Assessment of the effectiveness of the Umfolozi Link Canal

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Assessment: A restored Link Canal will significantly enhance the ability of the Lake St Lucia ecosystem to cope with a severe drought.

The restoration of the Umfolozi Link Canal so that it can be used to bring freshwater into St Lucia will cost in excess of R500 000. This report describes the exercise we have undertaken to assess whether the amount of Umfolozi water that can be introduced via the canal will have a significant impact on the ability of the lake St Lucia system to withstand a severe drought. We then give our assessment.

The approach taken was to create the bathymetry of the lake compartments and establish the linkage between them using a water balance approach. The computer model creates a water balance for each compartment and then establishes a balance between the compartments during periods when they are linked. The model provides for the influx of water from the various sources and then diverts it to other sections when the linkage occurs. Consequently, it can be used to simulate the effects of introducing freshwater from the Umfolozi into the lake systems under different conditions when the mouth is closed.. To achieve this we had to go through a number of steps:

Step 1: Understanding the ecosystem functioning

When the mouth is closed and the drought has been ongoing for some time, water levels in St Lucia drop to the extent that the lake is divided into several discrete compartments – each isolated from one another (Figure 1). Under such conditions each compartment functions independently of the adjacent compartments and has its own hydrological characteristics. Figure 1 depicts the lake shoreline when the mouth is open (lake full) and the compartmentalized systems in January 2004 when the mouth was closed and the lake had shrunk to form several discrete compartments. Inflow from the Umfolozi would be expected to recharge the narrows, which would overflow into Makakatana and ultimately into Catalina Bay and possible further north. The intricacies of the linkage between compartments were established from the bathymetry and water balance of the system during the past three years.

The water balance concept is also applied to the salt balance in the model to estimate the variability of the salinity during the mouth closure period when the salinity was found to reach unacceptable levels in certain compartments. If no salts are introduced into the system, then the salinity levels are controlled entirely by the fluctuations in water volume in each compartment.

Figure 1: Map of St Lucia in January 2005 showing the basins (compartments) which still retained water.

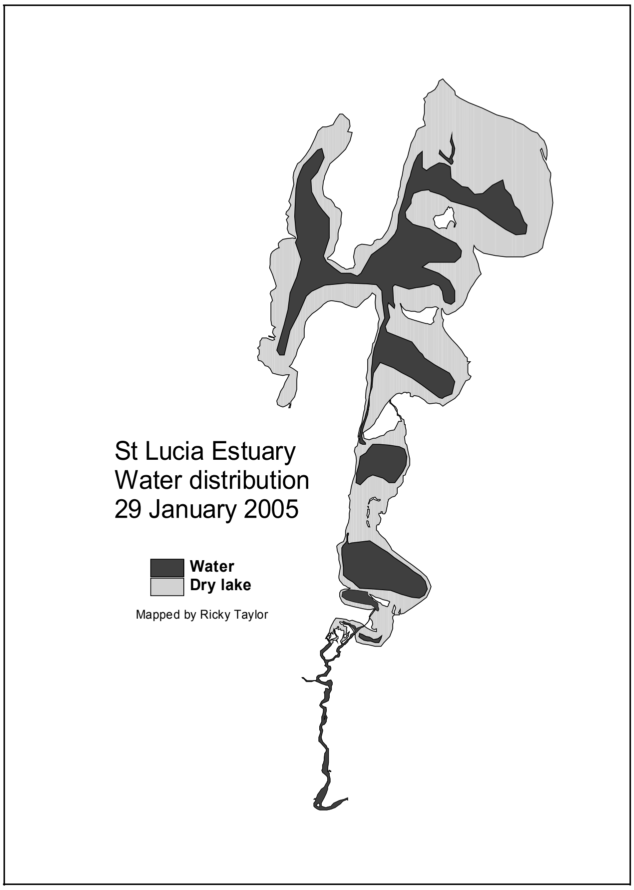


Figure 2 describes, in a schematic way, the main hydrological features of each basin that describe the water balance. The freshwater inflow is derived from direct rainfall, river inflow, groundwater seepage, inflows from the other compartments when they are connected and the inflows from the Link Canal should this be operational

Freshwater losses when the mouth is closed are derived from the lake evaporation and outflows to adjacent compartments – should they be connected.

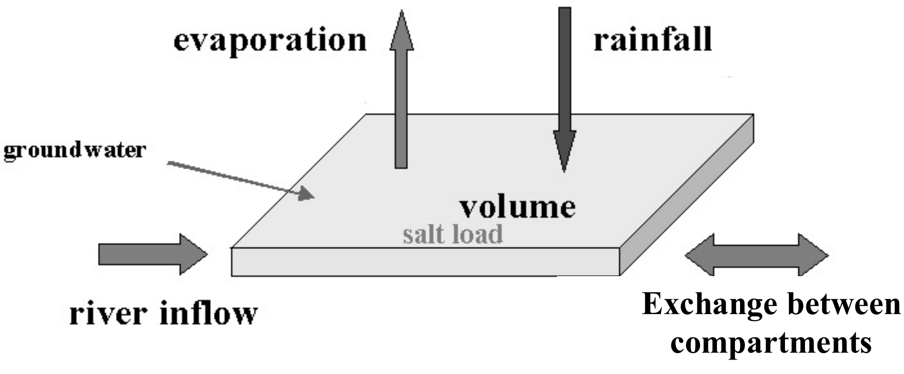
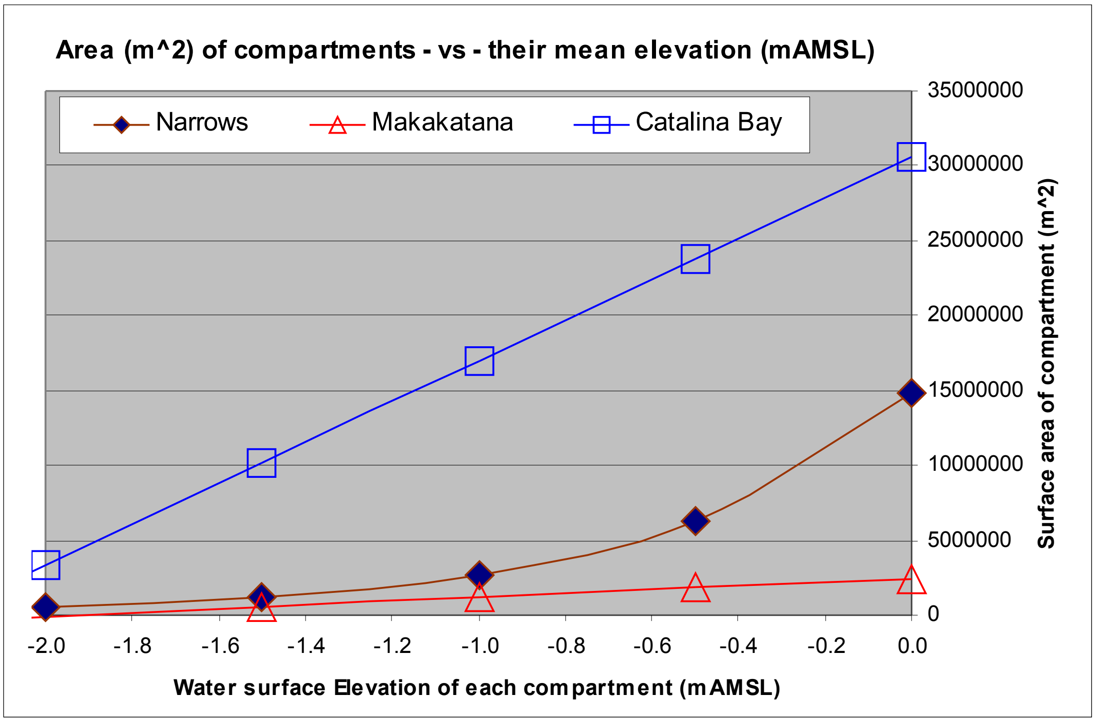


Figure 2: Schematic illustration of the hydrological balance of each compartment.

The compartments each have different dimensions. This means that each compartment has a different surface-area to water-depth relationship (Figure 3). In some compartments, a small change in depth means little change in surface area, while in others the effect can be considerable. This is important because the evaporation rate is affected by the surface area of each water body.

Figure 3. The relationship between the elevation of the lake (compartment) level (mAMSL) and the evaporating surface area (m^2)



When the lake levels drop and the compartments become isolated from their neighbours, the amount of salt trapped in the compartment does not change. However, as the volume changes so the concentration of salts changes. If the volume is halved, then the salinity is doubled. The initial mass (concentration) of salt in the lake system when it becomes isolated will remain relatively constant when the mouth closes and only small quantities of salts are introduced from relatively freshwater sources (rivers, groundwater and rainfall). Some quantities of salt are lost to the system when volumes of water flow out of the system but not through evaporation. Knowing the mass of salt trapped in the system at the start of a drought is very important in understanding how the system will cope with subsequent drought periods. At low salinity (associated with a relatively large volumes) a large evaporation loss has little influence on the changes in salinity. However, at higher salinity (associated with small volumes), a small evaporative loss has a large effect on the salinity concentration. Conversely, a small amount of water added to a small volume with high salinity can result in a large drop in salinity, and *vise versa*. It is important to remember that if the volume of water is halved, the salinity is doubled. For example, if the salinity is 4 ppt and the volume is halved, then salinity becomes 8ppt. These relatively low concentrations (ppt<10) affects few of the biota. However, if the salinity starts at 40 ppt, and it increases to 80ppt from a halving of the volume, the change can have a profound effect on much of the biota.

Since the changes in salinity concentrations are directly proportional to the change in lake volumes, a water balance model was developed to evaluate the compartmentalization of the lake and the changes in lake levels. The water balance model derives estimates of the water gained and lost from each of the southern compartments of lake St Lucia during a drought period when the mouth was closed (no inflow/outflow of marine water with its attendant salt loads) and drought conditions led to the cessation of river inflow from the north. The model calculates the water balance (gains and losses) for each of the southern compartments, and based on the dimensions of that compartment, we were able to simulate changes in water levels and salinity.

The model is driven by inflow and outflows that regulate the volume and water level. When the level drops below a certain elevation (parameter), the lake becomes compartmentalize Conversely, the compartments join together when the overflow from one compartment is able to fill both compartments.

In addition to the understanding of how each compartment behaves, we needed to know at what water level the compartments link to each other. When this happens, water spills over from the compartment with the higher water level into that with the lower water level. This adds water to the receiving compartment until both compartments have the same water level – after which they can be considered as a single compartment.

Step 2: What is the critical element of St Lucia?

We needed to determine the critical element of the St Lucia system that could be adversely affected by drought. This needed to be one that, if modified by the addition of Umfolozi water, would enable the system to be more resilient to the low rainfall and river inflow conditions. This led us to develop the water balance model to enables us to assess how Umfolozi water will influence the lake levels and salinity profiles during the critical periods.

The Catalina Bay basin is regarded as the most important compartment for the maintenance of the biota of St Lucia. This is because it is deeper than the other compartments and it has a large volume:surface area ratio – and hence its change in salinity is slower than the other compartments. The salt concentration of 70 to 80 ppt is the lethal threshold for many estuarine species. If we are able to maintain the salinity in the Catalina Bay compartment below this level, then it will serve as a refuge from which these species can colonise the lake once conditions improve.

Thus, for this assessment, the question we set out to answer was ***"Will water from the Umfolozi, introduced via the Link Canal, maintain the salinity in the Catalina Bay basin below the 70-80 ppt range?"***

Step 3: Description of the model.

The model simulates the change in the water balance for three compartments that become isolated under sever drought conditions (The Nnarrows, Makakatana and Catalina Bay). When the water volume (level) in the Narrows exceeds a specified value, it overflows into Makakatana and the combined volumes are partitioned according to the combined volumes. When their combined levels exceed a specified volume, they are combined in a similar manner with Catalina Bay. When the combined volumes of all three compartments exceed a specified value, it is assumed that the whole of the system has been recharged and the combined volume is partitioned between the three compartments with no outflow to the north. Consequently, the model is limited to simulating the water level and salinity changes in the southern part of St Lucia when the mouth is closed and when lake levels are so low that there is minimal or no connection northwards from Catalina Bay.

Separating each compartment is a sand ridge that acts as a spillway <<fig 3>>

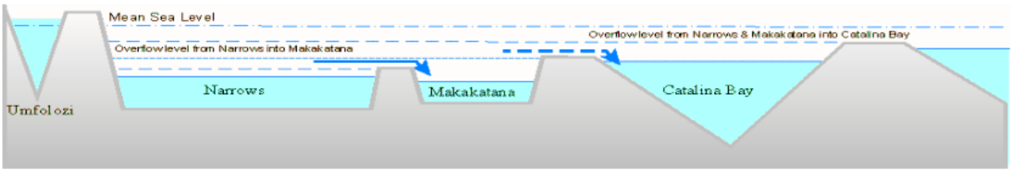


Figure 3: Schematic illustration of the model. As water is inserted into the Narrows from the Umfolozi Link Canal, it will first spill over into Makakatana. The water level will then risein both compartments until it spills over into the Catalina Bay. For the canal to be effective does not necessitate that the water level is raised to that of the combined Narrows-Makakatana basin – only that the salinity is diluted enough to remain below the 70-80 ppt.

The first step was to describe the relationship between water level and surface area, and water level and volume for each basin – and develop the equations for these (Figure 3). This was based on existing bathymetry surveys.

Then for each compartment the daily water balance was computed – based on measured rainfall, average monthly evaporation figures, simulated groundwater inputs, measured inflows from the Mpate River and simulated inflows from the Nkazana Stream. This model was designed to run on a daily time-step for the period from January 2002 (the mouth closed in June 2002) to March 2005.

The simulated water levels and salinity were then compared to measured salinity and water levels. Once reasonable correlations were obtained, then the model was used to simulate the effects of different quantities of water being injected into the system from the Umfolozi.

The simulated salinity series for various transfer rates of water from the Umfolozi to the Narrows for the period from January 2002 to May 2005 are shown in figure 4. The model indicated that a daily transfer of 10 000 cubic metres of water from the Umfolozi into the Narrows would have prevented the high build-up of salt in Catalina Bay that was experienced in both January 2004 and in January 2005.

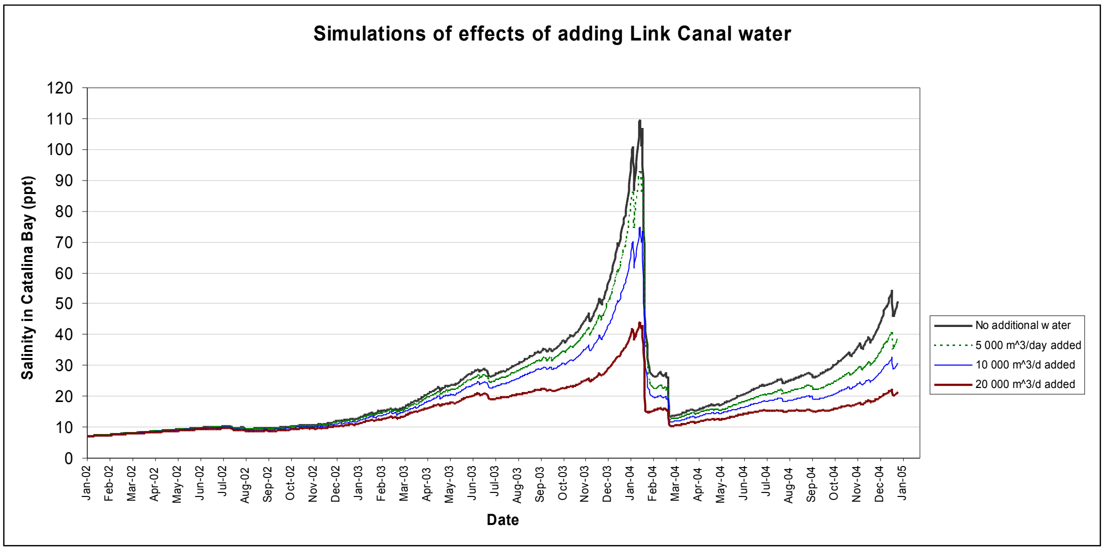


Figure 4: Simulations for the period Jan 2002 to Dec 2004 showing salinity levels without the addition of any water from the Umfolozi link Canal, and additions of 5000, 10 000 and 20 000 m^3/day.

These simulations (table 1) show how peak salinity (in January 2003) would have been reduced by the addition of fresh water.

Water added from the Umfolozi (m^3/day) since January 2002	Simulated peak salinity in January 2004 (ppt)
0	**110**
5 000	**93**
10 000	**74**
20 000	**44**

Table 1: Simulated peak salinity levels for different transfer rates of water from the Umfolzi to the Narrows for January 2004.

Step 4: Can the Umfolozi River supply sufficient water?

Figure 5 shows the frequency of different daily flow rates in the Umfolozi from 2002 to 2005. These data were provided by DWAF who have a measuring station about 5 km downstream of Monzi – this is below where water is abstracted for irrigation, but above the point where water is abstracted by RBM. The RBM abstractions are unlikely to have much influence, as they have a permit to abstract water only when flows are above certain levels.

At this stage we do not know if there is a correlation between flow rates and sediment loads in the Umfolozi nor the level at which the sediment loads become unacceptably for transfer to the lake as there no available data. This level would have to be established empirically.

Figure 5: The flow excedance curves provided by DWAF for the Umfolozi River. These show that flows in the Umfolozi do not fall below about 40 000 m^3/day. Empirical observations do show that this does occur – so these figures do need to be used with caution. However it can be taken that there are few periods with flows that are too low to be of benefit to the lake.

Confidence

1 The model can still be refined, but at this stage the simulated levels and salinities during the past three years of sever drought are adequate for the evaluation of the impact of inflow from the Umflozi.

2 One of the weaknesses comes from not having certain monitoring and survey data. The bathymetry used for Catalina bay is from a survey done in the early 1970s. We do not know if there have been changes in the lake morphology since then. What is particularly important for the model is the height of the spillways between each of the compartments. These levels were inferred from field observations at various lake levels and through the model calibrations. Another problem was the failure in the DWAF water level recorder at Charters Creek during part of the drought period when its sensor was exposed by low lake levels.

3 The groundwater seepage rates were derived from coarse simulations studies for lake full conditions. The rates need to be reassessed under low lake conditions.

4 The evaporation rates are based on seasonal values that have been adjusted during calibrations for each compartment where it is assumed that the rates for the Narrows are relatively lower than the corresponding rates for Makakatana and Catalina Bay.

Conclusions

The introduction of water from the Umfolozi River via the Link Canal would have a significant ecological effect during droughts of the magnitude currently being experienced. However the system is very sensitive to the amount of salt trapped in the lake at the start of a drought. If the initial salinity concentrations are high before a large amount of water is lost, the canal would delay the rapid rise in salinity condition while sufficient inflow prevailed. This delay in rising salinities would increase the probability of rain falling in that time period – hence reducing the probability of excessive salinities

Our assessment is that the restoration of the Link Canal will have beneficial effects on the St Lucia ecosystem during periods of extreme drought when the mouth is closed.

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