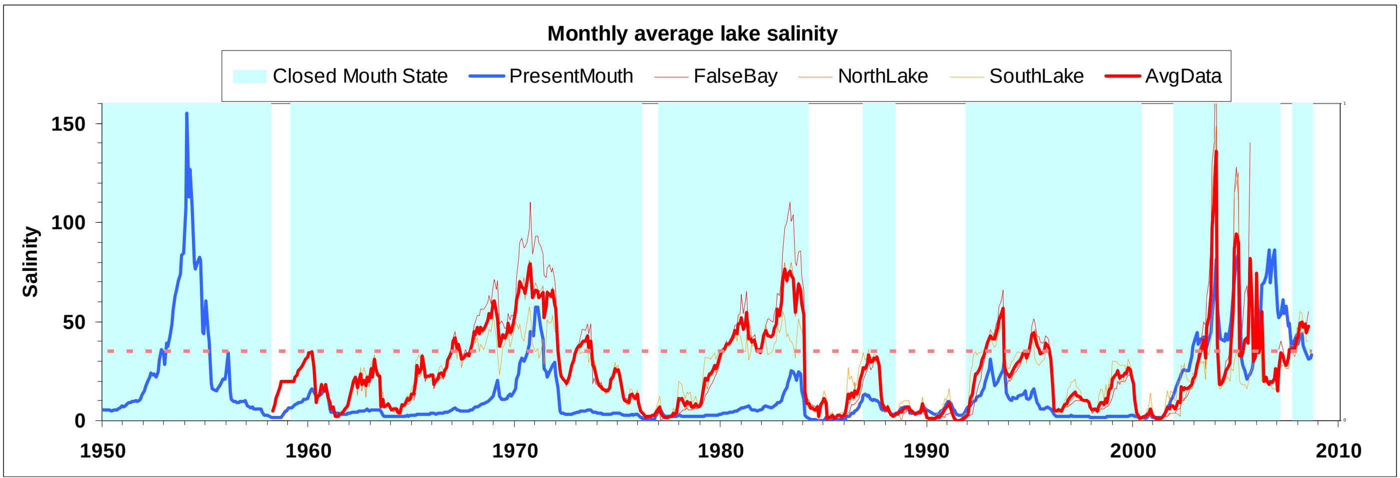

Figure 3.3 Measured versus simulated monthly average lake salinities with no artificial breaching.

3.2 Long Term Simulations

To illustrate the long-term behaviour of the system under different management strategies, water levels, salinities and mouth states were simulated for a 90-year period (1918 until present).

The following scenarios were modelled in order to address the objectives of this study:

- Scenario 1A : Separate Umfolozi mouth and no imported fresh water
- Scenario 2A : Reinstated combined mouth and no imported fresh water
- Scenario 1B : Separate Umfolozi mouth with imported fresh water

3.2.1 Scenario 1A: Separate Umfolozi mouth, no artificial breaching and no imported fresh water

With a mean annual runoff of 736 Mm^3 the Umfolozi was once an important source of fresh water to St Lucia when the combined system was closed. Water balance simulations indicate that the Umfolozi link provided an additional mean annual fresh water contribution of 150Mm^3 per year. Model simulations were run without the Umfolozi mouth link and with no imported fresh water. Figure 3.4 shows simulated annually averaged salinities, water levels and the mouth state for both *virgin* and *present* inflows. Note the significant increase in salinities, especially during hypersaline conditions, with *present* inflows. The grey shaded area in the mouth state figure represents mouth states under *virgin* conditions while the black shaded area represents mouth states under *present* conditions. The model indicates that without any artificial interference in the mouth state, St Lucia Lake would have been a predominantly closed system (about 88 % of the simulated period). At least a one in ten year flood would be required to "naturally" breach the mouth under these conditions, with the mouth subsequently staying open for only brief periods of about 18 months at a time. The lake is predicted to be a predominantly fresh system with highly variable water levels (refer to Figure 3.4 and Figure 3.5). Hypersaline conditions would generally occur during closed mouth phases and coincided with very low lake levels. Salinities tend to increase exponentially as water levels drop during dry cycles due to evaporation. Under severe drought conditions, the model predicts that the lake may be expected to dry up (as happened during the current drought in 2003). The salt loadings in the system depend on the inflows of sea water during open mouth periods. Since the model predicts these to be relatively rare and of short duration, the salt loadings are low.

In summary, the model results shown in Figure 3.4 predict the long-term implications of the current management policy with no artificial breaching of the mouth and with the Umfolozi separated from St Lucia.

It is important to note that the breaching of the St Lucia mouth in March 2007 was an extremely unusual event in the long-term context. The breaching occurred during a rare climatic event (with very high waves and tides) and during an extreme drought when lake water levels were very low. It should be noted that previous management strategies left the berm artificially narrow which added to the vulnerability of the system to wave breaching. The dredged sand trap at the mouth provided a sink for flood tide sediments, allowing the mouth to remain open for longer. This allowed a larger inflow of salt water, and hence higher salt loading, than is expected under natural circumstances.

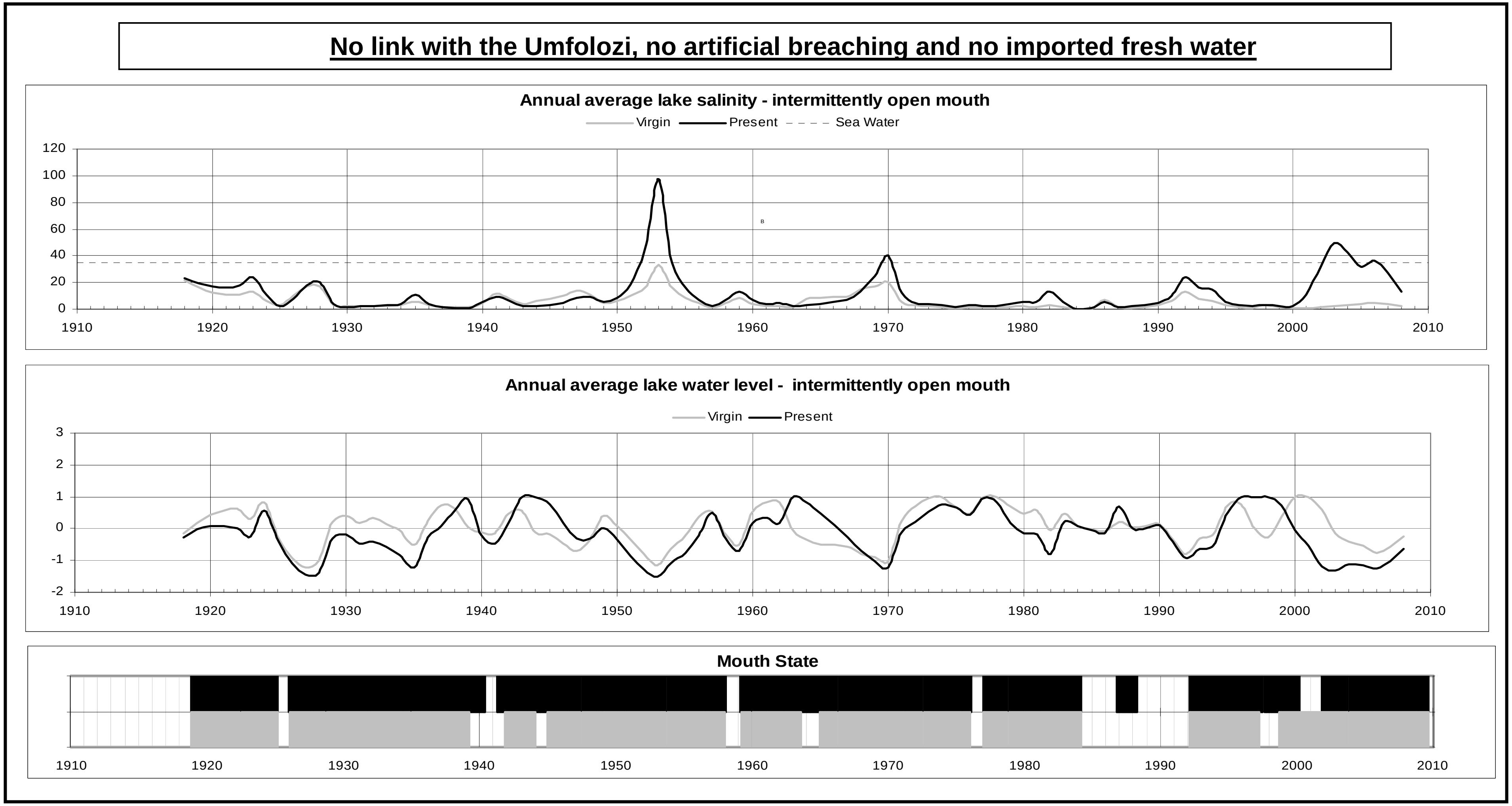

Figure 3.4 Simulations of Scenario 1A.

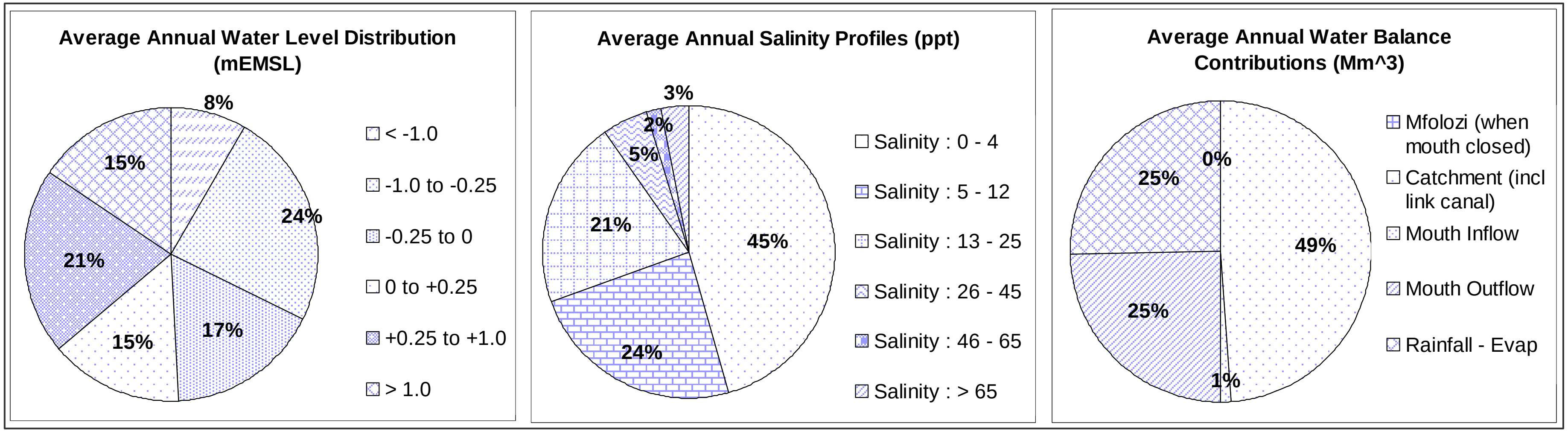

Figure 3.5 Average annual water level distribution, salinity profiles and water balance contributions for Scenario 1A.

3.2.2 Scenario 2A: Reinstated combined mouth and no imported fresh water

Scenario 2A considers the effect of reinstating the Umfolozi mouth on the functioning of the system. With the Umfolozi mouth joined to St Lucia as it was in the past (pre 1952), the mouth is predicted to be predominantly open (about 80 % of the simulation period). Closure of the combined mouth would occur during severe drought periods. We have assumed that fresh water from the Umfolozi flows into the lake during these periods. The addition of this fresh water plays an important role during dry periods as it decreases lake salinities and increases water levels until the breaching level is reached. Breaching occurs about ten times in the ninety year period with the system remaining closed for about 2 – 3 years duration (refer to Figure 3.6). The system is predicted to be more saline than for Scenario 1A. Furthermore, in contrast to that case, hypersaline conditions occur mainly during open mouth phases, when salinities increase linearly due to the combination of tidal inflows of sea water, evaporation and low fresh water inflows. Taylor (2006) notes that experience (from the 70's) has shown that the combination of high water levels (about EMWL) and high salinities can have a detrimental effect on fringe vegetation of the lake. Salinities during closed mouth conditions are generally low due to dilution by fresh water inflows from the Umfolozi. With *virgin* inflows, salinities remain lower than for *present* inflows. Water levels are predicted to be stable at an average of 0.1 m EMWL, with increases occurring during closed mouth phases(refer to Figure 3.6 and Figure 3.8). A one in three year flood is sufficient to cause breaching of the estuary mouth under these conditions. By reinstating a combined Umfolozi/St Lucia mouth and allowing the mouth to function naturally, the additional fresh water supplied to the Lake from the Umfolozi is on average about 150 Mm^3 per year (approx 12 Mm^3/month). This contributes a significant amount, approximately 35% ,of fresh water to the overall water balance (see Figure 3.8). The large percentage of mouth outflows is due to the frequently open mouth.

Notice how reinstating the Umfolozi mouth changes the system from a predominantly closed, almost fresh water system with highly variable water levels, to a predominantly open system with more stable water levels but more variable salinity regime. Drought conditions impact differently in these two scenarios: salinities increase exponentially with dropping water levels during closed mouth conditions without the Umfolozi link. With the Umfolozi link, salinities increase approximately linearly during open mouth conditions with fairly constant water levels. However, during severe droughts the combined mouth closes and the diversion of fresh water from the Umfolozi reduces salinities and increases water levels. The results indicate the profound influence that the Umfolozi has on the functioning of the St Lucia mouth and thereby on the water balance. However, the issue is complicated by a perceived threat of siltation from the silt laden Umfolozi.

3.2.3 Scenario 1B: Separate Umfolozi mouth with fresh water addition via the back-channel.

With the threat of silt from the Umfolozi building up in the narrows, another method of obtaining freshwater was investigated. The simulations for scenario 1A were repeated but for a case where additional fresh water is imported into St Lucia e.g. via the back-channel or link canal – the results are shown in Figure 3.7 for *virgin* and *present* conditions. The monthly fresh water addition was assumed constant throughout the year. Recall that an inflow of about 5 Mm^3 per month of fresh water into St Lucia approximately restores *virgin* inflow levels. This is illustrated in Figure 3.7, where water levels and salinities for both *virgin* and *present* conditions were predicted to be similar. Introducing the additional fresh water into St Lucia, would maintain salinities below 35ppt, however water levels remained highly variable (see Figure 3.7 and Figure 3.9). The model indicates that this increase in fresh water does not influence the mouth state of the St Lucia Estuary as indicated by the continued prevalence of closed mouth conditions (about 85 % of the simulated period). This emphasizes the significant role that the Umfolozi plays in the functioning of the combined mouth. Figure 3.9 provides the average annual salinity, water level and water balance statistics for this scenario. Note that water levels and salinities follow the same trends as for Scenario 1A, but are less variable.

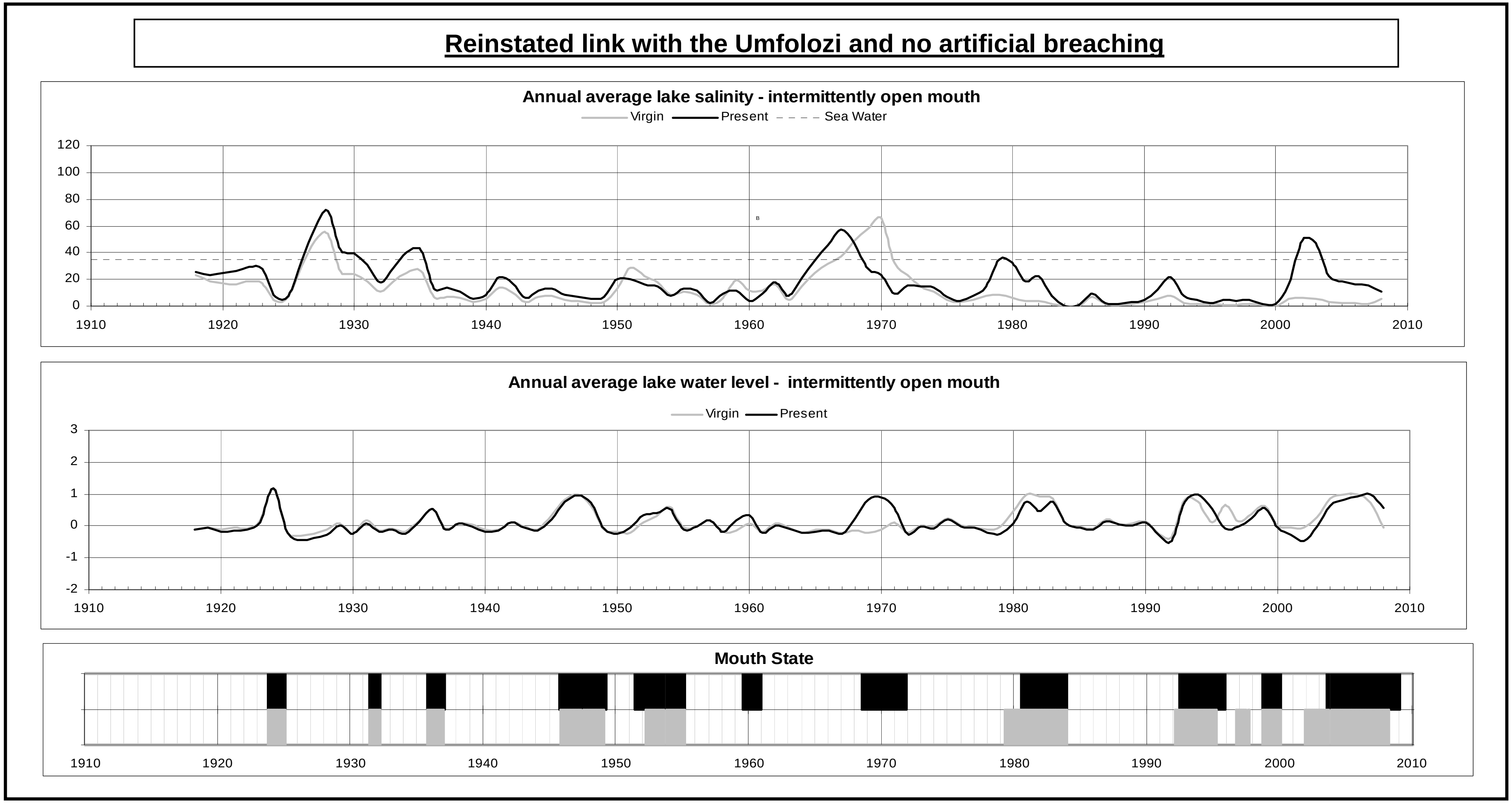

Figure 3.6 Simulations of Scenario 2A.

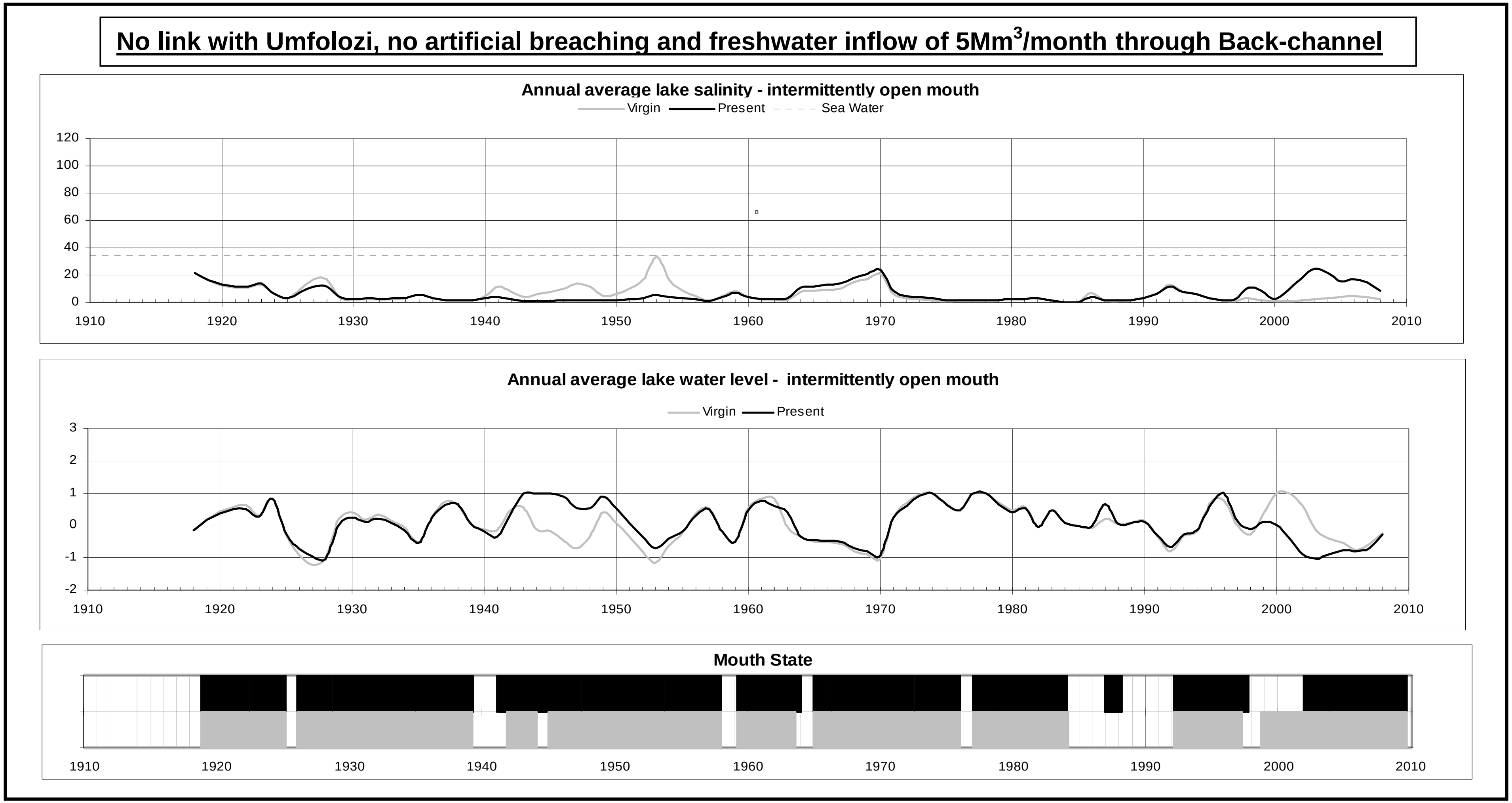

Figure 3.7 Simulations of Scenario 1B.

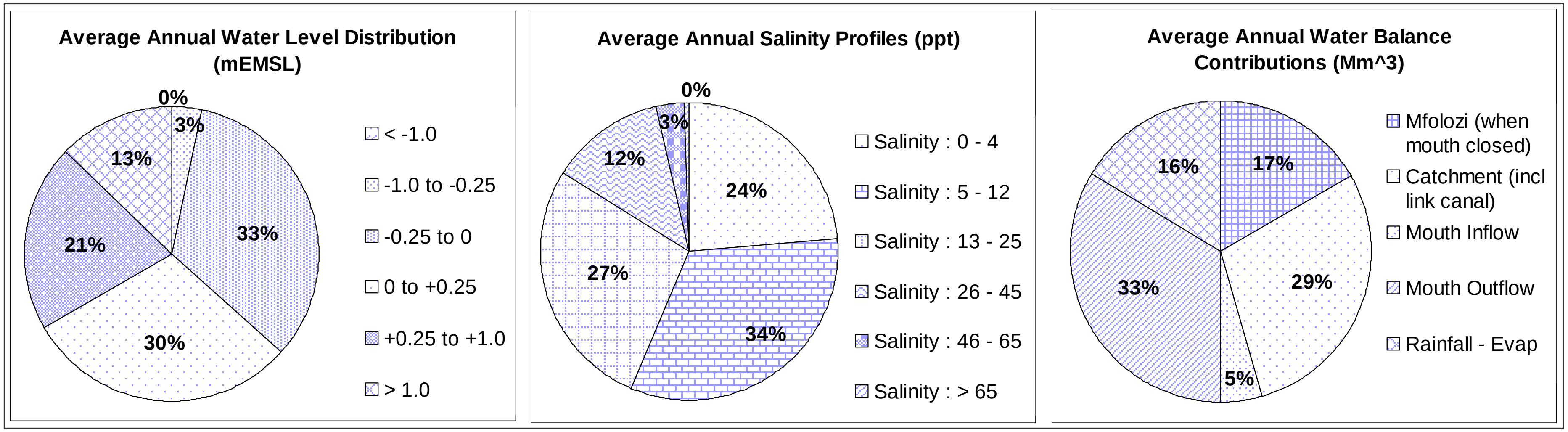

Figure 3.8 Average annual water level distribution, salinity profiles and water balance contributions for Scenario 2A.

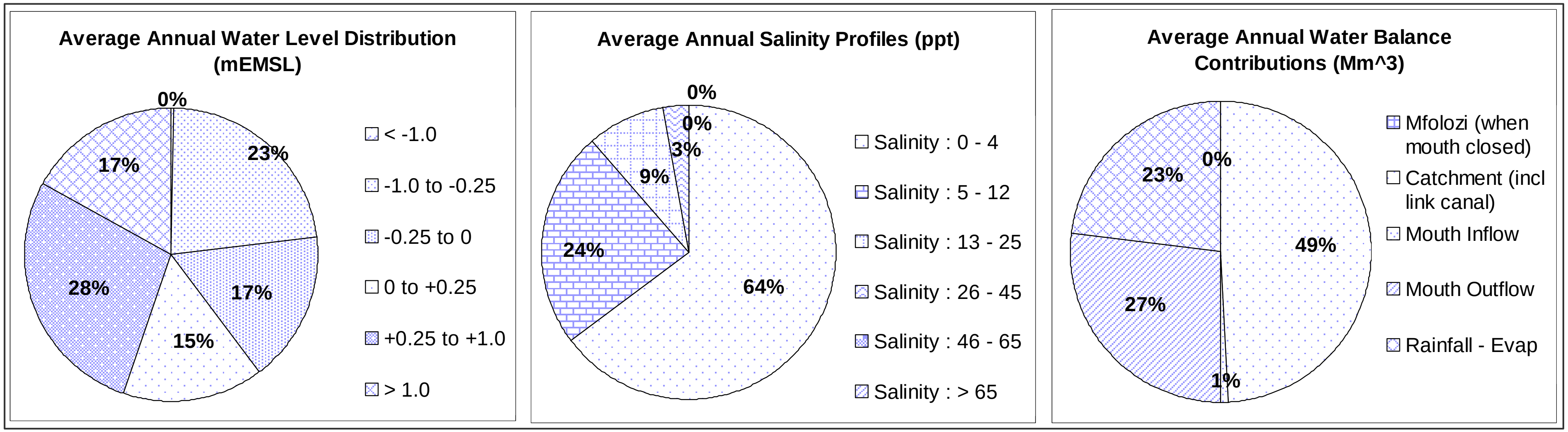

Figure 3.9 Average annual water level distribution, salinity profiles and water balance contributions for Scenario1B.

3.2.4 Summary

In summary, the three scenarios simulated illustrate the key role that the Umfolozi mouth plays in the functioning of this system. The model predicts that a combined mouth would be predominantly open with stable water levels and variable salinity regime. During dry periods, if the mouth remains open, salinities would increase linearly due to the reduced fresh water inflows and the inflow of salt water from the sea. However, in more severe droughts the combined mouth would close - water levels would then increase and salinities decrease due to fresh water contributions from the Umfolozi. This leads to subsequent re-opening of the mouth by breaching the berm – a small flood with a return period of about 3 years would suffice to naturally re-open the system. On the other hand, separation of the Umfolozi results in a predominantly closed system with highly variable water levels and generally very low salinities. During drought periods the salinities rise exponentially due to falling water levels. In order for the mouth to breach naturally under these conditions requires a flood of at least a 10-year return period. The importing of additional of fresh water can restore the *virgin* water balance contributions, but the mouth of St Lucia would remain mostly closed if it is not allowed to re-combine with that of the Umfolozi.

3.2.5 Sensitivity analysis of the model

To analyze the sensitivity of the model to changes in the key parameters, the model was run using different pan factors, breaching levels and threshold Umfolozi flows. The average water levels, salinities and the percentage that the mouth was predicted to be closed over the simulation period was noted for each simulation. The results are presented in Table 2.

Varying the pan factor by one percent had no significant affect on the average salinity, and the percentage that the mouth is closed. Average water levels however increased by about 0.04m with a one percent decrease in pan factor. Hutchison (1976) provided different pan factors for the different parts of the lake, ranging from 96.5% in the south to 106% in the north.

As expected, altering the breaching level of the estuary had a significant effect on the average water level and mouth state. Varying the breaching level would change the scouring ability of the system at a breach. Scouring of the system at a breach is important as it inhibits the accumulation of sediment and salt. At a breaching level of 1m a peak discharge of roughly 117m^3/s was estimated to occur at a breaching event and at a breaching level of 3m a discharge of roughly 578m^3/s was estimated. A mouth discharge of approximately 325m^3/s was estimated at a breaching level of 2m EMWL. The decrease in salinity as the breaching level was raised was due to the dilution by freshwater and almost permanently closed mouth conditions.

The sensitivity of the model to the threshold Umfolozi flows was investigated with a reinstated Umfolozi link. The threshold Umfolozi flows required to keep the Umfolozi mouth open have been estimated to be about 1.5m^3/s. If the Umfolozi threshold flow was lower, for example 1.1m^3/s, salinities would increase due to more prolonged open connections to the sea. Increasing the threshold flow to 1.9m^3/s, the mouth stays closed for longer periods, thereby allowing water levels to build up and salinities to decrease due to river inflows.

Table 2 Sensitivity analysis of the model to certain key parameter changes

Separate Umfolozi mouth	Pan Factor 101%	100%	90%
Average salinity	13	13	13
Average water level (mEMSL)	-0.16	-0.13	-0.1
Percentage mouth closed (%)	87%	87%	87%
Separate Umfolozi mouth	**Breaching level (mEMSL) 1**	**2**	**3**
Average salinity	12	12	6
Average water level (mEMSL)	-0.41	-0.15	0.36
Percentage mouth closed (%)	81%	88%	94%
Approx mouth discharge at the breach (Mm^3/month)	117	325	578
Link reinstated with the Umfolozi mouth	**Threshold Umfolozi flow at closing (m^3/s) 1.1**	**1.5**	**1.9**
Average salinity	28	18	16
Average water level (mEMSL)	-0.05	0.11	0.13
Percentage mouth closed (%)	14%	32%	35%

3.2.6 The functioning of the back-channel

Water levels in the Umfolozi estuary must be higher than those in the St Lucia Narrows in order to provide a hydraulic gradient to drive a flow of fresh water into the lake. As indicated in Section 3.2.3, a fresh water addition of 5 Mm^3 per month into St Lucia would restore the *virgin* fresh water inflow conditions.

Hutchison (1976) performed simulations using a one-dimensional tidal propagation model to investigate the effects of introducing fresh water into St Lucia at different locations to dilute inflowing seawater (for open mouth conditions) and thereby to reduce lake salinities. The locations investigated include the Narrows south of the St Lucia Bridge, at the Mpate confluence, and at Makakatana Bay. The loss of freshwater during outgoing tides obviously increases as the inlet point is moved closer to the mouth. Therefore, it is important to note that the addition of freshwater via the back-channel would be influenced by tidal activity when the St Lucia and/or the Umfolozi mouth are open.

The following St Lucia and Umfolozi mouth state combinations were considered to understand the functioning of the back-channel fresh water link for the maintenance of the St Lucia ecosystem. Note that to accurately and quantitatively address these issues, a fully linked water balance model for both the Umfolozi and St Lucia basins is required. We currently do not have sufficient data for the Umfolozi basin to develop such a model.

Open Umfolozi mouth with the St Lucia mouth open
When both the Umfolozi and St Lucia mouths are open, both estuaries would be dominated by tidal exchange flows. Measurements at St Lucia indicate an average exchange flow of about 650 000m^3 per tidal cycle (Chrystal and Stretch, 2008). Measurements at the Umfolozi have shown an average flow of about 500,000m^3 per tidal cycle (Lindsay *et al.*, 1996). Average water levels in each estuary would be approximately the same. Under these conditions the back channel would cease to be effective in providing any significant fresh water flow between the Umfolozi and St Lucia estuaries.

Open Umfolozi mouth with the St Lucia mouth closed
An open Umfolozi mouth would be strongly influenced by tidal exchange flows (except under flood conditions). The functioning of the back channel in this scenario depends on the crest level of the weir that controls the outflow at the downstream end of the channel. If this level is below the mean water level in the Umfolozi, saline water from the tidally

influenced Umfolozi could flow into the closed St Lucia system. Flow in the opposite direction could occur during ebb-tides if water levels in St Lucia are above the crest of the back channel weir. As noted previously accurate simulations of this scenario requires a linked water balance model for both basins. However, it is evident that the back channel would not be effective in providing significant fresh water flow into St Lucia in this scenario.

Closed Umfolozi mouth with the St Lucia mouth open
In this scenario the St Lucia estuary would be strongly influenced by tidal exchange flows. In order to maintain a fresh-water flow into St Lucia via the back-channel, the water level of the Umfolozi needs to be higher than that in the St Lucia Estuary. If it occurs, this fresh water could dilute the tidal inflow of seawater into St Lucia. However the tidal exchange simulations by Hutchison (1976) have shown that most of this water would simply be lost on the ebb tide. Nevertheless, with an average nett inflow into St Lucia of 5.5m^3/s (see Section 2.1.4) and incorporating 1.9m^3/s of fresh water from the back channel, a diluted salinity concentration of about 26ppt is theoretically possible for the mouth inflows into St Lucia. It is important to note that this scenario is highly improbable since the Umfolozi mouth remains open for most of the time and if the St Lucia estuary was breached naturally, it is likely that the Umfolozi would also be open.

Closed Umfolozi mouth with the St Lucia mouth closed
In the case of the Umfolozi mouth closed concurrently with the St Lucia mouth, water levels in both systems would be dependent on river flows. Provided that water levels in the Umfolozi are higher than in St Lucia, fresh water would flow into the lake increasing water levels and decreasing salinities. Scenario 1B provides a long-term simulation of a system with this configuration. However, as discussed in Section 3.4, the likelihood of the Umfolozi remaining closed for extended periods beyond the low flow season from June to September is very small.

In summary, the supply of water via the back-channel could dampen the effect of drought conditions in terms of lake salinities and water levels. However the configuration of the two mouths plays a major role in the functioning of this scenario. When both mouths are open, the back-channel will become ineffective. With the Umfolozi open and the St Lucia closed, sea water could flow into the system during high tide and flow out of St Lucia could occur during low tides. With the Umfolozi closed and the St Lucia open, the additional fresh water flow could dilute the salinity of the tidal inflows to about 26ppt as opposed to pure sea water (35ppt). In order for this strategy to work most effectively, both systems must be closed. The most suitable cross-sectional area of the back-channel is discussed in Section 3.5.2.

3.3 Short Term Simulations

The following scenarios were simulated for the next nine months both with and without the addition of fresh water via the Back-channel:

- Average rainfall scenario
- Above average rainfall scenario
- Below average rainfall scenario

The simulations were initialised using measured data at closure of the mouth in September 2007.

3.3.1 St Lucia water levels and salinity scenarios for the next nine months

Rainfall for the next nine months was forecast using statistical analysis of historical data. The median (50^{th} percentile, average rainfall), 75th percentile (above average rainfall) and the 25th percentiles (below average rainfall) were estimated for each month and are presented in Table 3. This rainfall was used to simulate the next nine months of runoff into the lake and the Mfolozi catchment using the FDC method and the resulting water balance for the system was predicted.

Table 3 Forecasted rainfall using percentiles

	Forecasted Rainfall (mm)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	MAP
75th	100	105	114	153	142	160	91	76	61	52	52	67	**1091**
50th	75	75	81	85	103	95	59	39	30	28	25	41	**863**
25th	40	60	50	53	61	63	42	22	14	16	12	20	**735**
10th	30	37	33	37	36	41	28	13	8	9	5	15	**624**

Rainfall forecasts for South Africa by Weather SA (2008) are provided in Appendix A1. Above and below "normal" rainfall for three consecutive months were compiled from a number of different weather models. The majority of the models predict that St Lucia will experience above normal rainfall for the next three months. Note that the darker colours (higher percentages) represent the number of models in agreement.

Figure 3.7 shows the nett annual rainfall/evaporation index from 2000 until 2010 for Lake St Lucia with the predicted average, below average and above average rainfall annual indices. Note the predicted negative nett rainfall index for both average and below average rainfall in 2008 and 2009.

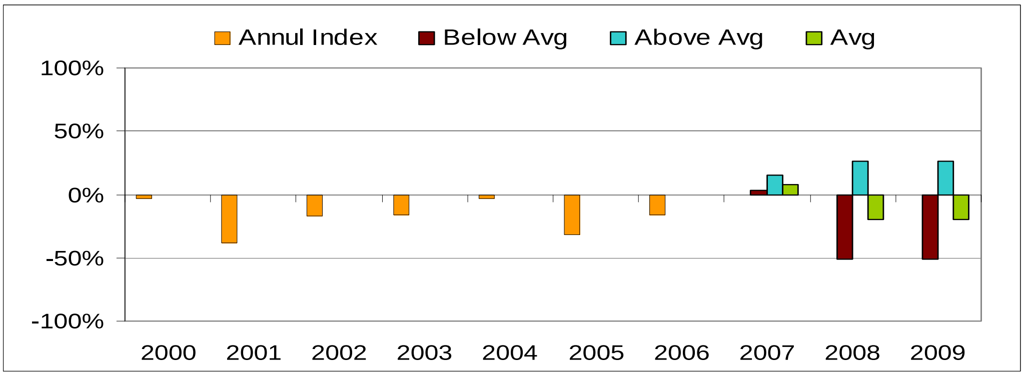

Figure 3.10 Nett Rainfall Index.

The monthly evaporation losses for the lake that were used in the water balance model are provided in Table 4 (Hutchison, 1976).

Table 4 Average Evaporation losses for Lake St Lucia

AVERAGE EVAPORATION (mm)												
Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Total**
140	155	175	175	145	150	105	85	65	70	90	115	1470

At average water levels the monthly losses to evaporation vary approximately in the range $20Mm^3$ to $60Mm^3$ (lowest during the period June to August). At low water levels (-1mEMWL) the evaporative losses are in the range $10Mm^3$ to $30Mm^3$

Average future rainfall scenario

Simulation results presented in Figure 3.8 illustrate monthly average salinities and water levels from September 2007 (when the mouth closed) and forecast (until 2010) with and without fresh water from the Umfolozi/Umsunduze via the back-channel. Forecast inputs were based on the median of the historical rainfall data. Note the overall increase in salinity, eventually reaching hypersaline conditions, and the overall drop in water levels from mouth closure in September 2007. The additional fresh water maintained salinities just above 35ppt, whereas without the additional fresh water, salinities continued to increase. Measured average lake salinities are also included in Figure 3.8 for comparison.

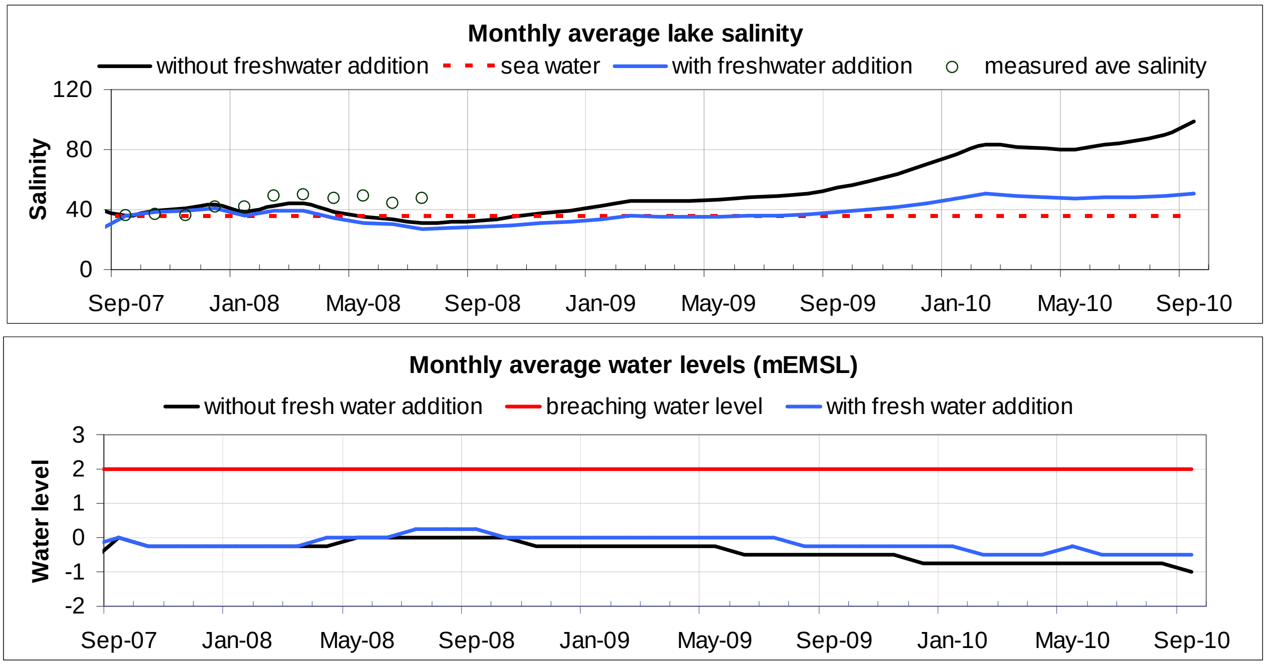

Figure 3.11 Simulations for average rainfall.

With the addition of fresh water from the Umfolozi/Umsunduze via the back-channel, the overall increase in salinity occurs at a much slower rate than without the link. Also, salinities tend to remain below 35 ppt in this case. The smaller decrease in water levels indicates the importance of the extra fresh water input for the prevention of desiccation. There is however still an upward trend in salinities and a downward trend in lake levels after mouth closure in September 2007. The probability that salinity levels will become intolerable is higher without the fresh water addition; however salinities continue to escalate in both cases. The mouth state is predicted to remain closed in both cases.

Above average future rainfall scenario

Simulation results presented in Figure 3.9 illustrate monthly average salinities and water levels with above average (75th percentile) monthly rainfall data. The system with and without a back-channel flow of 5Mm^3/month is shown. In this case the system is unlikely to experience high salinity levels within the next year. Water levels rise until a water level of about 1m EMWL is reached. The additional 5Mm^3/month of fresh water via the back-channel has no significant effect on the predicted salinities and water levels in this case. Obviously for this back-channel flow to occur, water levels on the Umfolozi side would have to exceed the levels on the St Lucia side.

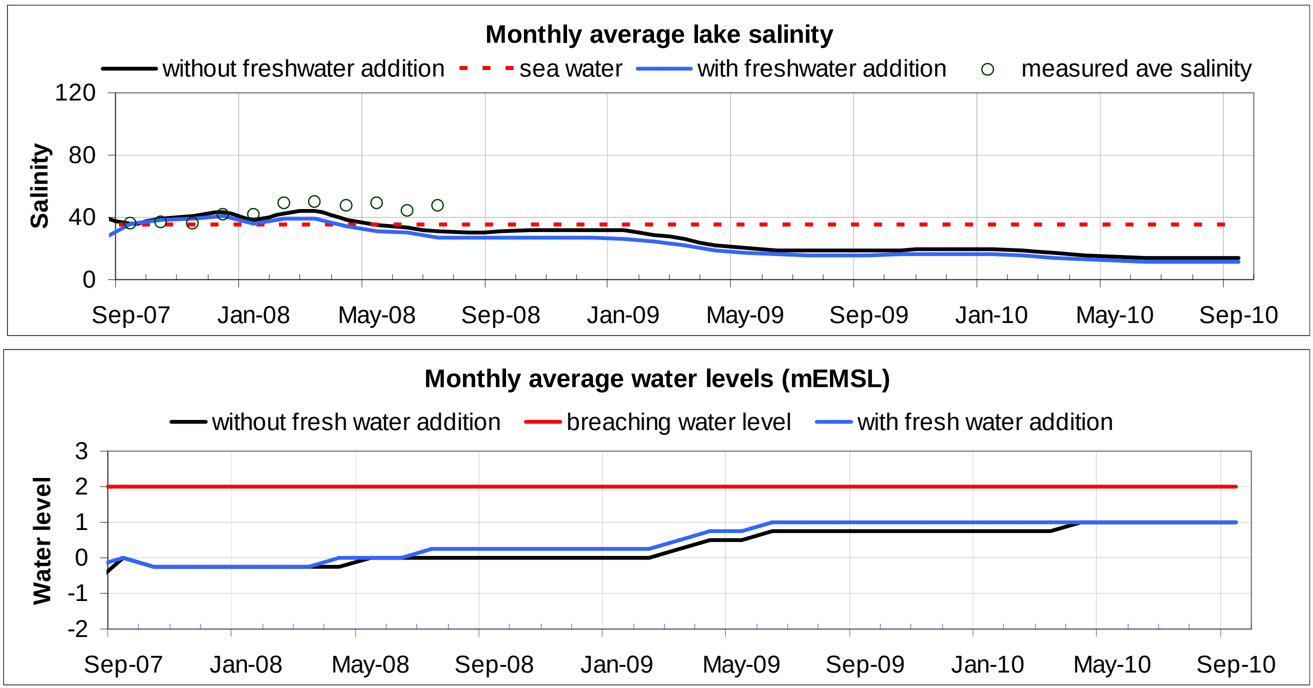

Figure 3.12 Simulations for above average rainfall.

Below average future rainfall scenario

Simulations assuming below average rainfall (25th percentile) until September 2010 are shown in Figure 3.10. In this case hypersaline conditions are predicted to occur both with and without the addition of fresh water. The additional fresh water delays the onset of hypersaline conditions by a few months. Water levels remain below EMWL with a slight increase during spring rains in 2008. With the significant increase in salinity and the drop in water levels, desiccation is likely to occur. The mouth is predicted to remain closed in both cases.

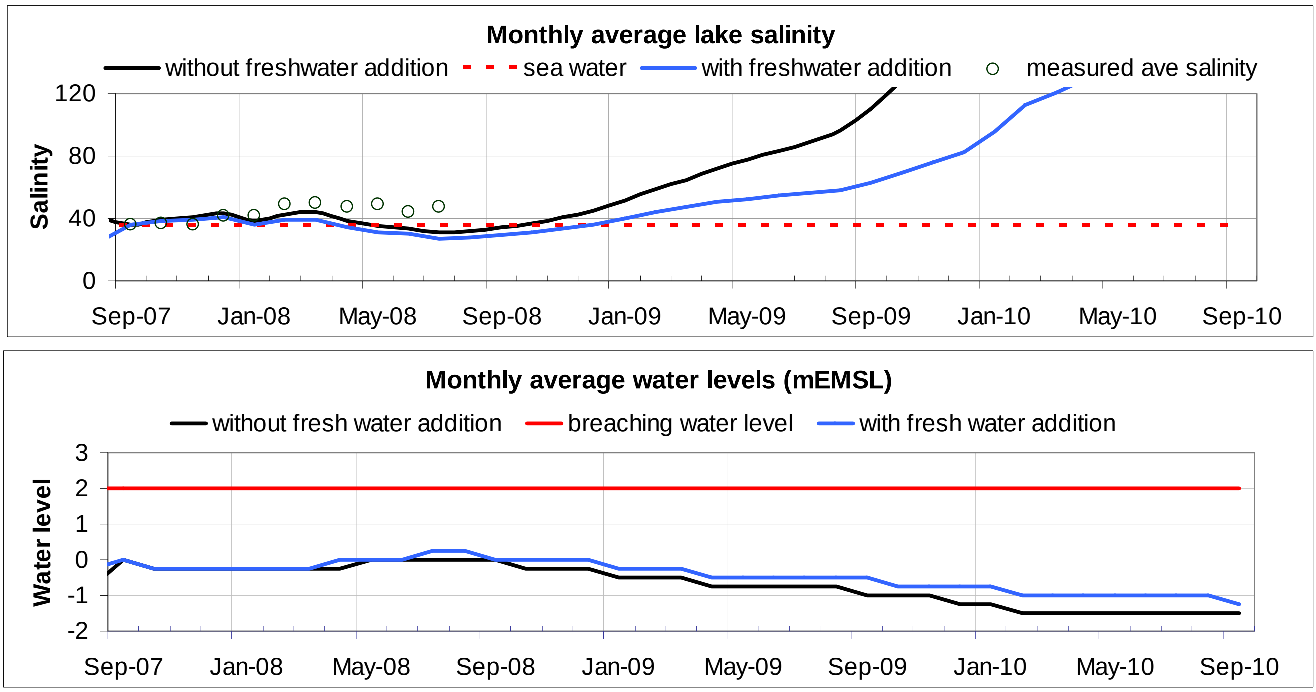

Figure 3.13 Simulations for below average rainfall.

In summary, the probability that intolerable salinities would be reached in the various scenarios discussed above is high if below average rainfall were to occur and low if above average rainfall were to occur. Hypersaline and even desiccation is likely if rainfall is below average. The addition of fresh water would however delay this by a few months. The addition of fresh water is valuable in dampening or delaying very high salinities and very low water levels.

3.4 Flow probabilities for the Umfolozi/Umsunduze

In order to investigate the probabilities attached to the flow of fresh water from the Umfolozi/Umsunduze for the next nine months, flow duration curves were plotted for each month (see Appendix B1) and a summary of the data is presented in Table 5.

Extremum analysis of the monthly Umfolozi flows indicate that a flow of 1183 Mm^3 has a 50-year return period, 604 Mm^3 has a 10-year return period, and 231 Mm^3 has a 3-year return period. The probabilities of these flows occurring in the next year are 2%, 10% and 33% respectively. The probability that flows will drop below 5Mm^3 is estimated to be 8% in any single month, 3% for two consecutive months and 1% for three consecutive months. Flows of below 5Mm^3 are emphasized in order to meet a minimum Back-channel flow of that amount. Note that monthly flows in the Umfolozi are lowest during the months June to September and are below 5Mm^3 for on average between 10% and 30% of the time during these four months (refer to Table 5).

Table 5 Umfolozi flow statistics

Umfolozi Flow Statistics (Mm^3/month)													
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	MAR
Mean	51	58	80	107	151	153	69	32	19	28	16	40	730
Standard deviation	108	71	79	150	201	378	139	33	19	66	28	111	
Flow exceedances….													
25%	28	64	117	120	142	115	53	35	20	15	12	13	843
50%	18	35	52	64	62	57	34	19	11	8	7	8	471
75%	10	18	26	41	36	32	22	12	9	6	5	4	327
90%	6	12	16	22	24	19	13	7	5	4	3	3	226
Probability that flows will be less than													
5Mm^3/month (%)	8	2	0	0	0	0	1	2	10	17	27	27	
10Mm^3/month (%)	22	3	2	2	1	0	6	16	39	61	67	63	

The expected change in water level for each month was estimated for the Umfolozi basin under closed mouth conditions and allowing for a 5Mm^3 monthly flow via the back-channel into St Lucia. We estimate that a flow between 5 Mm^3 and 6Mm^3 per month would open the Umfolozi mouth within that month. Therefore, the mouth would only be likely to remain closed during the months June to September. If above average rainfall (75th percentile) was to occur over the next nine months, simulations indicate that the mouth will breach and the back-channel will become ineffective (see Section 3.2.4). If however, average or below average rainfall were to occur, the Umfolozi may remain closed from June to September but could have insufficient flow to supply the full 5Mm^3 per month to the back-channel.

3.5 Back-channel Dimensions and Flow

In this section we discuss the deepening or widening of the back-channel (see Figure 3.11) to allow increased fresh water flow from the Umfolozi/Umsunduze into St Lucia, and making provision for the rapid closing of the back-channel in the event that the Umfolozi river comes down in flood.

Figure 3.14 Aerial view of the back-channel (Google Earth, 2008).

3.5.1 Back-channel flow

From long-term simulations, the estimated flow rate required to restore *virgin* flow contributions to the lake was found to be 5Mm^3 per month. This equates to a flow of approximately 1.9m^3/s. Broad-crested weir hydraulics (Equation 2.4) was used to estimate the critical depth and from that the maximum flow expected over the weir that controls the discharge from the back-channel. A critical depth of roughly 150mm with an extra 100mm for channel losses was found to be sufficient to provide a flow of 1.9m^3/s (5Mm^3 per month). Increasing the depth to 1m would provide a flow of about 36m^3/s (about 95Mm^3 per month), well above the required 1.9m^3/s.

Figure 3.12 illustrates the various water levels for the St Lucia Estuary, Umfolozi Estuary and the back-channel. The Estuary Mean Water Level is denoted as EMWL and is the mean water level of the estuary when open. The gauge plate refers to the St Lucia bridge gauge plate where EMWL is equal to +1.0m. In relation to geodetic mean sea level (GMSL), the actual mean sea level (MSL) is +0.20m and EMWL is +0.45m. A scale of GMSL is also provided in the sketch, but it should be noted that there remains a 200mm unresolved discrepancy in relating the GMSL datum to the St Lucia gauge plate. The levels shown are defined as follows :

- MFBL (the Umfolozi Breaching Level) - the minimum level required to meet hydraulic requirements for the back channel – its maximum value should be selected to prevent damage due to inundation of farmland
- SLBL (St Lucia Breaching Level) i.e. the natural berm levels for this location.
- BCWL (Back-Channel Weir Level) is the height of the weir crest at the discharge end of the back channel.
- HWS and LWS are the Spring High Tide Water Level (+1.05m MSL) and Spring Low Tide Water Level (-1.05m MSL) in the sea respectively. The neap high tide level is about +0.25m MSL and the neap low tide water level is -0.25m MSL.

- HWSE is the Spring High Tide Water Level in the Estuary when the mouth is open and is estimated to be between 1.6m and 2m on the gauge plate. Water level measurements, recorded by DWAF, at the St Lucia Bridge in 2007 indicated that the HWSE was about 1.6m.

The crest of the back-channel "weir" needs to be high enough to avoid the loss of water from St Lucia to the Umfolozi when water levels in the Umfolozi are lower than those in St Lucia and preferably high enough to avoid sea water from entering St Lucia during spring high tides when the Umfolozi mouth is open. Therefore we suggest BCWL must be larger or equal to HWSE (1.5 to 2m on the gauge plate). A water level of 0.25m above BCWL (1.75 to 2.25m on the gauge plate) is required to maintain a flow of 1.9m³/s. Therefore, the MFBL would have to be set from 1.8 to 2.3m (on the gauge plate) in order to allow for flow to occur through the back-channel. If MFBL is increased further, the flow via the back channel could be increased, but the MFBL level should be limited to prevent inundation of adjacent farmland. This does not leave much allowance for flow through the back-channel before a breaching event should occur in the Umfolozi. The SLBL level has been indicated as 2m above EMWL (3m on the gauge plate), which corresponds approximately to observed natural berm levels at this location.

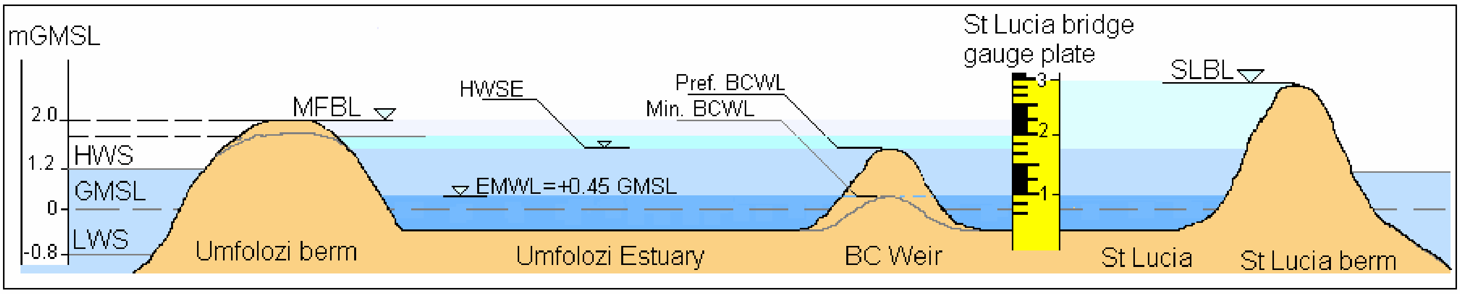

Figure 3.15 Schematic showing key levels required for the functioning of the back-channel (not drawn to scale). BCWL is the Back-Channel Weir Level and MFBL/STBL are the Umfolozi and St Lucia Breaching Levels respectively.

3.5.2 Back-channel dimensions

Flow is proportional to the cross sectional area of a channel, therefore an increase in channel area will result in an increase in flow and vice versa. Alternately, a larger channel will require less hydraulic head difference between the Umfolozi and St Lucia estuary to provide a specified flow rate.

A channel that is very large will in effect result in a joined mouth scenario. The larger channel, by allowing larger link flows into St Lucia, will reduce the build up of water levels in the Umfolozi and therefore reduce the likelihood of it breaching. However, in the event that the Umfolozi came down in flood, large silt loads could flow into the Narrows and providing a means for rapid closure of the back-channel would be difficult.

A small channel on the other hand would facilitate easier control of the flow rate and rapid closure if required. With a smaller channel, breaching of the Mfolozi will occur sooner in the event that the Umfolozi River comes down in flood, thus reducing the chance of high silt load entering the St Lucia system.

It is possible to generate linked water balance models for both the Umfolozi and the St Lucia basins that can simulate the functioning of the linked systems under various scenarios in more detail. This will however require a bathymetric survey to establish the water-level/surface area/volume relationships for the Umfolozi basin.

4 Conclusions

Due to the separation of the Umfolozi mouth, the system is functioning fundamentally differently to how it would naturally. Simulations suggest that with a combined mouth, the system would be predominantly open with stable water levels and salinities. During dry conditions, salinities increase linearly and reach hypersaline conditions during open mouth conditions until the mouth closure. During closed mouth conditions, water levels would rise and salinities would decrease due to the addition of fresh water from the Umfolozi. The rising water levels would cause the mouth to breach and the cycle would continue. Simulations indicate that a flood with a three-year return period would be sufficient to breach the system in this scenario.

The separation of the Umfolozi mouth results in a predominantly closed, fresh water system with highly variable water levels. The system would open briefly during floods. During drought conditions, the closed estuary would have salinities that would increase exponentially while water levels dropped. In order for the mouth to breach, this system would need approximately a ten-year return period flood. An additional $5Mm^3$ per month of fresh water delivered via the back-channel would restore the 20 % reduction in fresh water inflows to the system due to anthropogenic activities (primarily abstractions from the Mkuze). The additional fresh water would dampen the effect of drought conditions in terms of lake salinities and water levels and the mouth state would remain open longer. This is however dependant on the configuration of the mouths. In order for this strategy to work most effectively, both systems would have to be closed.

It has been estimated that a minimum depth of 250mm above the crest of the back-channel "weir" is required to maintain a flow of $1.9m^3/s$ ($5Mm^3$ per month). Therefore it is recommended that the crest of the back-channel "weir" be at HWSE (+1.5 to 2.0m on the St Lucia bridge water level gauge) and the MFBL at 1.8 to 2.3m (on the gauge plate).

The probability that the Umfolozi mouth will close (and remain so) is significant only during the low flow months from July to September. Therefore a continuous supply of fresh water into St Lucia via the back channel would generally not be maintained outside of this period.

Historical rainfall was used to forecast rainfall for the next nine months. Simulations suggest that above average rainfall will provide a positive nett rainfall/evaporation index and average and below average rainfall a negative nett rainfall/evaporation index. The probability that intolerable salinities would be reached in the next nine months is high if average or below average rainfall were to occur and low if above average rainfall were to occur. Hypersaline and even desiccation is very likely to occur if below average rainfall persists. The addition of fresh water would however delay this by about 6 months. Forecasted rainfall predictions by Weather SA indicate that above "normal" rainfall is expected over the next three months.

The probability of flows in the Umfolozi being less than $5Mm^3$/mth is in the range 10% to 30% during the months June to October, but is less than 2% during the remainder of the year. If above average rainfall is received over the next nine months, we predict that there should be sufficient water to supply $5Mm^3$/mth into St Lucia. However if average or below average rainfall is received, we predict that there will be insufficient water to provide this supply into St Lucia.

5 Recommendations

Our model simulations suggest that the long-term implications of past management decisions have completely altered the natural functioning of the system and the system is now functioning fundamentally differently to how it did in the past. The key result of the simulations is the conclusion that the separation of the Umfolozi and St Lucia mouths is by far the most significant anthropogenic intervention in terms of long-term impacts on the functioning of the St Lucia system. Aside from providing an important source of fresh water inflow to the system when the combined mouths are closed, the Mfolozi also plays a key role in providing a more stable mouth state regime for the system.

The perceived threat of siltation to the lake due to the silt-laden Umfolozi is the fundamental driver for a strategy of artificially maintaining a separate Umfolozi mouth. However, the issue is poorly understood and there appears to be no scientific evidence linking the silt deposits in the St Lucia lake basin to the Umfolozi. This needs to be thoroughly and expeditiously investigated and the sediment origins for the St Lucia basin clarified. The mechanisms governing the mouth dynamics also need to be further researched to develop our understanding of this complex issue and improve our confidence in the modelling of mouth processes.

In summary our primary recommendations are that:

1. The back-channel link should be maintained essentially as it is, with some adjustment of the control point elevations if required. Overall the additional freshwater delivered via the back-channel is beneficial to the system in its current state. However these benefits are limited and are likely to be short-lived since there is a high probability that the Umfolozi will breach at the onset of spring rains.

2. The management strategy should move away from persistent intervention towards a new strategy of non-intervention, supplemented by detailed monitoring. This implies allowing the re-establishment of the historical configuration of a combined Umfolozi/St Lucia mouth. The monitoring program, together with on-going research, should focus on the uncertain issues concerning siltation and mouth dynamics. For example the recent high resolution bathymetric survey of the lower Narrows will be a useful baseline from which to monitor siltation effects.

Finally we note that while considerable scientific research has been undertaken on the biological component of the system, there has been limited research on the physical dynamics of the systems and on how the biology responds to changes in the physico-chemical environment and mouth dynamics. The development of an integrated biophysical model should help us understand how different management strategies affect the biological functioning of the system.

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APPENDICES

Appendix A: Forecasted rainfall of South Africa for the next three months

Appendix B: FDCs of the Umfolozi River for each month of the year

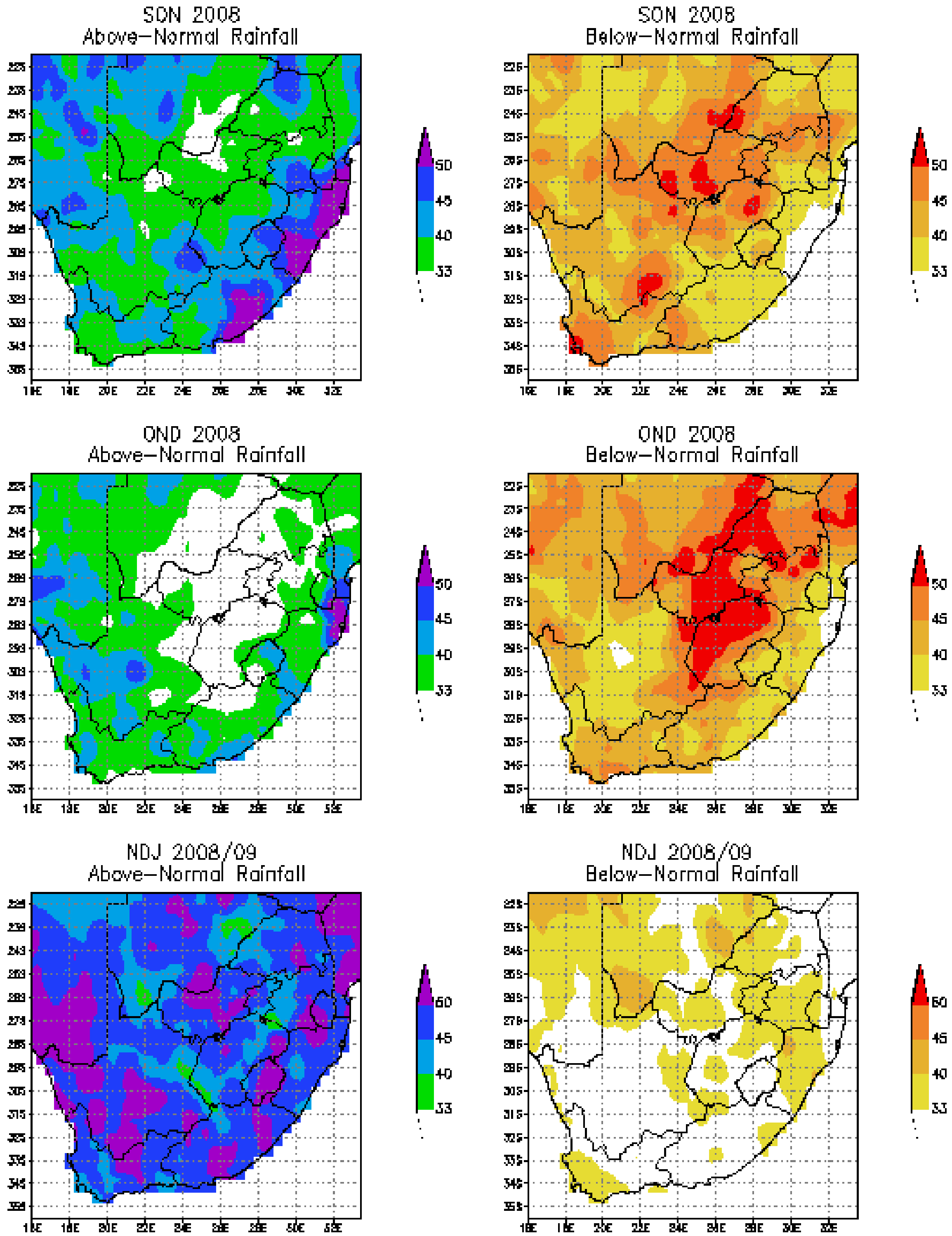

Figure A1 Three month above and below normal rainfall forecast for Southern Africa 2008 (Weather SA).

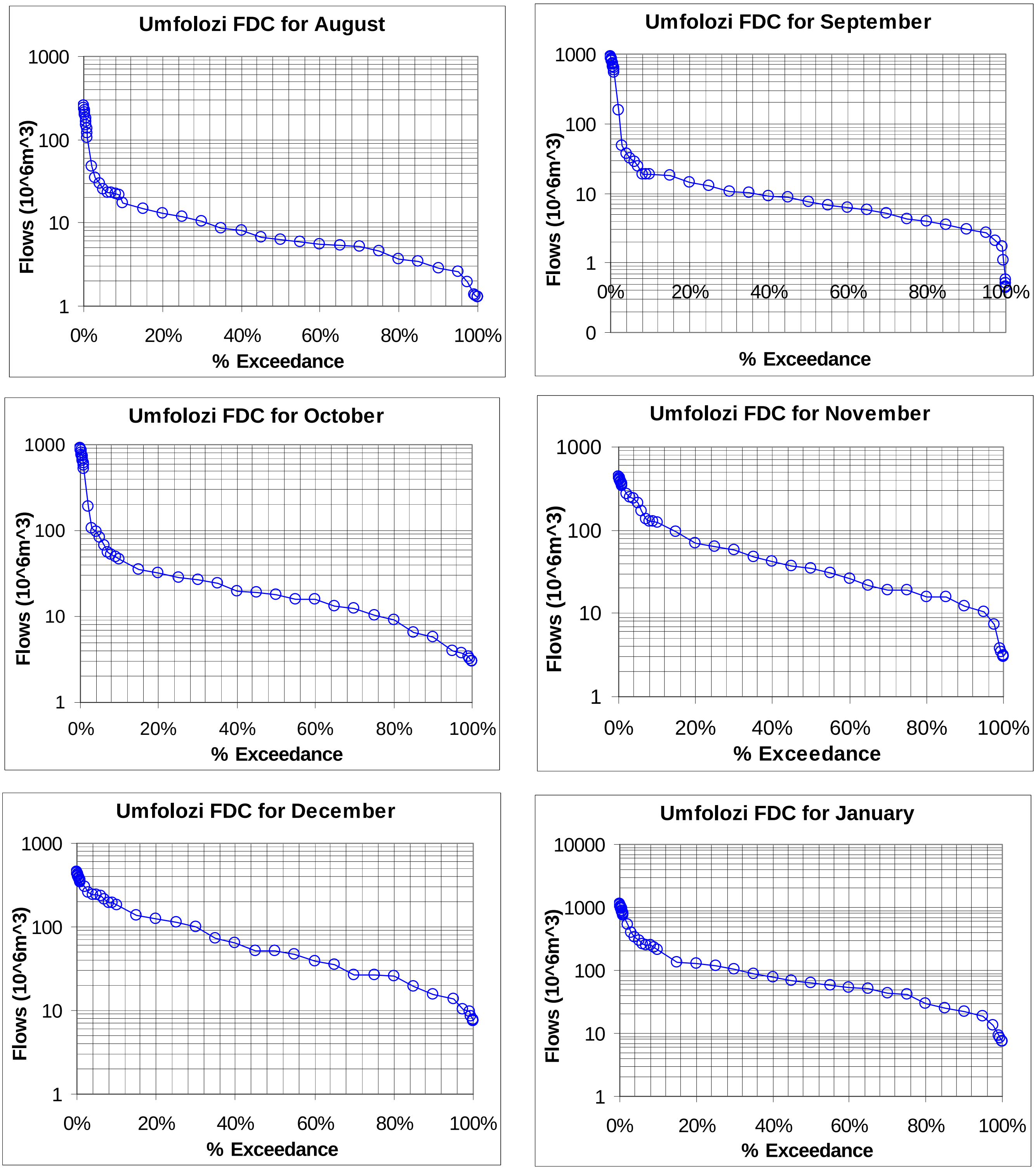

Figure B1: FDC of the Umfolozi from August to January

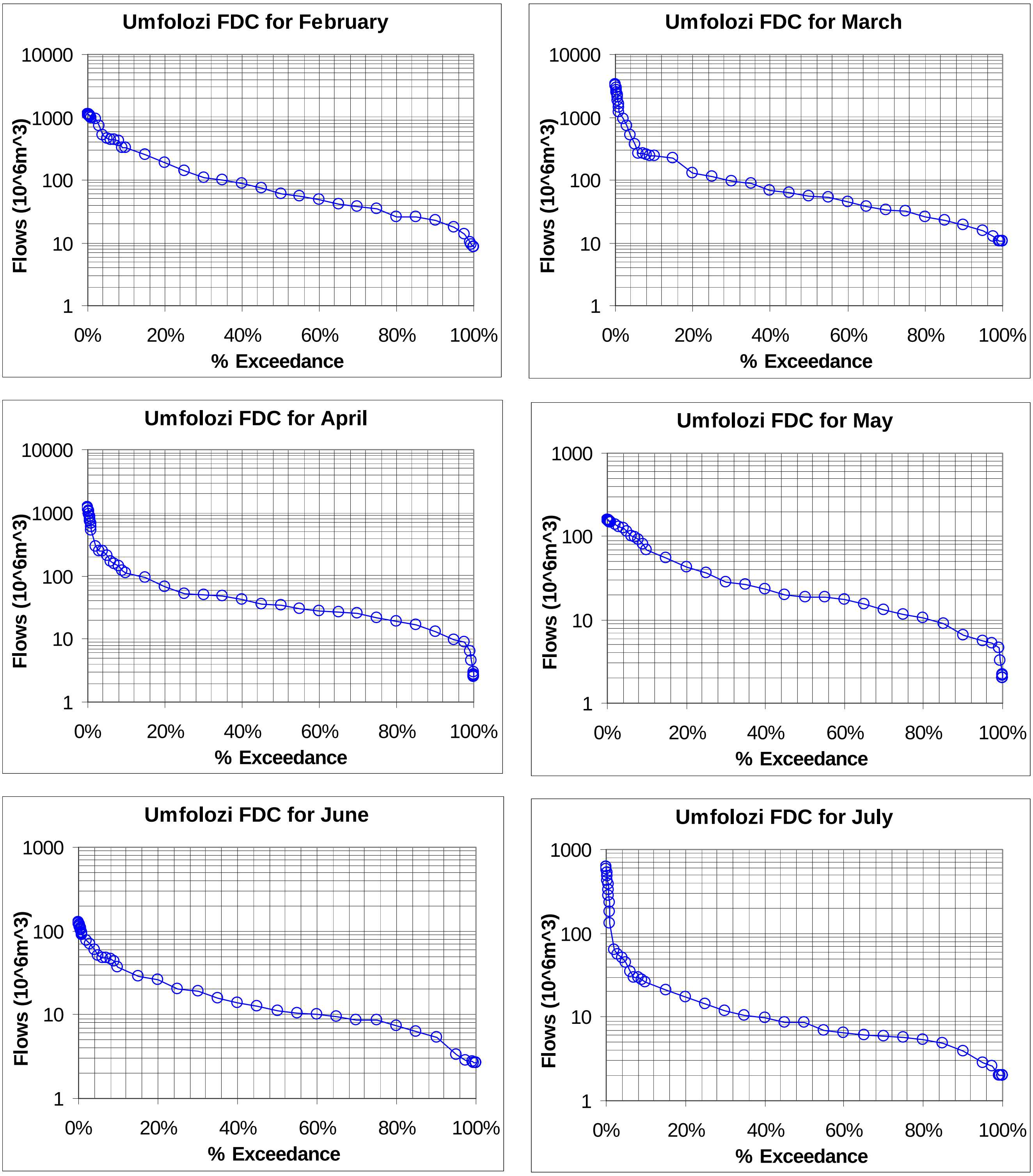

Figure B2: FDC of the Umfolozi from February to July