water & sanitation

Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

RESERVE DETERMINATION STUDIES FOR SELECTED SURFACE WATER, GROUNDWATER, ESTUARIES AND WETLANDS IN THE USUTU/MHLATUZE WATER MANAGEMENT AREA

WP 10544

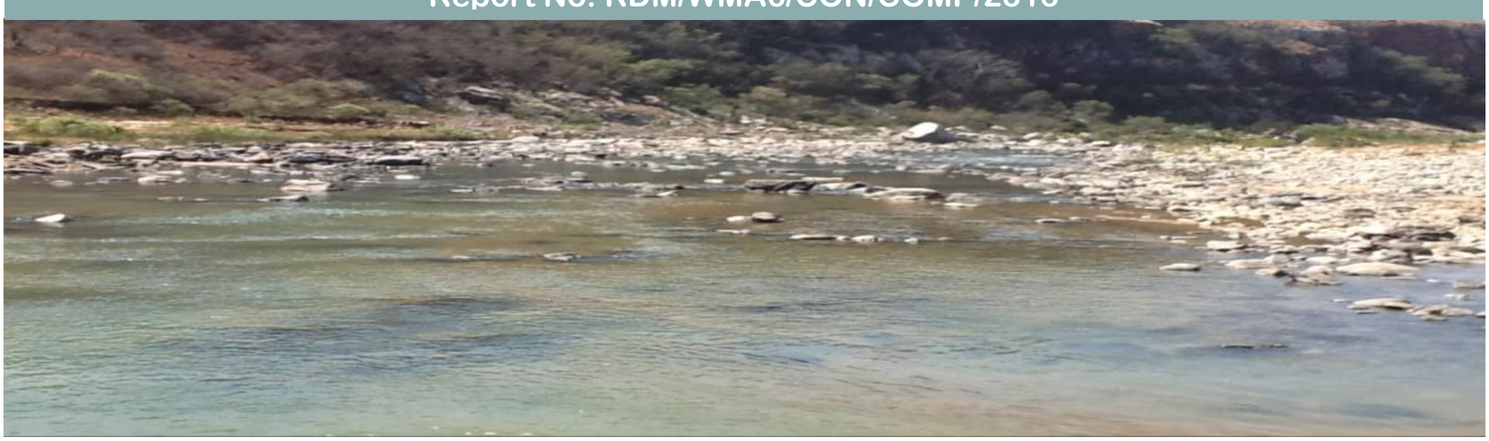
ST LUCIA

VOLUME 2: HYDRODYNAMIC MODELLING OF SALINITY AND SUSPENDED SEDIMENT

FINAL

JULY 2016

Report No. RDM/WMA6/CON/COMP/2313



DEPARTMENT OF WATER AND SANITATION

CHIEF DIRECTORATE: WATER ECOSYSTEMS
CONTRACT NO. WP 10544

RESERVE DETERMINATION STUDIES FOR SELECTED SURFACE WATER, GROUNDWATER, ESTUARIES AND WETLANDS IN THE USUTHU/MHLATUZE WATER MANAGEMENT AREA:

ST LUCIA
VOLUME 2: HYDRODYNAMIC MODELLING OF SALINITY AND SUSPENDED SEDIMENT

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Contract Title: Reserve determination studies for selected surface water, groundwater, estuaries and wetlands in the Usuthu - Mhlathuze Water Management Area

Report Title: St Lucia Intermediate EWR Assessment Report - Volume 2: Hydrodynamic modelling of salinity and suspended sediment

Compilation: B Clark

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EXECUTIVE SUMMARY

The objectives of the tasks of this report were to simulate and evaluate the hydrodynamics, salinity and sediment transport in the St Lucia Lake and estuarine system, for various hydrological scenarios, for the period 1962 to 2010. Daily output data from the modelling was used in the ecological modelling task of the project.

Hydrodynamic modelling was carried out in this task on hydraulics, salinity (TDS) and suspended sediment (TSS) dynamics, to evaluate different scenarios and long terms trends in the St Lucia estuarine lake system. The study investigated single (combined) mouth conditions without artificial breaching of the mouth, for the period 1962 to 2010. Open or closed mouth conditions were simulated based on empirical rules in a one dimensional (1D) hydrodynamic model which was calibrated successfully against historical water level and salinity data in the Lake, considering the reliability of the daily flow data generated in the hydrology task, the TDS data reliability of especially the earlier records and the TDS sampling during droughts from the banks in some locations (iSimangaliso, 2015). Long-term water level and TDS concentrations were simulated in this study for the Reference (Acocks land cover and agricultural use of 1920), Baseline (current) and five possible development scenarios. The daily flow hydrology for this study differs from the hydrology of the iSimangaliso (2015) study in that rainfall input data was scaled in this study (which is scientifically more correct), to calibrate the ACRU model flows against the Pitman model, while in the iSimangaliso (2015) study the simulated daily flows were scaled.

Suspended sediment transport was simulated in Lake St Lucia, the Narrows, and the uMfolozi River, considering the bed sediment grading, the sediment yields, floodplain flow during large floods, open and closed mouths, for a single mouth system which is not breached artificially when closed, and wind wave re-suspension of sediment in the Lake. The simulated suspended sediment concentrations were validated against limited available observed data and were found to be in the same order of magnitude (iSimangaliso, 2015). Long term simulations including land use and water use change impacts were simulated and compared.

This report assumed that the mouth is never breached artificially. If the mouth is allowed to breach when the water spills over the berm at a high level, this could inundate farmland or cause drainage problems, but breaching at a high water level ensures flushing of sediment and creation of a relatively large mouth (width and depth) with more tidal flow. The berm lowest crest level could typically be at about 2.5 m MSL to 3.0 m MSL and flooding to these elevations during low river flow conditions when the mouth could close have to be considered for future land use planning.

A mouth state “A”, based on the 2013 topographical survey (iSimangaliso, 2015), with a small spillway channel excavated parallel with the beach berm to link the uMfolozi River estuary with the Lake estuary, as well as a mouth state with a larger first phase spillway channel based on the dredging contract of iSimangaliso (2016) (state B), were used in the

hydrodynamic model simulations. Note that for mouth state B the spillway channel in this study differs from the state B of the iSimangaliso (2015) study, because the 2015 study proposed removal of the north eastern end of the dredged spoil dump while the iSimangaliso 2016 dredge contract proposes a channel parallel with the beach berm (used in this study). The Reference scenario setup at the mouth of this study differs from the iSimangaliso (2015) study in that the single mouth in this study was placed opposite the Lake estuary, with the uMfolozi River extended to downstream of Honeymoon Bend, based on a survey of 1905 and an aerial photo of 1937.

The key findings of this study are:

- The lowest mean Lake level is simulated in scenario 5B at Lister's Point. For mouth state B, the mean Lake levels corresponding closest to the Reference condition are found with the **Baseline scenario**. **Scenario 1B** minimum Lake levels are found to agree the closest to those of the Reference scenario.
- Under Reference conditions the lake water levels dropped to below 0.1 m MSL about 16% of the time (such a low Lake level is one of the triggers to close the mouth if the uMfolozi River flow is also low). The **Baseline B** scenario percentage of time below 0.1 m MSL is the closest to that of the Reference scenario in general. The percentage of time the water level is below 0.1 m MSL for Lister's point and the Northern Lake for **scenarios 1B and 3B** are also close to those of the Reference values.
- The net flow in the Narrows for all the scenarios are out of the Lake. All the scenarios (baseline and future) however differ significantly from the Reference scenario, with the latter having a significantly larger Lake outflow due to larger Lake river inflows.
- The Lake estuary tidal prism mean annual flows for the **Baseline B and scenarios 1B and 2B** were found closest to that of the Reference condition. On the river estuary the **scenarios 2B and 4B** gave tidal prism results similar to those of the Reference condition. This does not mean that scenarios 2B and 4B are better or should be implemented, because the tidal prism statistics are determined by many factors. For example the Lake inflow from rivers under Reference conditions were much more than under all other scenarios and this decreased the net tidal prism calculated as flow up the Narrows for the Reference scenario.
- Under Reference conditions the mouth was open for 84% of the time. The **Baseline scenario B** (61.8% open) is the closest to the Reference condition, followed closely by **scenario 1B** (61.6% open) and then **scenario 2B** (61.2% open). Scenario B mouth conditions improves the percentage of time the mouth is open by about 3 % to 6% of the time compared to mouth state A scenarios. Scenario 5 causes a drastic decrease in the percentage of time the mouth is open compared to all other scenarios.
- TDS: For mouth condition A, the **Baseline A** TDS concentrations at Lister's Point and at the Northern Lake, and of **scenario 5A** at Charter's Creek, are closest to the Reference scenario TDS median concentrations. For mouth state **B, scenario 1** simulates median TDS Lake concentrations closest to that of the Reference scenario in the Lake. When considering TDS values exceeded 10 % of the time for mouth

state A, scenarios 3A, 2A and 5A are closest to the Reference scenario TDS values at Lister's Point, Northern Lake and Charters Creek, respectively. For TDS values exceeded 10% of the time for mouth **state B, the Baseline scenario, scenario 4B** and scenario 5B are closest to the Reference scenario TDS values at Lister's Point, Northern Lake and Charters Creek, respectively. In mouth state A, TDS peaks based on 10 % of time exceedance are below 35000 mg/l, but in mouth state B, for scenarios 3B and 5B the TDS values exceed 35000 mg/l.

- TSS in the Lake: Re-suspension by wind generated waves of fine sediment in the Lake is the dominant mechanism affecting the suspended sediment concentrations. The highest concentrations generated by flow occur in the Northern Lake originating from the uMkhuze River, downstream of the swamp. The flow-generated suspended sediment concentrations are generally quite small, but some high concentrations are present for short periods when lake levels are low. The Reference scenario total suspended sediment concentrations are, on average, very similar to the concentrations for the **scenarios 1B** at Lister's Point and the Northern Lake, and also similar to the **Baseline scenario B and scenario 4B** at Charters Creek. Although the simulated sediment concentration differences in the Lake are not large, the highest concentrations are generally found at Charters Creek, followed by the Northern Lake. The highest mean total suspended sediment concentrations are simulated for scenarios 5A and 2B.
- TSS in the Narrows: The simulated average TSS concentrations are relatively small. The average sediment concentration at the Upper Narrows is less than at Honeymoon Bend, due to sediment deposition in the Narrows. In the Narrows, **scenarios 3A and 3B** have average TSS concentrations similar to the Reference scenario probably due to the proposed large dam in the uMfolozi River catchment which will trap most of the Upper catchment sediment. The other scenarios, however, all have relatively small TSS average concentrations in the Narrows of 50 mg/l or less.

In general it seems that the **Baseline B scenario followed by scenarios 1B and 2B** have hydrodynamic, TDS and TSS characteristics more similar to the Reference scenario than the other scenarios. This is expected since the uMfolozi and uMsunduzi combined river flows for these three scenarios are 95%, 94% and 93% of the Reference MARs respectively. Scenarios 3B, 4B and 5B have combined uMfolozi and uMsunduzi River MARs of 88%, 89% and 38% respectively of the Reference scenario, and therefore are much more affected by possible development.

In all current or future possible development scenarios it is important to note that:

- Lake local river inflows should not be decreased in future but should rather be increased by deforestation.
- The mouth closes when the river flow averaged over 30 days is less than 1.5 m^3/s at the uMfolozi River DWS gauging station W2H032 and the water level in Lake at Charters Creek (Southern Lake) is less than 0.35 m MSL. The EWR of the uMfolozi River should consider the minimum uMfolozi River flow requirement

so that the mouth stays open most of the time as under Reference conditions. Note that the DWS flow gauging station on which the 1.5 m^3/s minimum flow is based is inaccurate and it is recommended that the EWR rather consider a minimum uMfolozi River flow of 3.0 m^3/s which triggers mouth closure. This should be monitored in the field against actual mouth closure with accurate flow measurement in future.

- As part of the EWR the mouth should never be breached artificially and should be allowed to dam water in the river and Lake estuaries to typically 2.5 m MSL or even 3.0 m MSL, depending on the closed beach berm height. This will allow more river flow north through the Narrows towards the Lake during droughts and when breaching occurs naturally it will open up a large mouth with a large tidal flow.
- Mouth state B scenarios in this study assumed a dredged equilibrium beach channel parallel with the beach berm as proposed by the iSimangaliso (2016) dredging contract. The dredging of the beach side of the dredged spoil dump should only be seen as a first phase, however, and to ensure the stability and equilibrium of the “spillway” channel between the estuaries, all of the dredged spoil dump should be removed eventually (refer to iSimangaliso, 2015, for more details).
- The EWR should mainly be based on the hydrodynamics and TDS of the Lake system, rather than on TSS. In the Lake and Narrows the flow transported suspended sediment concentrations are relatively small for all scenarios. The Lake is dominated by wind wave generated suspended sediment.
- In general the mouth state B works best at Charters Creek to get the Lake salinity relatively high similar to the Reference condition, but then the TDS at Lister’s Point and the Northern Lake are too high (compared to Reference) because the freshwater inflow in the northern Lake is too low in current scenarios. Therefore mouth state A TDS values in the Northern Lake and False Bay are closer to the Reference scenario TDS concentrations, because the seawater flow to the Lake is throttled at the small spillway channel at the beach berm. Mouth state A spillway channel will however probably silt up as happened recently and the Lake salinity will then not behave as simulated. Therefore mouth state B with the proposed larger dredged spillway channel is the recommended scenario to assess in the EWR study, with the recommendation that fresh water river inflows to False Bay and the Northern Lake are supplemented to reduce the TDS at Lister’s Point and at the Northern Lake (Refer to the iSimangaliso (2015) study for possible mitigation measures).
- It is proposed that the uMfolozi River EWR is based on the **Baseline B** scenario hydrology (and not scenarios 1 to 5) to try and improve especially the drought flow conditions in the river (which affect mouth closure and Lake levels), which are currently unnatural due to the existing upstream irrigation and potable water abstraction, especially during droughts.

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1 INTRODUCTION

The Chief Directorate: Resource Directed Measures issued an open tender invitation for the "Appointment of a Professional Service Provider to undertake Reserve Determinations for selected Surface water, Groundwater, Estuaries and Wetlands in the Usutu to Mhlatuze Basins". The focus on this area was a result of the high conservation status and importance of various water resources in the basin and the significant development pressures in the area affecting the availability of water.

Preliminary Reserve determinations are required to assist the Department of Water and Sanitation (DWS) in making informed decisions regarding the authorisations of future water use and the magnitude of the impacts of the proposed developments on the water resources in the WMA, and to provide the input data for Classification of the area's water resources, and eventual gazetting of the Reserve (DWA, 1998). On 19th November 2012, DWA appointed Tlou Consulting to undertake the project.

The St Lucia Estuarine Lake System is one of the most important estuaries in South Africa. It is the largest of only three estuarine lake systems in the country, with a water surface of 300 km^2 and a shoreline of over 400 km (Figure 1-1). It incorporates over 80% of the estuarine area of the southern African sub-tropical region and 60% of the estuarine area of the country, making it the most important nursery ground for juvenile marine fish and prawns along the east coast. The estuarine lake system is located wholly within the iSimangaliso Wetland Park, listed as the first World Heritage site in South Africa in 2000. In its natural condition, the St Lucia estuarine system received freshwater from the uMfolozi, uMsunduzi, Mpate, Nyalazi, Hluhluwe, Mzinene and uMkhuze Rivers. The system, in its natural state, is likely to have been open to the sea for most of the time. However, the St Lucia system has been subject to numerous anthropogenic pressures over the past century, which have altered its hydrodynamic functioning and undermined its health. The artificial separation of the uMfolozi River from the St Lucia system in 1952 has arguably had the greatest impact on the system and was done to address the perceived threat of siltation from the uMfolozi River.

This report describes the tasks on hydrodynamic, salinity and sedimentation modelling carried out on the St Lucia Lake, estuary and rivers.

Prof Basson of ASP Technology (Pty) Ltd, South Africa, was appointed on 26 June 2015 to carry out the tasks of this study related to the hydrodynamics, salinity and sedimentation of the St Lucia system.

Figure 1-1 Map of Lake St Lucia system (Perissinotto *et al*. 2013)

2 OBJECTIVES OF THE STUDY IN GENERAL AND THE TASKS OF THIS REPORT: HYDRODYNAMIC, SALINITY AND SEDIMENTATION MODELLING

The general objectives of the study are to:

- determine the Ecological Reserve (DWAF 1998), at various levels of detail, for the Nyoni, Matigulu, Mlalazi, Mhlatuze, uMfolozi, Nyalazi, Hluhluwe, Mzinene, Mkuze, Assegaai and Pongola Rivers;
- determine the Ecological Reserve, at an Intermediate level for the Pongola floodplain;
- determine the Ecological Reserve, at an Intermediate level for the St Lucia/uMfolozi, Estuary System;
- determine the Ecological Reserve, at an Intermediate level for the Mlalazi Estuary;
- determine the Ecological Reserve, at a Rapid level for the Amatikulu Estuary;
- determine the Ecological Reserve, at an Intermediate level for Lake Sibaya;
- determine the Ecological Reserve, at a Rapid level for Kozi Lake and Estuary;
- classify the causal links between water supply and condition of key wetlands
- incorporate existing EWR assessments on the Mhlatuze (river and estuary) and Nhlabane (lake and estuary) into study outputs;
- determine the groundwater contribution to the Ecological Reserve, with particular reference to the wetlands;
- determine the Basic Human Needs Reserve for the Usutu/Mhlatuze WMA;
- outline the socio-economic water use in the Usutu/Mhlatuze WMA;
- build the capacity of team members and stakeholders with respect to EWR determinations and the ecological Reserve.

The objectives of the tasks of this report were to simulate and evaluate the hydrodynamics, salinity and sediment transport in the St Lucia Lake and estuarine system, for various hydrological scenarios, for the period 1962 to 2010. Daily output data from the modelling was used in the ecological modelling task of the project.

3 METHODOLOGY

Sophisticated hydrodynamic models have been used in this study in an attempt to simulate the physical processes in great detail and in the long term, based on daily flow records for the period 1962 to 2010 that were obtained from the hydrological task. Salinity (TDS) was simulated using the fully hydrodynamic one dimensional hydrodynamic model, Mike 11, of the DHI Group, Denmark. The model was calibrated against water level and TDS data. A single mouth was considered and mouth opening and closure were simulated by empirical rules in the model. Rainfall and evaporation on the Lake was included in the simulations.

The long term suspended sediment transport in the system was simulated by using 1D hydrodynamic modelling. The hydrodynamic model calibrated for the TDS simulations was used with a cohesive sediment module to simulate the cohesive fraction suspended sediment concentrations from 1962 to 2010, based on daily hydrological data. The simulation results were validated against field data obtained during previous studies.

The models used in this study were calibrated against field data for a historical scenario (1962 to 2010) during a recent study for the iSimangaliso Wetland Park Authority (2015).

4 HYDRODYNAMIC MODELLING AND SALINITY

4.1 Background

Hydrodynamic modelling of St Lucia Estuarine Lake System was required to predict long term changes in water levels, flow depths and salinity, associated with a range of hydrological scenarios based on daily flows for the period 1962 to 2010. A one dimensional (1D) fully hydrodynamic model was selected to simulate the various components required for this study such as mass balance of flow and salinity, rainfall and evaporation, mouth opening and closure based on river flow and Lake levels, different berm heights, low flow and flood conditions, etc.

4.2 One dimensional modelling

4.2.1 Model setup

The one dimensional hydrodynamic model Mike 11 of the DHI Group, Denmark, was used for the modelling of the hydrodynamics, salinity and long term suspended sediment concentrations of the Lake system. The model is fully hydrodynamic and uses cross-sections obtained from the 2013 survey (iSimangaliso, 2015). The model of the St Lucia estuary with all the main inflowing rivers, as well as evaporation and rainfall on the Lake was set up. The uMfolozi and Msunduze Rivers were added in the model in the south.

Following the 1984 flood a 600 m weir was constructed on the right bank floodplain to control the natural diversion of water in a southerly direction towards the uMsunduzi River (Figure 4.2.1-1). At the same time the uMfolozi River flow width was constricted by berms which are protected by gabion mattresses and supported by wooden piling, forming a bifurcation. Later a 400 m length diversion spillway was also constructed upstream of the 600 m spillway. The diverted water flows to the uMsunduzi River which joins the uMfolozi River at the mouth.

The uMfolozi River bifurcation and flow diversion was not modelled directly but was included in the inflow boundary conditions of the model. The diversion discharge capacity was based on a physical model study carried out at the University of Stellenbosch during 2004 to optimize the diversion (US, 2004). During large floods about 90% percent of the uMfolozi River flood flow is diverted to the uMsunduzi River in the south (Table 4.2.1.1). The two rivers join up again upstream of the mouth.

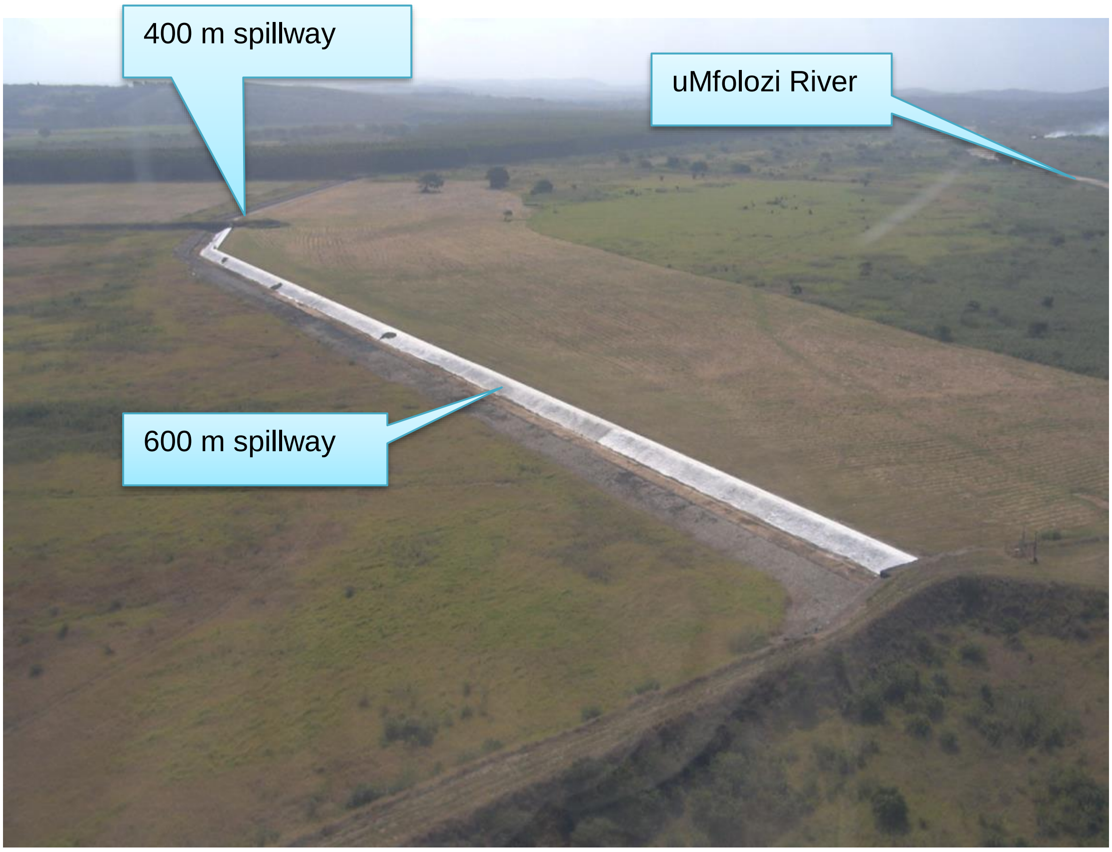


Figure 4.2.1-1 Aerial view of the 600 m and 400 m spillways of the uMfolozi River Diversion viewed from the south

A shorter “emergency” spillway is also located downstream of the bifurcator on the right bank, about 300 m upstream of the Domoina Bridge.

Table 4.2.1.1 uMfolozi River Diversion discharge rating (US, 2004)

uMfolozi River inflow upstream of diversion	Diverted to uMsunduzi River	uMfolozi River flow downstream of the diversion
(m^3/s)	(m^3/s)	(m^3/s)
0	0	0
772	0	772
1000	267	733
2082	1204	878
8565	7353	1212
13615	12206	1409

For the historical calibration scenario a single mouth or two separate mouths were simulated (iSimangaliso, 2015). In the latter case there was no connection between the St Lucia estuary and the uMfolozi River during normal river flow or tidal flow conditions, but during floods a western channel was included in the model to simulate spillage from the uMfolozi River into the Lake estuary. A floodplain channel was also included which linked the uMfolozi and uMsunduzi Rivers during large floods (information obtained from the 2D modelling, iSimangaliso (2015)), which is located downstream of the bifurcation on the uMfolozi River.

The schematic layouts of the model for a single mouth and for two mouth scenarios are shown in Figure 4.2.1-2. For all the scenarios (except the historical calibration scenario), it was assumed that no artificial breaching of the mouth would be undertaken. The scenarios in this study only considered single mouth conditions, with the Lake and river estuary mouths combined. **Appendix B** provides the surveyed water level-volume-area relationship of the Lake from the 2013 survey (iSimangaliso, 2015).

Figure 4.2.1-3 shows a longitudinal profile of the one dimensional model from the Northern Lake through the Narrows to the mouth (The elevations in this figure and all the figures in this report refer to m MSL. Please refer to **Appendix C** for a datum comparison between m MSL and EMSL). During droughts, the various parts of the Lake and estuary could be cut off from one another with different water levels in the various parts of the Lake as shown in Figure 4.2.1-3 below. This agrees with observations in the field as shown in Figure 4.2.1-4 during the 2003 drought. The benefit of the 1D model of this study compared to the 0 D model used in the past by Lawrie and Stretch (2008) is that each part of the lake is simulated separately (based on mass balance and fully hydrodynamic flow routing) and therefore during droughts False Bay could for example have a lower water level than the South Lake, with associated hyper saline conditions at False Bay. The 0 D model used in the past by Lawrie and Stretch (2008) considered the mass balance of the complete lake system, but had no fully hydrodynamic routing features, and therefore no detailed simulations could be carried out of what happens in different parts of the Lake.

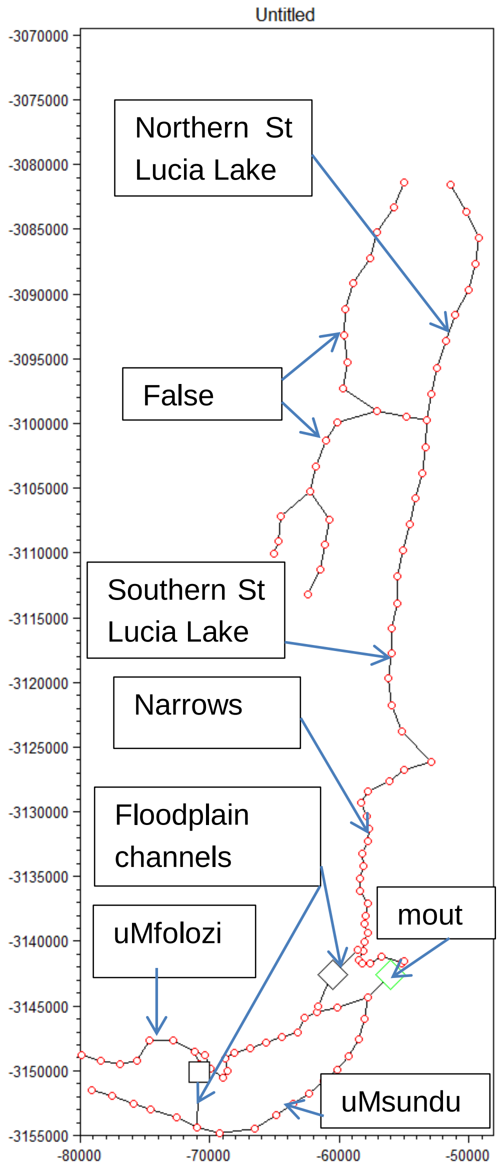


Figure 4.2.1-2 1D model network layout with single mouth (left) and two mouth setups (right) (iSimangaliso, 2015)

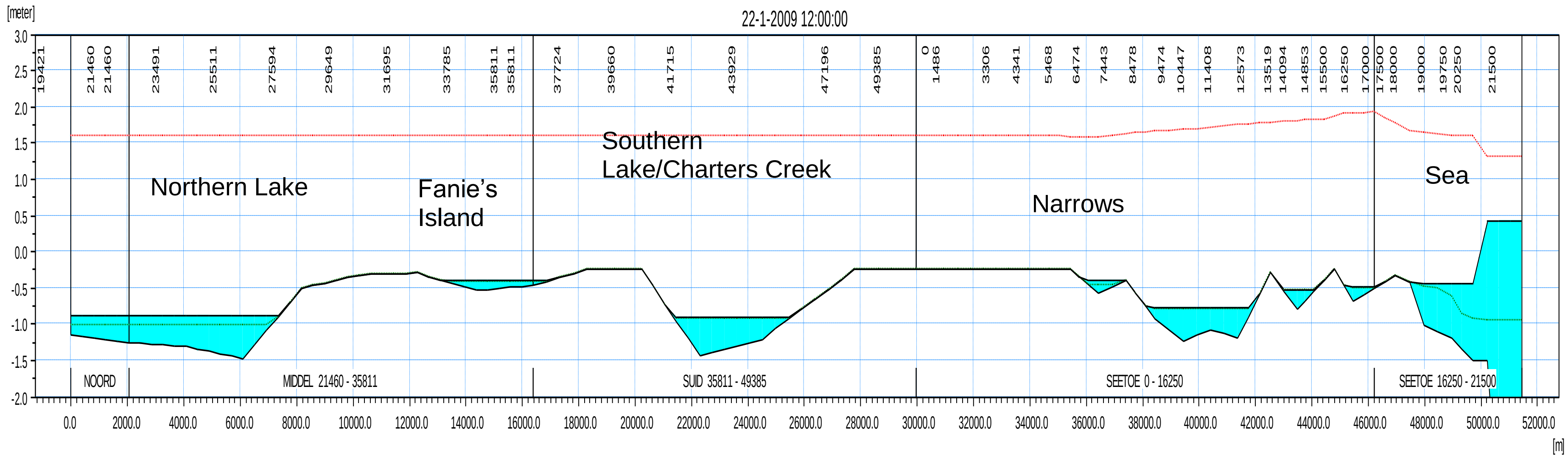


Figure 4.2.1-3 Longitudinal section with simulated water levels from the Northern Lake to the sea from left to right (water levels illustrate a possible scenario during drought periods (blue); the red line indicates the maximum simulated water level (m MSL)).

(Note: all the figures in this report refer to m MSL; Refer to **Appendix C**, Figure C-2, for the relationship between EMSL and m MSL) (iSimangaliso, 2015).

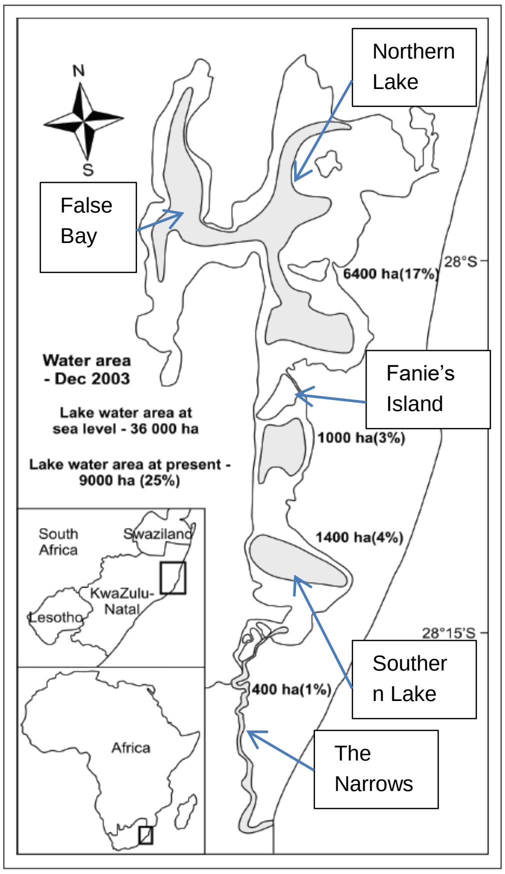


Figure 4.2.1-4 Water coverage of Lake St Lucia in December 2003 reduced to 25% of surface area (Cyrus *et al*., 2011; Original figure compiled by Ezemvelo KZN Wildlife) (iSimangaliso, 2015)

The open or closed historical mouth conditions were obtained from published records and from an evaluation of tidal levels at the St Lucia bridge gauging station. The historical mouth conditions are shown graphically in Figure 4.2.1-5a: which is a summary of mouth states recorded (i), according to Lawrie & Stretch (2008) rules (ii) and combination of (i) and (ii) = (iii) (where (i) overrides (ii)). More detailed data was available on monthly resolution to generate this figure. Figure 4.2.1-5b was generated from Figure 4.2.1-5a which was used as basis, with further minor adjustment based on observed data. Note that the closed and open mouth elevations shown in the graph are plotted (schematically) at different elevations to make it easier to read the graph and are related to open/closed conditions, not to actual elevations.

The uMfolozi River mouth was generally open in the past (due to mechanical breaching when the water level in the estuary exceeds 0.95 m MSL which causes drainage problems at some of the sugarcane farms), except during three prolonged periods of low rainfall when the mouth remained closed for several years at a time. Since 2008, the river mouth was breached artificially several times and was not allowed to close for long periods due to the impacts of inundation on farm land upstream. The St Lucia estuary mouth has been closed for much of the time since 2003. In the period 1962 to 2003, the St Lucia estuary mouth was generally maintained open by dredging and before the flood of 1984 also by engineering structures at the mouth.

The survey task of the iSimangaliso (2015) study generated the water level-area-volume relationships of the St Lucia Lake, The Narrows and uMfolozi River, which are enclosed in **Appendix B**. The new 2013 stage–volume relationship agrees well with the survey data provided by Hutchison (1974).

Figure 4.2.1-5a Summary of mouth states recorded (i), according to Lawrie & Stretch rules (ii) and combination of (i) and (ii) = (iii) (where (i) overrides (ii)); (More detailed data available on monthly resolution) (iSimangaliso, 2015)

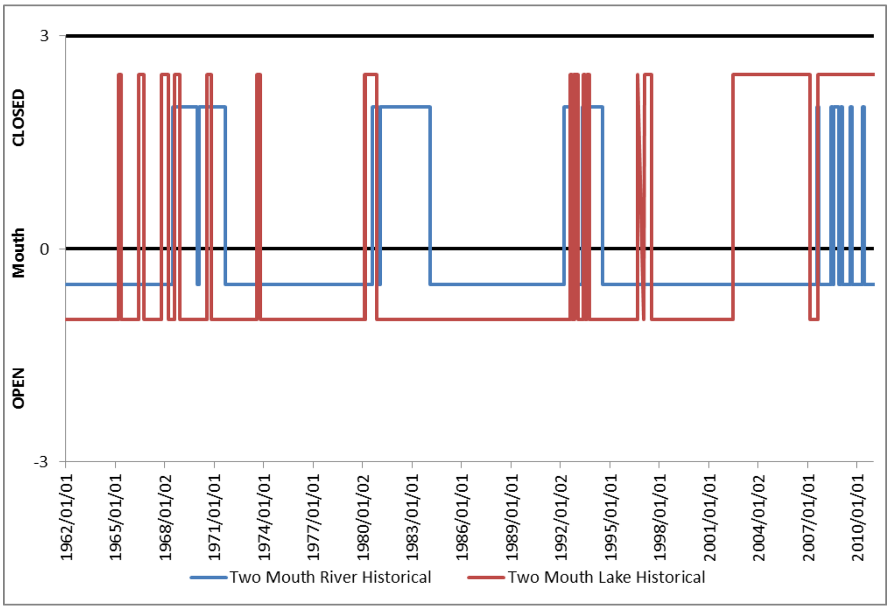


Figure 4.2.1-5b Historical observed open or closed mouth conditions (iSimangaliso, 2015)

Historically, the St Lucia estuary and uMfolozi River mouths were artificially breached when they closed and were kept separate. This resulted in the nearly 100% of time that the uMfolozi River mouth was open. The St Lucia estuary mouth was open historically for 77% of the time, maintained mechanically or by engineering structures, which is also a relatively high percentage.

Closed beach berm heights. The 2013 LiDAR survey indicated that the lowest point on top of the berm was 2.45 m MSL and this elevation was used in the modelling to simulate closed berm conditions. No other historical reliable survey data could be obtained of the berm crest levels at St Lucia. The project team's experience during the 1970s at Richards Bay, however, indicates that the berm crest is likely to vary between 2.5 to 3.0 m MSL. In the case of a berm with wave overwash as at St Lucia, a valley is formed at each overwash which lowers the crest level, mainly due to landward erosion during the wave overspill action.

The berm at St Lucia is likely to be overtopped at several places (low points) during spring tide whenever there is a strong storm at sea as shown in the satellite image in Figure 4.2.1-6. The spillage valleys which are formed on the berm will give a good indication of the berm height variation. Spillage from the St Lucia estuary or uMfolozi River during floods will always spill first at these low points on the berm; the highest points on the berm are therefore not that important. The 2013 survey data of the berm was investigated and it was found that a berm crest level of 2.45 m MSL is realistic to use, based on the lowest elevation of the berm. A sensitivity analysis was however carried out on berm crest levels of 2.95 m and 3.45 m MSL, for Total Dissolved Solids (TDS) and Total Suspended Sediments (TSS) under current conditions during the iSimangaliso (2015) study.

Figure 4.2.1-6 Sand berm extending across the mouth of the St Lucia estuarine lake system: evidence of wave over-wash

Mouth spillway channel. Scenario A is the current bed (2013) survey condition with the small excavated spillway channel at the mouth as it was surveyed in 2013. Scenario B mouth state refers to partial removal of the dredge spoil dump at the mouth to improve flow along the beach berm based on the iSimangaliso (2016) dredging contract. Note that in scenario B in this study the spillway channel has a different shape than in the iSimangaliso (2015) study due to different proposed first phase dredging options in the two studies. Figures 4.2.1-7 and 4.2.1-8 show the spillway channel as in 2013 (mouth state A) and the mouth state B used in the different studies, respectively.

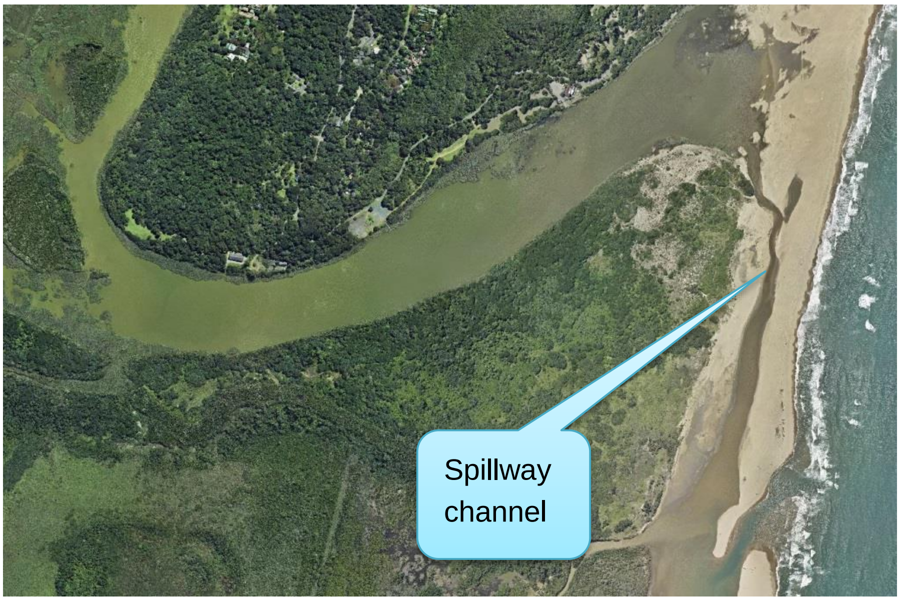


Figure 4.2.1-7 Spillway channel as mouth state A as surveyed in 2013

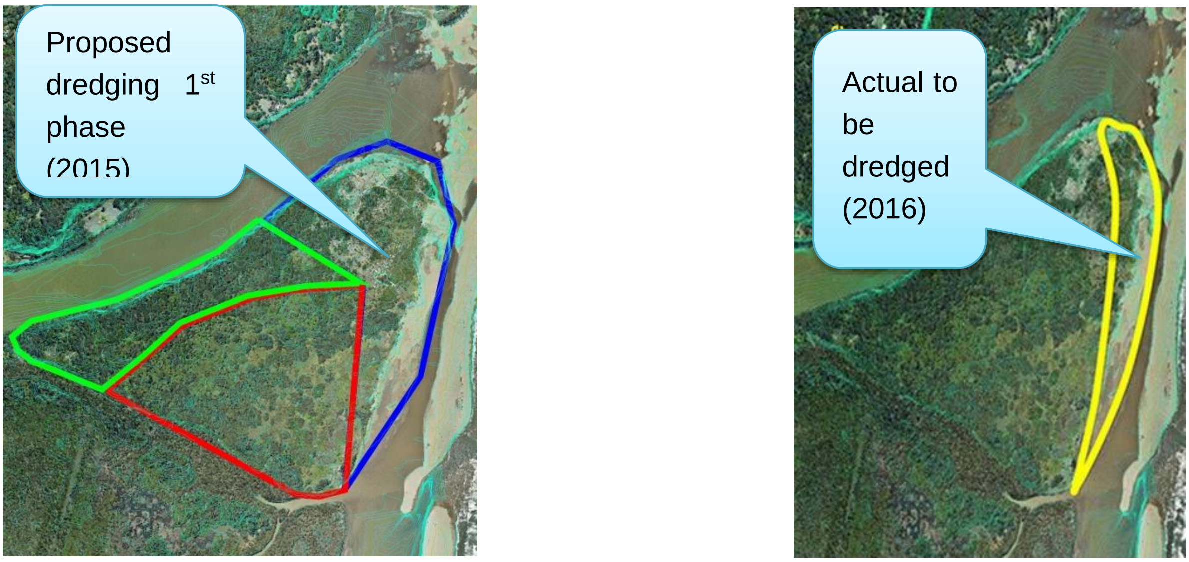


Figure 4.2.1-8 Mouth state B with first phase dredging of dredged spoil dump based on the iSimangaliso (2015) study (LHS) and this study based on iSimangaliso (2016) dredging contract (RHS)

The Reference scenario setup at the mouth of this study differs from the iSimangaliso (2015) study in that the mouth in this study was placed opposite the Lake estuary, with the uMfolozi River extended to downstream of Honeymoon Bend, based on a survey of 1905 and an aerial photo of 1937 (Figure 4.2.1-9). Note that the mean sea level in the Reference scenario was 0.14 m lower than in the Baseline and other scenarios investigated in this study.

Figure 4.2.1-9 Aerial photo of 1937 used to set up the Reference mouth condition

4.2.2 Model boundary conditions

Sea level data for the period 1962 to 2010 are shown in Figure 4.2.2-1. The tidal data is based on recorded tidal data for Durban (recorded data of the SA Navy was obtained from the University Hawaii Sea Level Centre) for the period 1992 to 2010 and adjusted by +0.0822 m for St Lucia. The adjustment of +.0822 was derived from a comparison of hindcast tides for Durban with that for Richards Bay (Richards Bay being the closest tidal station to St Lucia and assumed to be similar). The tidal data for the period prior to 1992 was based on hindcast data for Richards Bay. All the hindcast tidal data was obtained from the software WXTide32. A mean sea level 0.14 m lower than the current MSL level was used in the Reference scenario in 1920.

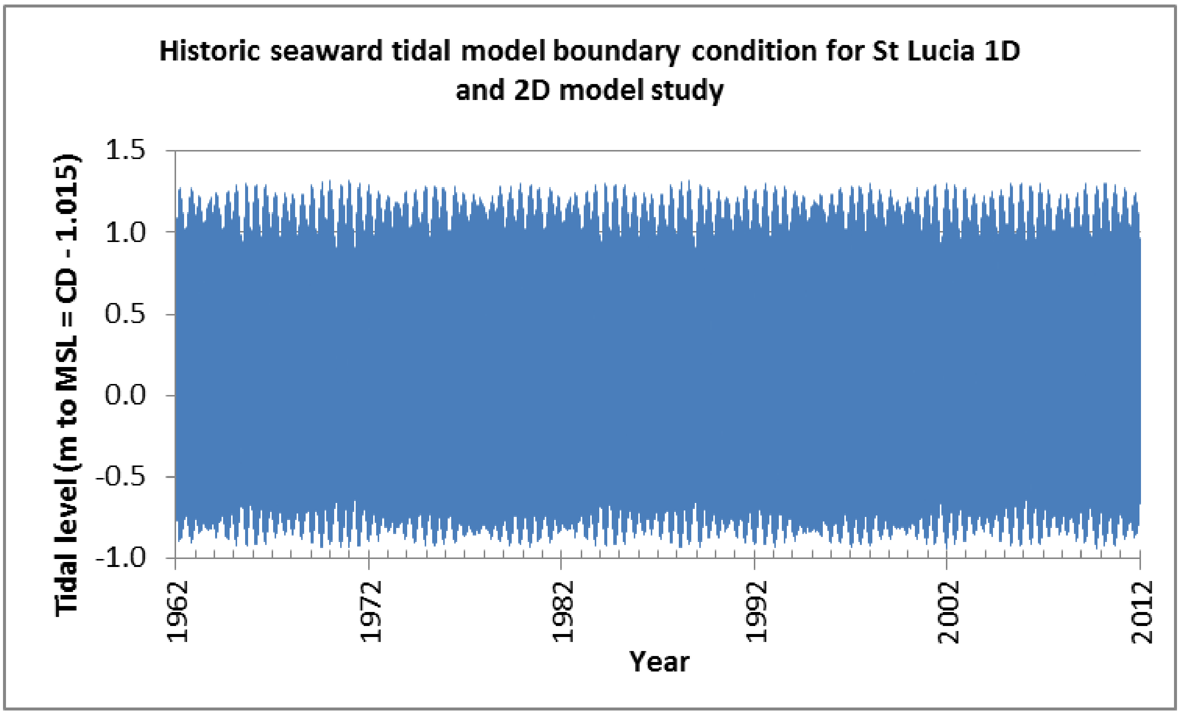
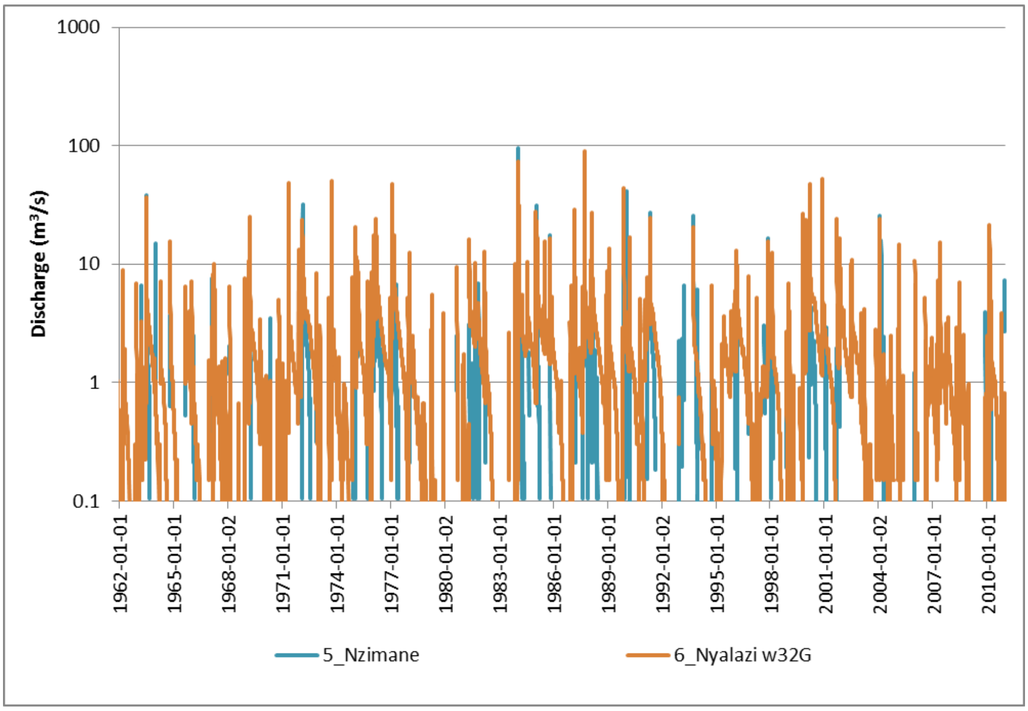


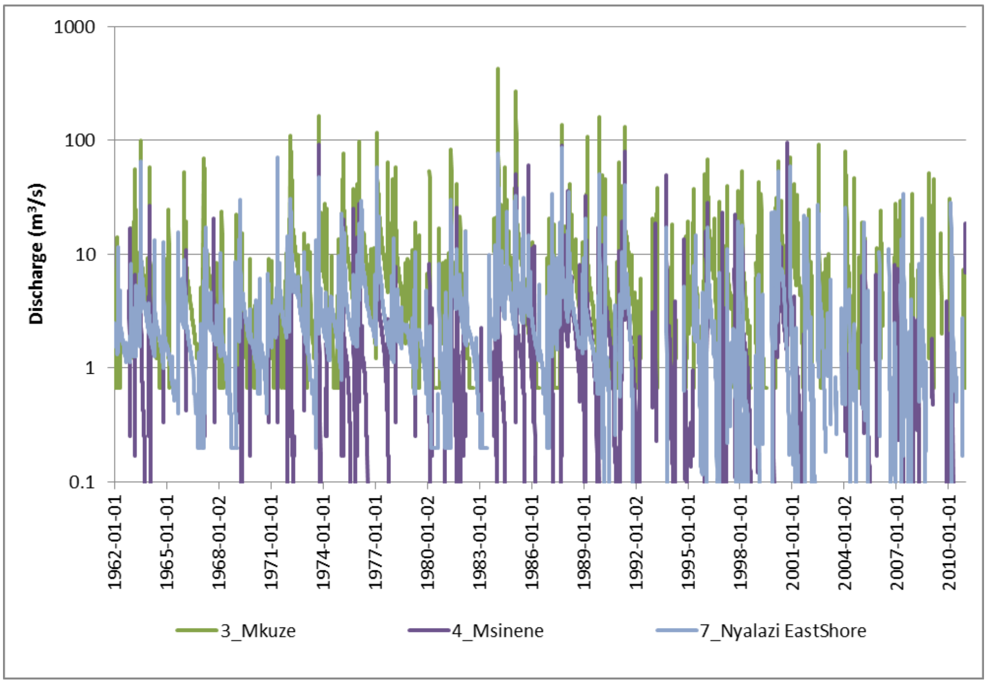
Figure 4.2.2-1 Generated historical hourly sea levels 1962 to 2010 (iSimangaliso, 2015)

The final historical model inflows used for model calibration are shown in Figures 4.2.2-2 and 4.2.2-3. The uMkhuze River has the largest flood peaks of the rivers flowing into the Lake St Lucia. Flow data for rivers discharging directly into the Lake were generated by the ACRU model in the hydrology task. The hydrodynamic model developed as part of the iSimangaliso (2015) study that was used to simulate mass balances in the Lake based on this historical data initially indicated, however, that the ACRU data overestimates these inflows. The reliability of the ACRU flow series could not be improved due to the poor quality of observed flow records and were thus scaled to previously published Pitman model mean annual runoffs which were based on monthly flow data (Hutchison, 1974). The power scaling method used in this approach scaled the floods (daily data) down considerably as can be seen in Figure 4.2.2-2. Further calibration was carried out in the hydrodynamic model against historical water level and salinity data to make sure the scaled ACRU hydrology was reliable. For TDS simulations, the scaled ACRU hydrology worked well, but was not ideal for simulating suspended sediment transport processes, as the sediment transport capacity in the model domain in the Lake was then smaller than in reality. The total Mean Annual Runoff (MAR) and total mass balance are therefore correct, but large floods which typically transport most of the sediment are scaled down considerably at the boundaries and so have smaller sediment transport capacities than in reality (iSimangaliso, 2015).

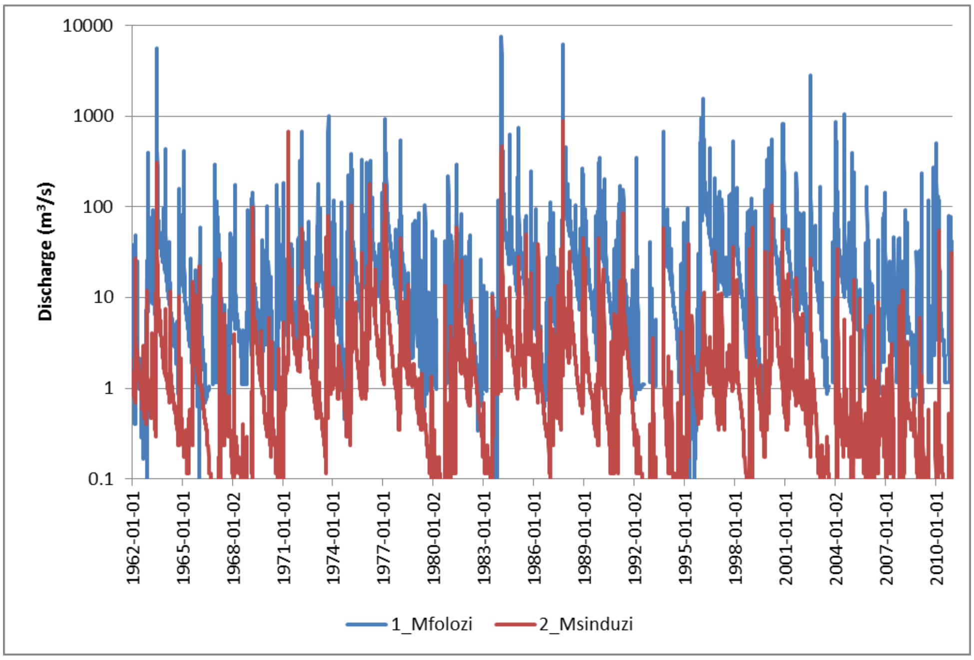
The uMfolozi and uMsunduzi River hydrology were scaled to Pitman MARs using a different scaling methodology than at the Lake in order to limit flood peak scaling (reduction) as far as possible. The instantaneous flood peaks on the uMfolozi River in 1984 and 1987 were 16 000 m^3/s and 4 480 m^3/s respectively (estimated by DWS), while Figure 4.2.2-3 indicates these flood peaks (daily average) to be about 7 600 and 6 200 m^3/s, respectively. For more details on the scaling of the ACRU model hydrology, the reader is referred to the hydrology task of this study and to the iSimangaliso (2015) hydrology task report.



Figures 4.2.2-2a Lake St Lucia daily inflows: Nzimane and Nyalazi (historical scenario) (iSimangaliso, 2015)



Figures 4.2.2-2b Lake St Lucia daily inflows: Mkuze, Msinene, Nyalazi and Eastern shores (historical scenario) (iSimangaliso, 2015)



Figures 4.2.2-3 uMfolozi and uMsunduzi River historical daily flows upstream of the bifurcation (iSimangaliso, 2015)

Rainfall and evaporation data for Lake St Lucia is shown in Figures 5.2.2-4 and 5.2.2-5. The rainfall record was obtained from the hydrological task, while the evaporation records at 3 stations around the Lake were used to generate the Lake evaporation file (Figure 4.2.2-5). The pan factors were calibrated against water level and salinity data in the Lake (Table

4.2.2.1). Note that towards the end of the record (Figure 4.2.2-5) the data had to be patched based on mean monthly observed data, and therefore the smaller variation in data is shown. The dip in mean and maximum evaporation data observed during 1980 to 1983 cannot be explained (iSimangaliso, 2015).

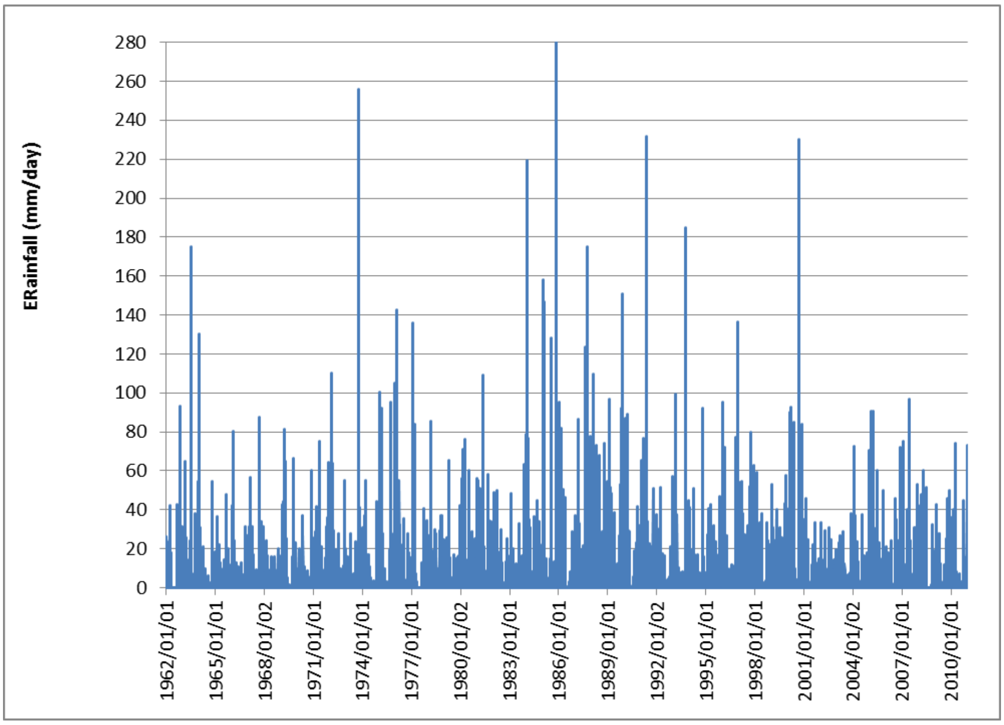


Figure 4.2.2-4 Rainfall at Lake St Lucia: Historical scenario (iSimangaliso, 2015)

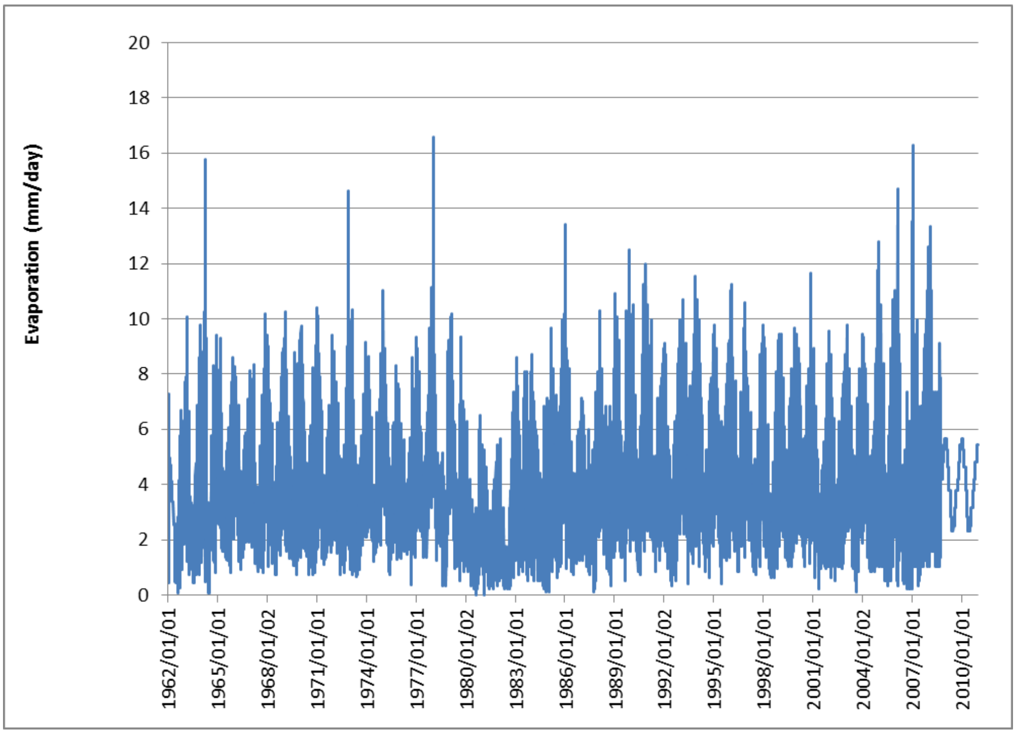


Figure 4.2.2-5 Evaporation at Lake St Lucia: Current scenario (iSimangaliso, 2015)

Table 4.2.2.1 Evaporation pan factors (iSimangaliso, 2015)

Month		Theoretical pan factors	Calibrated pan factors used
1	Jan	0.84	0.920
2	Feb	0.88	0.940
3	Mar	0.88	0.940
4	Apr	0.88	0.940
5	May	0.87	0.935
6	Jun	0.85	0.925
7	Jul	0.83	0.915
8	Aug	0.81	0.905
9	Sep	0.81	0.905
10	Oct	0.81	0.905
11	Nov	0.82	0.910
12	Dec	0.83	0.915

4.2.3 Model calibration (iSimangaliso, 2015)

4.2.3.1 Hydrodynamics calibration

Model calibration was carried out for the period 1962 to 2010. Water level and salinity (TDS) data at Lister's Point, Fanie's Island and Charters Creek were used for calibration. The daily flow data obtained from the hydrology task was used to simulate the Lake levels and salinity.

Generated sea tidal levels were used in the model, with the observed mouth conditions (open or closed, and one or two mouths). The tidal levels at the sea boundary are shown in Figure 4.2.2-1. Tidal variation in the St Lucia estuary under the open mouth condition could unfortunately not be measured in the field for model calibration purposes. Recorded data published by Hutchison (1974) for a 40 hour period during 1973 was, however, compared with the predicted tidal sea levels used in this study, and the agreement was found to be satisfactorily. Refer to **Appendix C** for datum levels as referred to in the vertical axis of Figure 4.2.3-1.

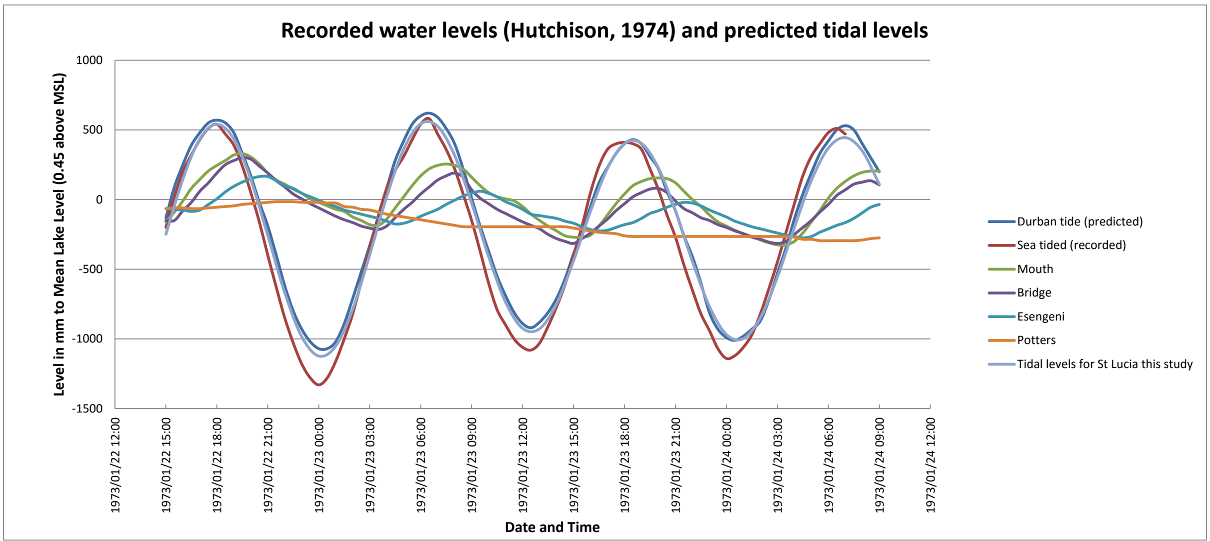


Figure 4.2.3-1 Recorded water levels compared with predicted tidal levels at St Lucia (Hutchison, 1974) (iSimangaliso, 2015)

Simulations of the Historical (calibration) Scenario based on observed mouth conditions are shown in Figures 4.2.3-2 and 4.2.3-3 below. At both Lister's Point and Charters Creek, wind setup caused typical daily fluctuations in water levels in the range of 0.1 to 0.2 m. Wind setup with hourly wind data could be simulated by the 1D hydrodynamic model used in this study, but for TDS simulation sensitivity tests showed that it does not make a huge difference to the results when the wind setup is included or not. In the end it was decided not to include wind setup in the model since hourly recorded wind speed data at the Lake was only available for a relatively short period. Wind generated waves and the influence on suspended sediment in the lake is of more importance than wind setup in this study, and was not simulated by the model but an analytical procedure was followed as discussed in Section 5.2. Note that a 2D modelling approach could be followed to simulate TDS and TSS with wind generated waves and wind setup, but that a 1D approach was adopted for the following reasons: (a) the available long term wind data can only be generated at 3 hourly intervals, (b) the 2D model would be computationally heavy which would make it impossible to simulate more than a few years of only a few scenarios. The selected 1D model is calibrated on long term historical data over many years (it is only the quality of the flow and TDS data which prevents improvement of the calibration), and it is possible to simulated numerous scenarios of nearly 50 years in length. Figures 4.2.3-2 and 4.2.3-3 show monthly average lines of the observed water levels which smooth the water level fluctuations caused by the wind setup on the Lake.

There are also gaps in the observed record, indicated by the straight line in 2004 in both figures. The simulated water levels follow the observed levels reasonably closely and an improved recalibration would only be possible with more reliable daily flow data which would be difficult to achieve because of the unreliable flow records of the DWS (Refer to the hydrology task report for more details on this).

As mentioned in the hydrology report of this project, the accuracy of the rainfall-runoff data simulated using the ACRU model could generally not be validated due to non-existent flow records or poor quality flow records on the rivers. Where flow records were available, the indication was that the ACRU flows exceeded observed flows. The approach followed during the hydrodynamic modelling was to scale these daily flow records, to achieve the best possible model calibration. The flows generated by ACRU were first scaled using a power scaling function such that high flows were scaled down proportionately more than the low flows, the aim being to obtain MARs similar to what was obtained in previous studies (refer to the hydrological report). Fine tuning by additional scaling was done on a trial and error basis by running and rerunning the hydrodynamic model (iSimangaliso, 2015).

Based on the historical flow records from ACRU, calibrated using the hydrodynamic model, the uMkhuze River contributes by far the largest amount of water to Lake, followed by the eastern shores and then the Nyalazi River.

The calibration results shown in Figures 4.2.3-2 and 4.2.3-3 below were obtained using the 1D Mike 11 model, with daily inflow data, a time step of less than 0.5 minutes, and output saved every 2 hours which was converted to daily average data as plotted in the figures. A 30 day moving average line (black) has been added in these Figures in order to smooth the observed water level fluctuations due to wind setup.

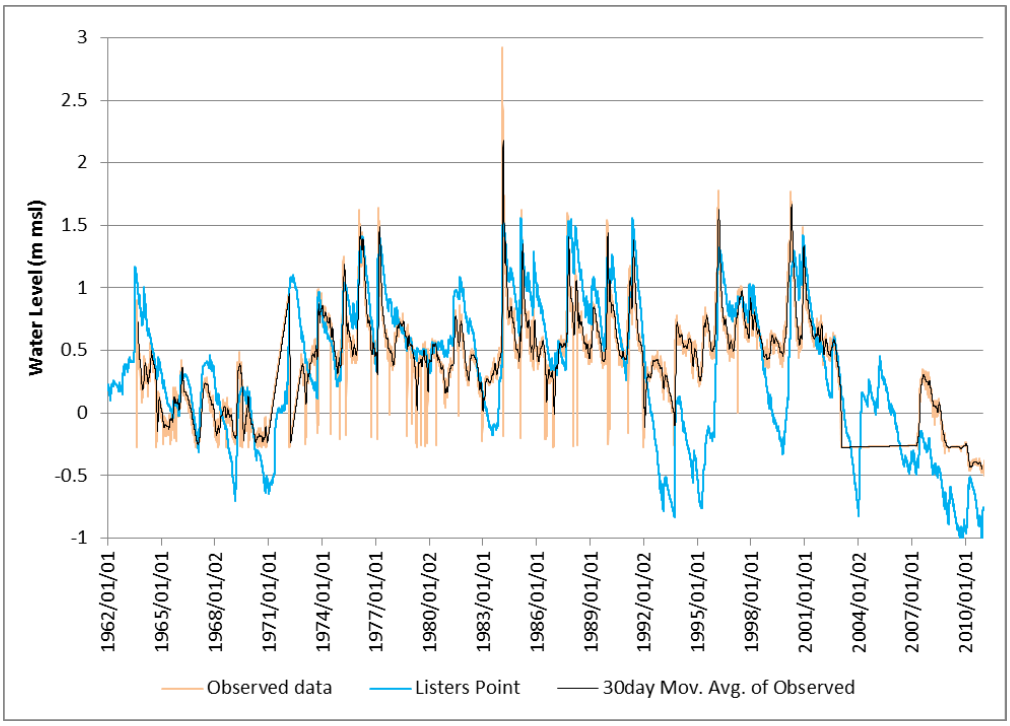


Figure 4.2.3-2 Calibrated water levels for the Historical Scenario at Lister's Point (iSimangaliso, 2015)

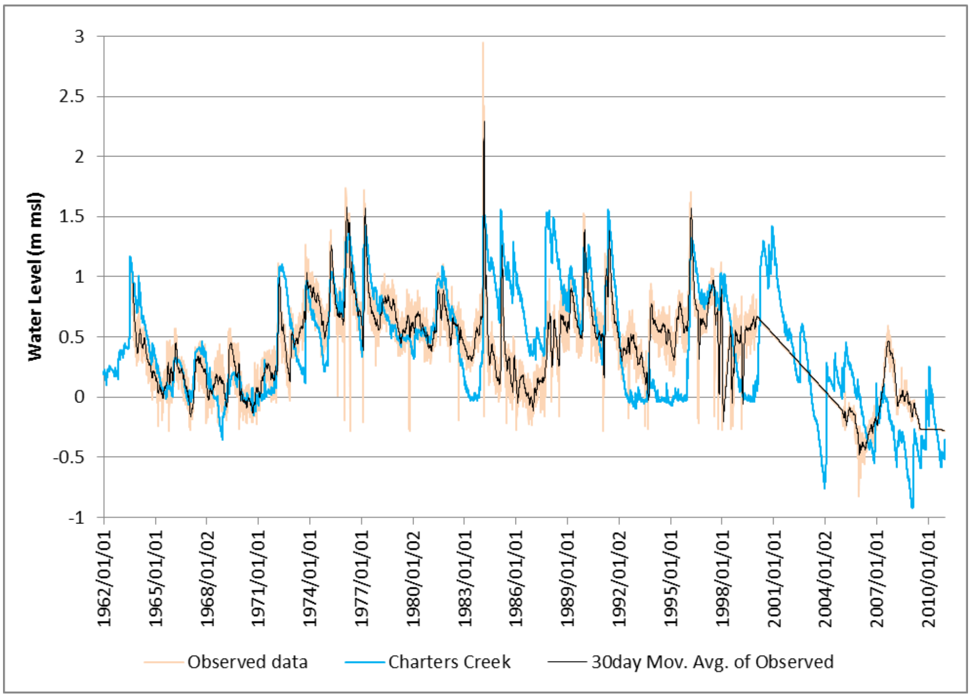


Figure 4.2.3-3 Calibrated water levels for the Historical Scenario at Charters Creek (iSimangaliso, 2015)

Table 4.2.3.1 and Figure 4.2.3-4 provide a summary of the final (calibrated) mean annual runoff (MAR) data used in this study. The change in volume of the Lake over the simulation period 1962 to 2010 shows that there has been a net outflow of 118 Million m^3/a. One of the major components of the Lake mass balance is the Lake net evaporation which was 166 million m^3/a, for the period 1962 to 2010. The sum of all the river derived inflows to the Lake was 280 million m^3/a. Therefore, 59% of the total Lake inflow from rivers was evaporated at the Lake on average per year. The net evaporation is equal to the rainfall-evaporation as shown in Figure 4.2.3-4.

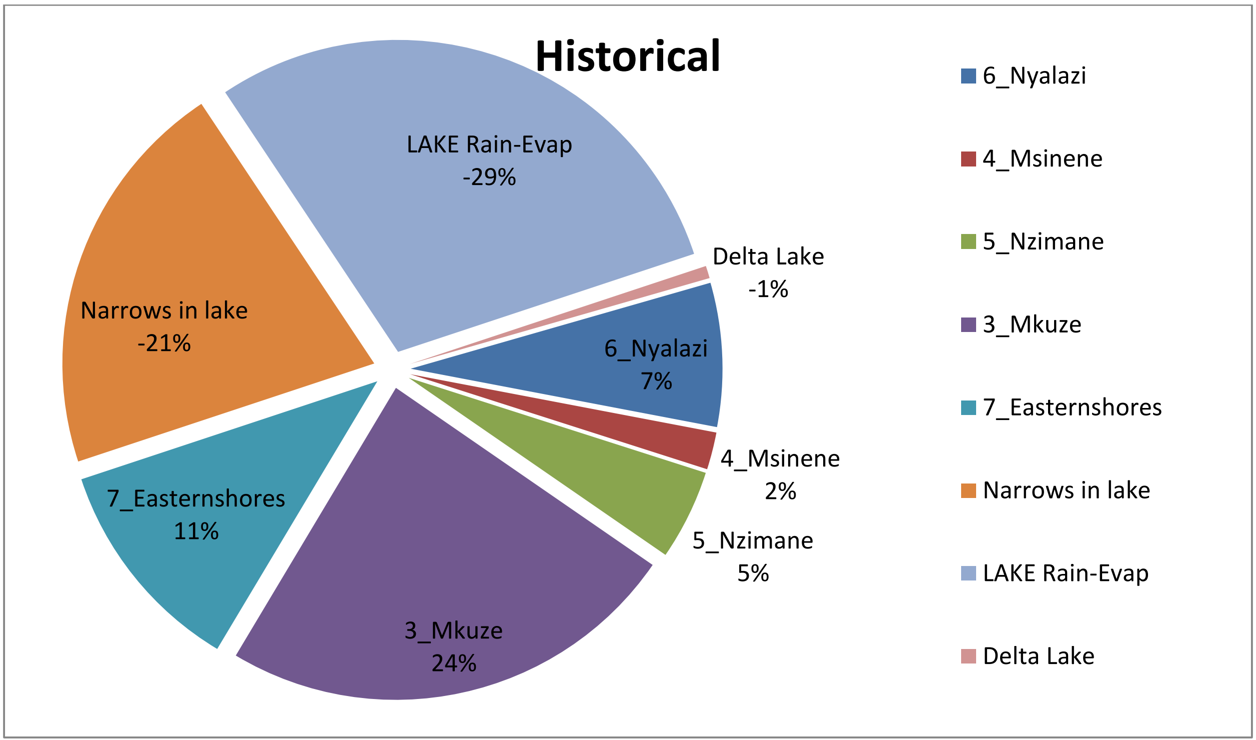


Figure 4.2.3-4 Simulated Lake St Lucia mass balance for the historical (Calibration) Scenario with observed mouth conditions for the period 1962 to 2010 (iSimangaliso, 2015)

Table 4.2.3.1 Calibrated model boundary conditions (iSimangaliso, 2015)

Scenario	uMfolozi	uMsunduzi**	Nyalazi	Mzinene	Nzimane	uMkhuze	Eastern shores	Narrows into Lake***	Lake Rain-Evap	Delta Lake*
	Million m^3/a	Million m^3/a	Million m^3/a	Million m^3/a	Million m^3/a	Million m^3/a	Million m^3/a	Million m^3/a	Million m^3/a	Million m^3/a
Historical	150.7	657.9	42.2	11.0	26.6	136.1	64.3	-117.7	-166.1	-3.7

Notes: * End Lake volume minus starting condition Lake volume divided by simulation time to obtain million m^3/a

** uMsunduzi includes diverted flood flow from the uMfolozi as well as own catchment runoff

*** Simulated by the model; negative means out of the Lake

4.2.3.2 Salinity model setup and calibration

Salinity (TDS) was simulated using an advection-dispersion module of the one dimensional hydrodynamic model. At the river-Lake inflow boundaries, TDS-discharge relationships were determined from observed historical data obtained from DWA where available. The model considered rainfall and evaporation in the salinity mass balance. No source of TDS from groundwater or the soil was considered in the modelling because of the relatively small expected loads from these sources.

The calibration covered the period from 1962 to 2010. For model numerical stability due to the gate control of the mouth conditions in the model and because of wind mixing, a dispersion factor of 30 m^2/s was used. This is a typical value which has been calibrated on open mouth conditions with this model in South Africa at other estuaries. In rivers the dispersion coefficient is typically in the order of 5 to 10 m^2/s increasing to between 30 and 100 m^2/s as two-dimensional processes (secondary currents, wind induced turbulence) become more dominant, e.g. in estuaries (DHI, 2014).

The model simulation outputs were saved 2 hourly, and then averaged to obtain daily data. The calibrated salinities for the Historical Scenario with observed mouth conditions are shown in Figures 4.2.3-5 to 4.2.3-7. The TDS simulations at Lister's Point exceeded measured levels during three events in 1971, 1995, and 2010, but also underestimated concentrations in the 1983 and 2003 low flows events. At Charters Creek the calibration generally looks much better than at Lister's Point. The same applied at Fanie's Island. It is not possible to improve these calibrations without a new hydrology data set.

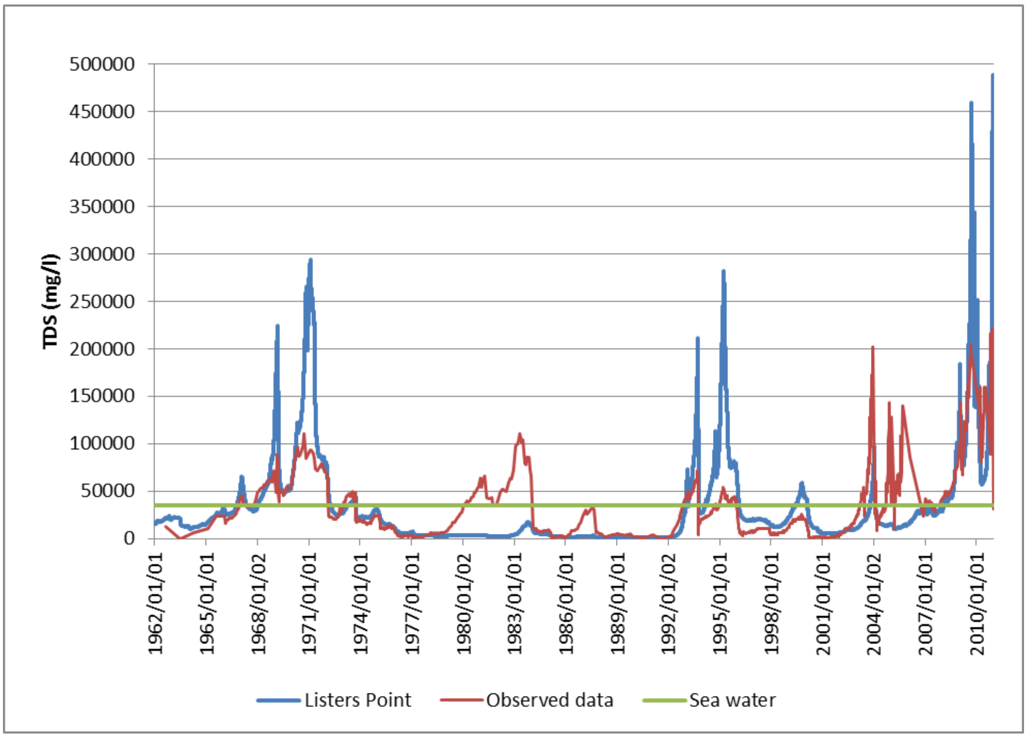


Figure 4.2.3-5 Calibrated TDS time series at Lister's Point (iSimangaliso, 2015)

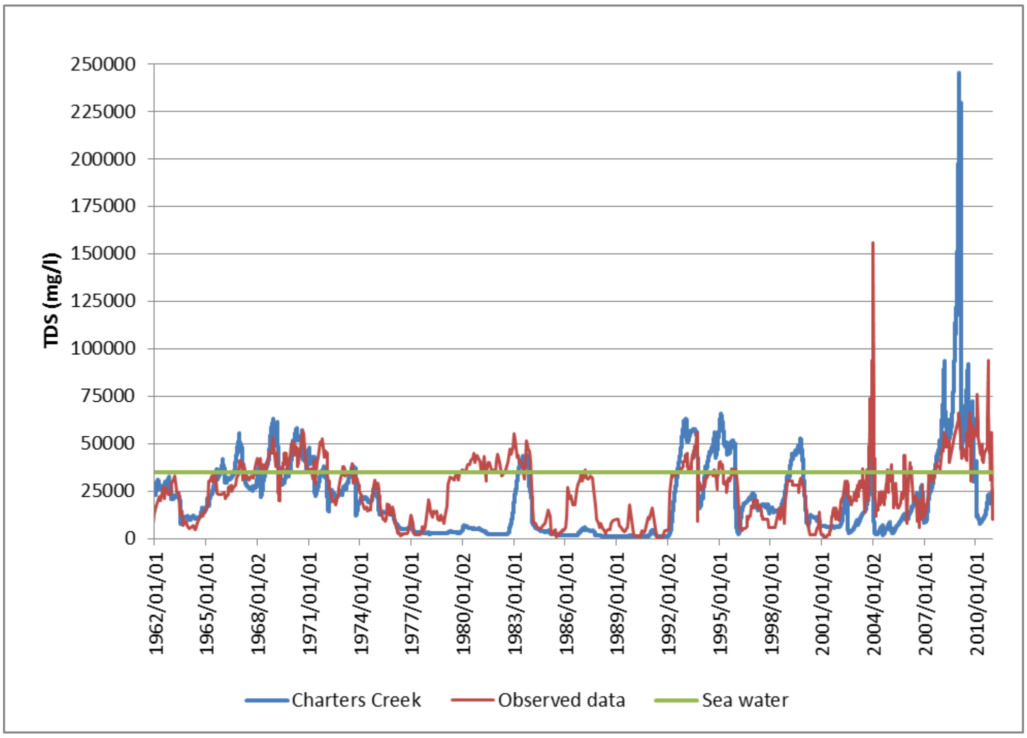


Figure 4.2.3-6 Calibrated TDS time series at Charters Creek (iSimangaliso, 2015)

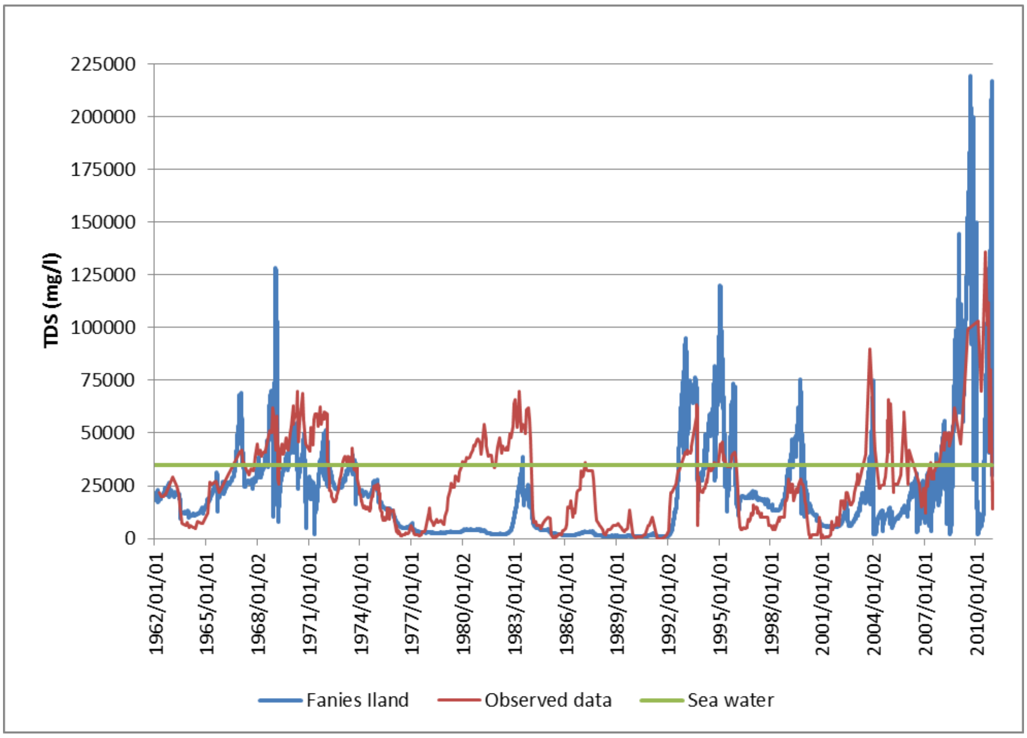


Figure 4.2.3-7 Calibrated TDS time series at Fanie's Island (iSimangaliso, 2015)

Discussions with Taylor (2014) who has been responsible for collecting most of the data from the 1970's onwards until recently, provided details on the sampling methods and accuracy of the observed TDS data. Measurements were taken using an optical refractometer from the 1970's onwards and in his opinion should be accurate to within 1-2 ppt. This depends on the range of the specific refractometer used. Earlier data would have been collected using a hydrometer or a salt bridge which measures water density which can vary in response to salt content.

Hydrometers are reportedly notoriously inaccurate and different instruments report widely different readings. Comments posted on oceanographic internet suggest that measurement accuracy varies very widely from one instrument to another and that it is not really possible to provide an absolute measure of accuracy. It is generally recommended therefore that hydrometer or salt bridge data be treated with caution.

Taylor (2014) also mentioned that he would be more confident with boat-based as opposed to shore-based measurements. Shore-based measurements could be influenced quite strongly by weather conditions – salinity on the shallow margins of the lakes can be very different from that further offshore owing to "contamination" by crusted salt on the sand/mud flats or vegetation on the margins of the Lake or by freshwater runoff during a rainstorm (freshwater would float on the surface). He reported that the method used for collecting data was mostly dependent on water level (a boat was used whenever water levels were high enough to permit this) rather than by location. From this, we have inferred that measurements taken when water levels were low should be treated with more circumspection than those taken when water levels were high. Taylor also indicated that the Charters Creek data were on the whole good and this agrees with the calibration data of this study (these were mostly taken from a jetty which gave access to deeper water at all times), but that Lister' Point data were probably less reliable (often taken from the shore especially when water levels were low), and therefore salt in the soil/sediment could elevate local water salinity where the samples are taken). Measurements taken in the Narrows (e.g. at the bridge) would also be fairly reliable as they were mostly taken from the bridge, adjacent to the jetty or boat.

4.2.4 Model simulation scenarios

The hydrological scenarios of this study are discussed in the hydrology specialist task report and are summarized below in Table 4.2.4.1. A summary of the scenario setup and assumptions as obtained from the hydrology task is enclosed in **Appendix A**.

The Reference scenario is based on Acocks (natural) plus limited agricultural development (about 350 km^2) in the St Lucia system, to represent the conditions in 1920. The Baseline scenario represents the current development scenario but with a single mouth and without artificial breaching of the mouth. Scenarios 1 to 5 are all development scenarios in the catchments of the uMfolozi and uMsunduzi Rivers. The runoff in all the other smaller catchments is the same for all the scenarios. Scenario 3 has an in-channel dam on the uMfolozi River with a 90 million m^3 storage capacity, while scenario 4 has an off-channel dam of 90 million m^3 storage capacity in the uMfolozi River system. Scenario 5 represents a large dam(s) in the uMfolozi River catchment with EWR releases from the dam. No climate change impacts were considered in the runoff, rainfall, evaporation or sea level rise in any of the baseline scenario or scenarios 1 to 5.

Table 4.2.4.1 Simulation scenarios of this study

<table>
<tr><th>Scenario name of this report</th><th>uMfolozi</th><th>uMsunduzi</th><th>Nyalazi</th><th>Nzimane (Hluhluwe)</th><th>Mzinene</th><th>Mkuze</th></tr>
<tr><td>Reference</td><td colspan="6">Acocks (Natural) hydrology with 1920 land use</td></tr>
<tr><td>Baseline</td><td colspan="2">LMF1-1* (Baseline)</td><td rowspan="6">NYAL-C (Baseline)</td><td colspan="2" rowspan="6">HH1-1 (Baseline)
MSIN-C (Baseline)</td><td rowspan="6">MK1-1 (Baseline)</td></tr>
<tr><td>Scenario 1</td><td colspan="2">LMF1-4</td></tr>
<tr><td>Scenario 2</td><td colspan="2">LMF1-7</td></tr>
<tr><td>Scenario 3</td><td colspan="2">LMF1-8</td></tr>
<tr><td>Scenario 4</td><td colspan="2">LMF1-9</td></tr>
<tr><td>Scenario 5</td><td colspan="2">LMF1-EWR</td></tr>
</table>

Note: * Refer to Hydrology Task report and **Appendix A** of this report

To control the Lake and river estuary mouth conditions, a set of rules was built into the hydrodynamic model. Historically the mouths were managed to be separated and but sometimes operated as one. For the model calibration it was important to consider single mouth and two separated mouth conditions. For this study only single mouth scenarios were considered. The model operating rules for a single mouth are as follows:

a) Mouth opens when the "river estuary" water level > 2.45 m MSL due to flood overtopping breaching (no opening of the berm by storms at sea was considered). The 2.45 m MSL level is the lowest point on the berm as surveyed during 2013. Higher berm levels were however also tested in a sensitivity study (iSimangaliso, 2015).
b) Mouth closes when the river discharge averaged over 30 days < 1.5 m^3/s <u>and</u> the water level in Lake at Charters Creek (Southern Lake) < 0.35 m MSL. This is a similar rule used by Lawrie and Stretch (2008). Table 4.2.4.2 shows observed daily flows at DWS gauge W2H032 and generated ACRU flows for historical closure periods. The low flow discharge measurement at W2H032 is probably highly inaccurate because there is no weir at the station and the alluvial river bed is dynamic. The lowest discharge at W2H032 is 1.54 m^3/s when the mouth closed. The average flow for the same closure over a 30 day period was 1.62 m^3/s. It was therefore decided to use 1.5 m^3/s river flow on the uMfolozi River as the critical discharge for mouth closure.

Lawrie and Stretch (2008) used their 0D model due to the lack of measured data to estimate the mouth model parameters. They compared predicted mouth states with recorded historical observations for the period 1918 to 1952. The threshold Lake volume at closure of the mouth was estimated at about 300 million m^3, with a corresponding lake level of -0.1 m below EMWL = 0.35 m above GMSL or 0.165 m ML (actual mean sea level). Refer to **Appendix C** for the definitions of these elevation reference systems.

Table 4.2.4.3 shows the observed mouth closures and Lake water levels at Charters Creek. The mean and median of the data is 0.39 and 0.31 m MSL respectively. This study used a critical Charters Creek Lake level of 0.35 m MSL.

Table 4.2.4.2 Observed river mouth closures and corresponding uMfolozi River flows

Mouth closure date	Observed discharge at W2H032 (m^3/s)	Simulated Mike 11 from ACRU uMfolozi River flow daily on date of closure (m^3/s)
1968/07	No data	2.2
1970/02	No data	18.2
1980/08	No data	0.1
1981/02	No data	19.6
1992/04	No data	2.0
1993/05	No data	0.1
2007/08	4.72	-
2008/06	5.57	-
2008/08	3.35	-
2009/01	14.13	-
2009/08	1.54	-
2010/05	8.81	-
2011/06	6.66	No data
2012/06	2.64	No data

Table 4.2.4.3 Observed Lake mouth closure and water levels at Charters Creek

Date of closure	Charters Creek water level observed (m MSL)
1965/03/22	0.13
1966/06/17	0.25
1967/11/01	0.23
1968/08/16	0.19
1970/08/01	-0.06
1973/08/01	0.73
1980/02/08	0.76
1980/03/07	0.76
1992/08/15	0.43
1992/10/02	0.46
1992/11/02	0.60
1992/11/17	0.28
1993/06/02	0.22
1993/08/10	0.17
1996/09/01	0.31
1997/02/01	0.67
2002/06/18	No data
2007/08/22	0.51

Note that no artificial breaching of the mouth was considered in the simulations, except for the historical scenario where observed mouth states were used. Tidal flow is not included in the mouth open/close rules.

The uMfolozi River and St Lucia estuary could close due to waves and the long shore current from south to north, whenever the river flow is low or when the Lake outflow is small due to a low Lake level. The open or closed mouth conditions were controlled and simulated in the model using a gate. When the estuary water level exceeded the berm crest level (> 2.45 m MSL) the gate would open completely for a given time period to obtain a channel invert level of -1.5 m MSL. The mouth(s) closed based on low river inflow and a low Lake level. From observed flow records on the uMfolozi River the critical river flow is 1.5 m^3/s. The critical Lake level of 0.35 m MSL gives no Lake outflow and therefore the St Lucia estuary could close.

Figure 4.2.4-1 shows the typical model generated mouth conditions for the Two-mouth Scenario A. Note that Scenario A refers to the present survey condition, and is thus based on the 2013 survey. No complete detailed historical surveys were available to compare with the 2013 survey and therefore no old surveys could be used to generate the historical or natural bathymetries. Later a scenario B will be introduced which is a mitigation scenario with a part of the dredged spoil dump removed at the Lake Mouth.

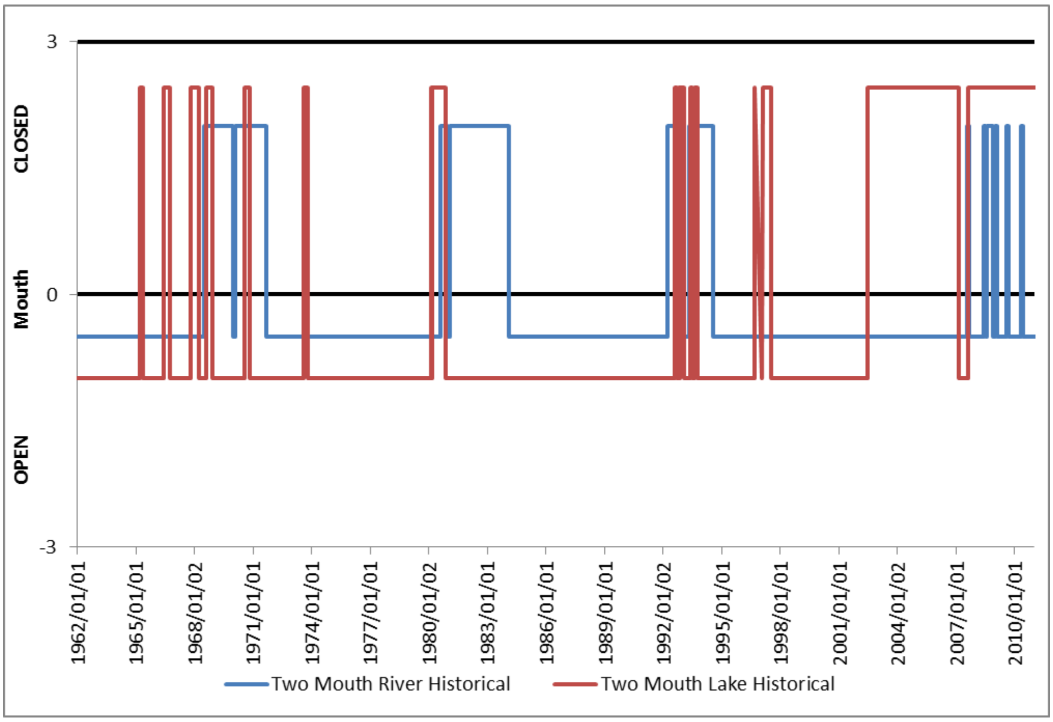


Figure 4.2.4-1 Historical observed mouth conditions (Scenario A) (iSimangaliso, 2015)

4.2.5 Simulation results: Hydrodynamics

Following the successful calibration of the hydrodynamics and salinity models, simulations were carried out for the period 1962 to 2010, for the scenarios as indicated in Table 4.2.5.1 for a single mouth condition. This table indicates the mean annual flows into (positive) or out of the Lake (negative). The change in Lake volume over the simulation period is also indicated and thus provides the complete mass balance of the Lake for each scenario.

The inflows into the Lake were obtained from the ACRU hydrological model. The uMfolozi and uMsunduzi River flows indicated in Table 4.2.5.1 are downstream of the bifurcation and diversion on the uMfolozi River. The combined uMfolozi and uMsunduzi River flows are potentially by far the largest sources of fresh water to the St Lucia system, but are not necessarily available during droughts.

Of the rivers flowing directly into the Lake the uMkhuze is the largest in terms of MAR, followed by the Nylazi River (Baseline scenario). The Eastern shores inflow has a similar MAR to that of the Nylazi River.

The MAR (net evaporation = rainfall-evaporation) at the Lake is much larger than the individual rivers flowing into the Lake. The Lake MARs for all the scenarios are very similar, except for scenario 5 due to the lower Lake levels. The Reference scenario has significantly more inflow at the Lake compared to all other scenarios, especially for the Nyalazi, Nsimane and uMkhuze Rivers. The uMkhomazi and uMsunduzi river flows of the Reference scenario also have higher MARs than the Baseline or other scenarios, and scenario 5 has by far the most reduced river flows of all the scenarios.

Table 4.2.5.2 shows the MARs of the one mouth (scenario B) simulations. Scenario B in the table refers to partial removal of the dredged spoil dump at the mouth to improve the flow conditions along the beach berm, based on the 2016 dredging contract details of iSimangaliso wetland Park. Scenario A is the current (2013) survey scenario with the excavated spillway channel at the mouth of 2012 (iSimangaliso, 2015).

The net flow in the Narrows for all the scenarios are out of the Lake. All the scenarios (baseline and future) however differ significantly from the Reference scenario.

Table 4.2.5.1 Model boundary conditions (from ACRU) and simulated mass balance for the Scenario A single mouth condition

Scenario	uMfolozi**	uMsunduzi**	Nyalazi	Mzinene	Nzimane	uMkhuze	Eastern shores***	Narrows into Lake	LAKE Rain-Evap	Delta Lake*
	Million m^3/a	Million m^3/a	Million m^3/a	Million m^3/a	Million m^3/a	Million m^3/a	Million m^3/a	Million m^3/a	Million m^3/a	Million m^3/a
Reference	695.1	142.2	50.1	32.2	29.3	180.5	36.6	-146.5	-189.6	-7.4
Baseline A	662.8	133.2	35	31.3	12	125.6	44.6	-64.55	-187.8	-3.8
Scenario 1A	653.6	133.1	35	31.3	12	125.6	44.6	-64.13	-188.5	-4.1
Scenario 2A	643.4	133.1	35	31.3	12	125.6	44.6	-65.70	-187.3	-4.5
Scenario 3A	601.5	133.1	35	31.3	12	125.6	44.6	-73.59	-180.9	-6.0
Scenario 4A	612.0	133.0	35	31.3	12	125.6	44.6	-70.03	-183.6	-5.1
Scenario 5A	247.4	71.8	35	31.3	12	125.6	44.6	-76.28	-178.5	-6.3

Notes: * End Lake volume minus starting condition Lake volume divided by simulation time to obtain million m^3/a

** Downstream of the bifurcation and diversion

The "Natural" scenario refers to Acocks land cover as in 1920 and is not a real natural state of say 1000 years ago.

***Eastern shores defined in the hydrology task report.

Table 4.2.5.2 Model boundary conditions (from ACRU) and simulated mass balance for single mouth conditions Scenario B

Scenario	uMfolozi**	uMsunduzi**	Nyalazi	Mzinene	Nzimane	uMkhuze	Eastern shores	Narrows into lake	Lake Rain-Evap	Delta Lake*
	Million m^3/a	Million m^3/a	Million m^3/a	Million m^3/a	Million m^3/a	Million m^3/a	Million m^3/a	Million m^3/a	Million m^3/a	Million m^3/a
Reference	695.1	142.2	50.1	32.2	29.3	180.5	36.6	-146.5	-189.6	-7.4
Baseline B	662.8	133.2	35	31.3	12	125.6	44.6	-66.02	-186.0	-3.5
Scenario 1B	653.6	133.1	35	31.3	12	125.6	44.6	-64.55	-187.5	-3.5
Scenario 2B	643.4	133.1	35	31.3	12	125.6	44.6	-65.93	-186.4	-3.8
Scenario 3B	601.5	133.1	35	31.3	12	125.6	44.6	-70.52	-183.1	-5.1
Scenario 4B	612.0	133.0	35	31.3	12	125.6	44.6	-69.00	-184.3	-4.8
Scenario 5B	247.4	71.8	35	31.3	12	125.6	44.6	-75.39	-179.1	-6.0

Note: * Delta Lake is the change in volume from 1962 to 2010 in million m^3/a

** uMfolozi and uMsunduzi Rivers downstream of diversion/bifurcation in the river

Table 4.2.5.3 provides a summary of simulated water levels in the Lake. Scenario B in the table refers to partial removal of the dredge spoil dump at the mouth to improve flow along the beach berm based on the iSimangaliso (2016) dredging contract. Note that in scenario B in this study the spillway channel has a different shape than in the iSimangaliso (2015) study due to different proposed first phase dredging options in the two studies. Scenario A is the current bed (2013) survey condition with the small excavated spillway channel at the mouth as it was surveyed in 2013.

The lowest mean Lake level is simulated in scenario 5B at Lister's Point. For mouth state B, the mean Lake levels closest to the Reference condition are found for the Baseline scenario. Scenario 1B minimum Lake levels are found the closest to the Reference scenario.

Refer to **Appendix E** for graphs of the simulated water levels in the Lake.

Table 4.2.5.4 shows the simulated lake levels as percentage of time below 0.1 m MSL. Under Reference conditions the Lake water levels dropped to below 0.1 m MSL about 16% of the time. The Baseline B scenario output is the closest to that of the Reference scenario. The percentage output for Lister's point and the Northern Lake for scenarios 1B and 3B are also close to that of the Reference values.

Table 4.2.5.4 Simulated % of time Lake St Lucia water level < 0.1 m MSL

Scenario	Mouth(s)	Lister's Point	Northern Lake	Charters Creek
Baseline	A	15.70	15.70	14.00
	B	16.50	16.50	14.50
Scenario 1	A	15.50	15.50	14.00
	B	16.10	16.10	14.40
Scenario 2	A	15.80	15.80	14.10
	B	20.30	20.30	18.00
Scenario 3	A	20.30	20.30	18.00
	B	16.50	16.50	14.30
Scenario 4	A	16.60	16.60	14.90
	B	14.60	14.60	12.90
Scenario 5	A	25.80	25.80	23.10
	B	22.20	22.20	19.10
Reference	-	16.3	16.3	15.6

Table 4.2.5.3 Simulated minimum and mean Lake water levels for 1962 to 2010 (m MSL) with berm crest at 2.45 m MSL

		One Mouth – A**			One Mouth – B**		
Scenario	Water level	Lister's Point	Northern Lake	Charters Creek	Lister's Point	Northern Lake	Charters Creek
Baseline	Minimum	-1.11	-0.66	-0.53	-1.11	-0.66	-0.31
	Mean	0.612	0.617	0.657	0.547	0.552	0.597
Scenario 1	Minimum	-1.02	-0.66	-0.30	-0.88	-0.66	-0.25
	Mean	0.610	0.615	0.659	0.554	0.556	0.600
Scenario 2	Minimum	-1.04	-0.66	-0.25	-0.96	-0.66	-0.32
	Mean	0.595	0.599	0.643	0.543	0.545	0.584
Scenario 3	Minimum	-1.13	-0.66	-0.54	-0.99	-0.65	-0.32
	Mean	0.519	0.526	0.572	0.498	0.501	0.542
Scenario 4	Minimum	-1.04	-0.66	-0.48	-0.94	-0.66	-0.27
	Mean	0.548	0.553	0.598	0.519	0.521	0.561
Scenario 5	Minimum	-1.15	-0.66	-0.41	-1.12	-0.66	-0.29
	Mean	0.527	0.538	0.591	0.514	0.520	0.572
Reference	Minimum	-0.63	-0.59	-0.24			
	Mean	0545	0.545	0.564			

Note: *The "Reference" scenario refers to Acocks land cover as in 1920 and not a real natural state of say 1000 years ago.

** Scenario A is based on the surveyed 2013 bathymetry while Scenario B refers to partial removal of the dredge spoil dump at the mouth designed to improve tidal flow (iSimangaliso, 2016).

Tidal prism

An indication of the tidal prism of the estuary was obtained from the simulation results near the mouth. This was done with the model flow output, saved every 2 hours, to obtain the mean annual flow volumes indicated in Table 4.2.5.5. The annual flow volumes indicated in Table 4.2.5.5 could flow up into the uMfolozi River or towards the Lake. It is therefore not net flows (flood minus ebb tides), but only flows in an inland direction upstream in the river estuary or towards the Lake that were considered. The data was only analysed for open mouth conditions. The total simulated tidal flow volumes near the mouth do not necessarily reach Lake St Lucia. The tidal prism data in Table 4.2.5.5 are indicated separately for the St Lucia estuary and the uMfolozi/uMsunduzi River.

The Lake estuary tidal prism flows for the Baseline and scenarios 1B and 2B were found closest to that of the Reference condition. On the river estuary the scenarios 2B and 4B gave results similar to the Reference condition. This does not mean that scenarios 2 and 4 are better than some of the other scenarios, because the tidal prism statistics are determined by many factors: The lake inflow from rivers under Reference conditions were much more than under all other scenarios and this decreased the net tidal prism calculated as flow up the Narrows for the Reference scenario.

Simulated Mouth states

Information on the durations of open mouth states are given in Table 4.2.5.6. Under Reference conditions the mouth was open 84% of the time. The Baseline scenario B is the closest to the Reference condition, followed by scenario 1B and scenario 2B. Scenario B mouth conditions improves the percentage of time the mouth is open by about 3 to 6% of the time, compared the mouth state A scenarios. Scenario 5 causes a drastic decrease in the percentage of time the mouth is open compared to all other scenarios.

Table 4.2.5.6 Simulated mouth states

Mouth state and scenario	Reference	Baseline	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
	% Open	% Open*	% Open	% Open	% Open	% Open	% Open
Reference mouth	84						
One Mouth – Scenario A		56.8	56.5	56.2	54.6	55.3	42.2
One Mouth – Scenarios B		61.8	61.6	61.2	57.9	59.8	48.2

Note: * "% open" means percentage of time from 1962 to 2010 the mouth was simulated as open without any intervention to open the mouth

Appendix D presents simulated graphical comparisons between Scenarios A and B under the single mouth condition. In the Reference scenario the mouth only closed 6 times from 1962 to 2010. In the other scenarios the mouth closed more frequently and for longer periods, significantly different from the Reference scenario closure pattern.

Table 4.2.5.5 Simulated mean annual tidal flow per annum contributing to the tidal prism**

Mouth condition and scenario	Reference		Base line		Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5	
	to Lake	to Rivers	to Lake	to Rivers	to Lake	to Rives	to Lake	to Rivers	to Lake	to Rivers	to Lake	to Rivers	to Lake	to Rivers
	million m^3/a	million m^3/a	million m^3/a	million m^3/a	million m^3/a	million m^3/a	million m^3/a	million m^3/a	million m^3/a	million m^3/a	million m^3/a	million m^3/a	million m^3/a	million m^3/a
Reference Mouth	88	134												
One Mouth – Scenario A			2	115	2	110	2	117	2	118	2	119	2	110
One Mouth – Scenarios B*			75	129	75	124	75	132	69	127	73	133	63	127

Note: *See discussion on next page

**Only flows considered towards the Lake or in an inland direction on the river estuary, therefore not net flows: flood minus ebb tide.

4.2.6 Simulation results: TDS

Figures 4.2.6-1 to 4.2.6-6 show simulation results at three locations in the Lake: Lister's Point, Northern Lake and Charters Creek, for Scenarios A and B. The maximum TDS scale has been limited to 100 000 mg/l in the graphs and sea water TDS is also indicated as a reference line. Note that these simulation results are also plotted in **Appendix E** in more detail with Lake water levels.

At Lister's Point (False Bay) the simulated the One-Mouth Reference Scenario simulation, TDS values generally remain below 35 000 mg/l but slightly exceed 35000 mg/l on 3 occasions for relatively short periods, while in the Baseline A scenario, TDS levels exceed the concentration of sea water on two occasions with high concentrations and relatively long durations. For the Baseline B scenario, TDS levels exceeded sea water concentration twice with high concentrations and long durations (several years at a time). Scenario B for all non-Reference scenarios cause a significant spike in TDS values in 1999 which is not present in scenario A mouth conditions. Scenarios 5A and 5B give significantly higher TDS peaks than the other scenarios.

At the Northern Lake, the Reference Scenario simulation TDS levels are below 35000 mg/l and with the Baseline A scenario are generally below 35 000 mg/l. The Baseline Scenario B yields higher TDS concentrations than the Scenario A. Scenarios 1 to 5 at the Northern Lake show very similar trends to the Lister's Point simulation data.

At Charters Creek, it is clear that the TDS is more affected by the open mouth conditions than elsewhere in the Lake. The Reference scenario therefore sometimes gives higher TDS values than the other scenarios. The Reference scenario also exceeds sea water TDS values several time but for relatively short periods.

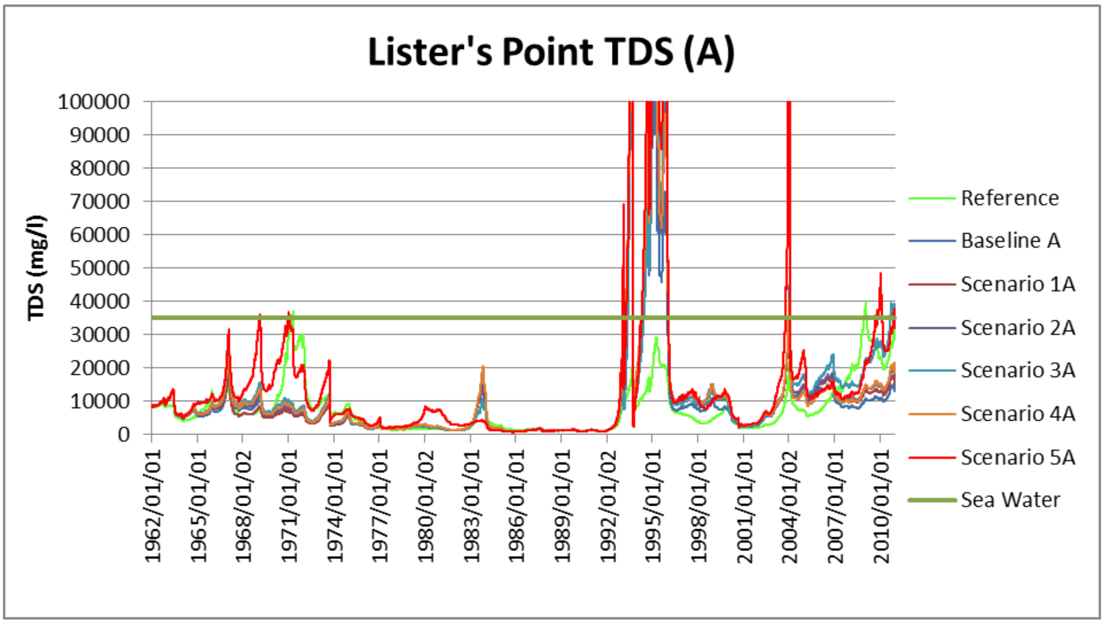


Figure 4.2.6-1 Simulated TDS at Lister's Point - One-Mouth Scenario A

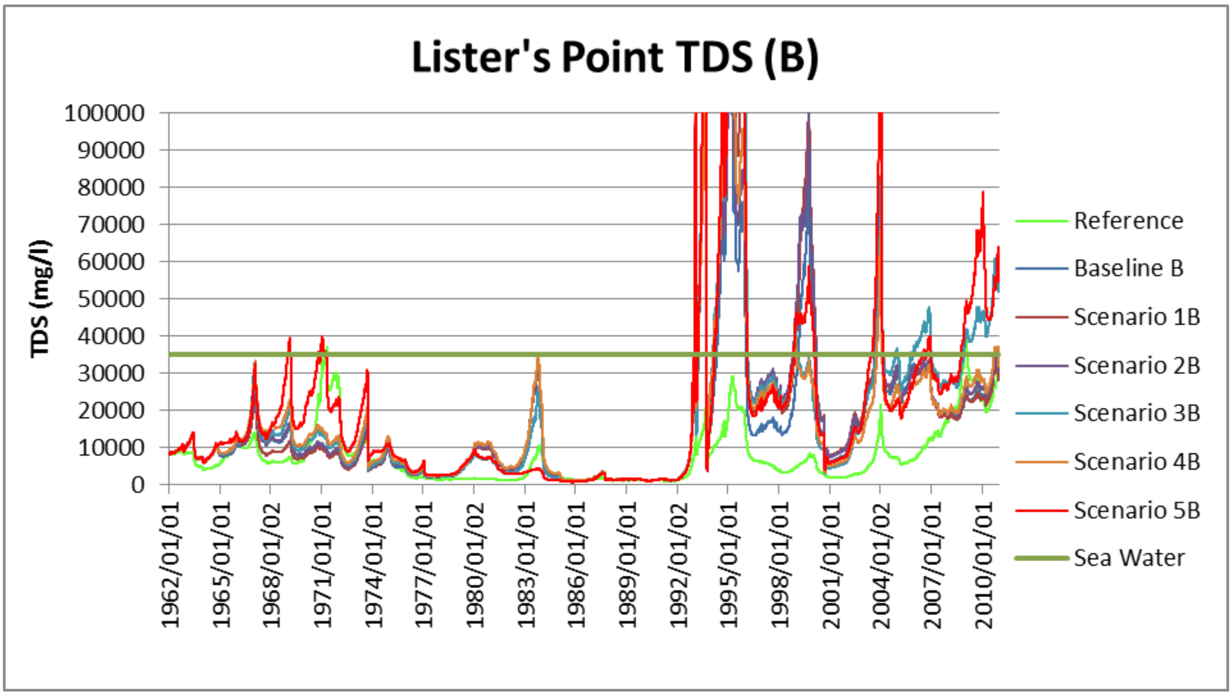


Figure 4.2.6-2 **Simulated TDS at Lister's Point - One-Mouth Scenario B**

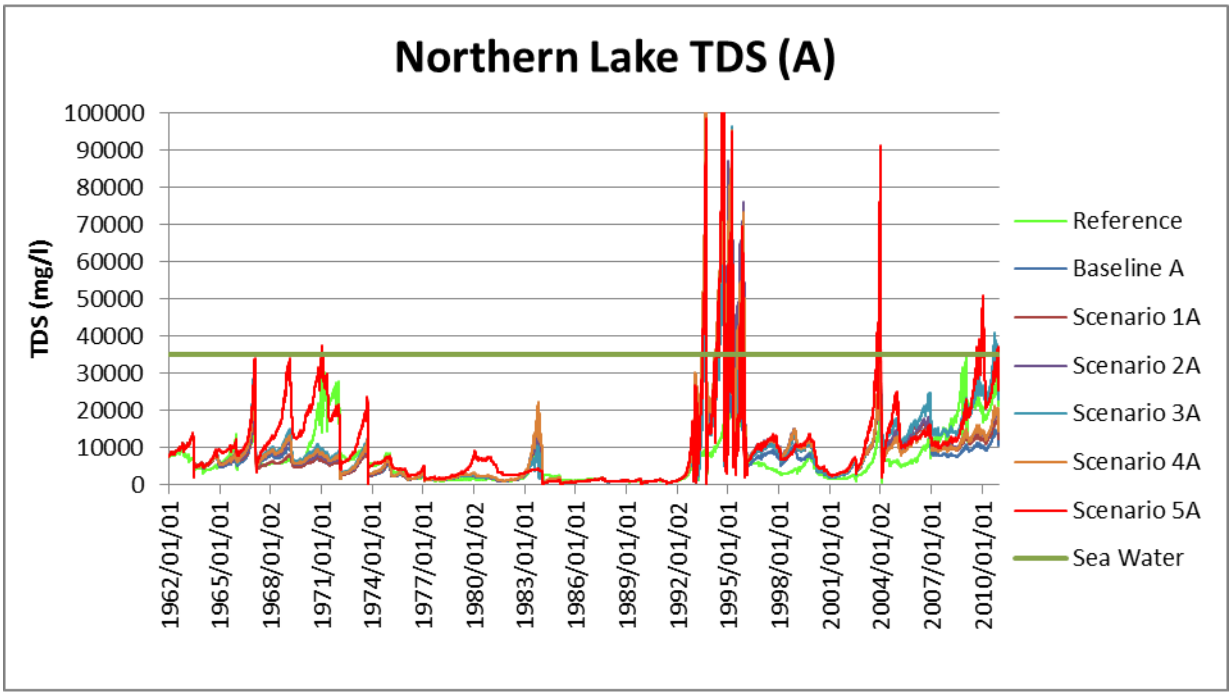


Figure 4.2.6-3 **Simulated TDS at Northern Lake - One-Mouth Scenario A**

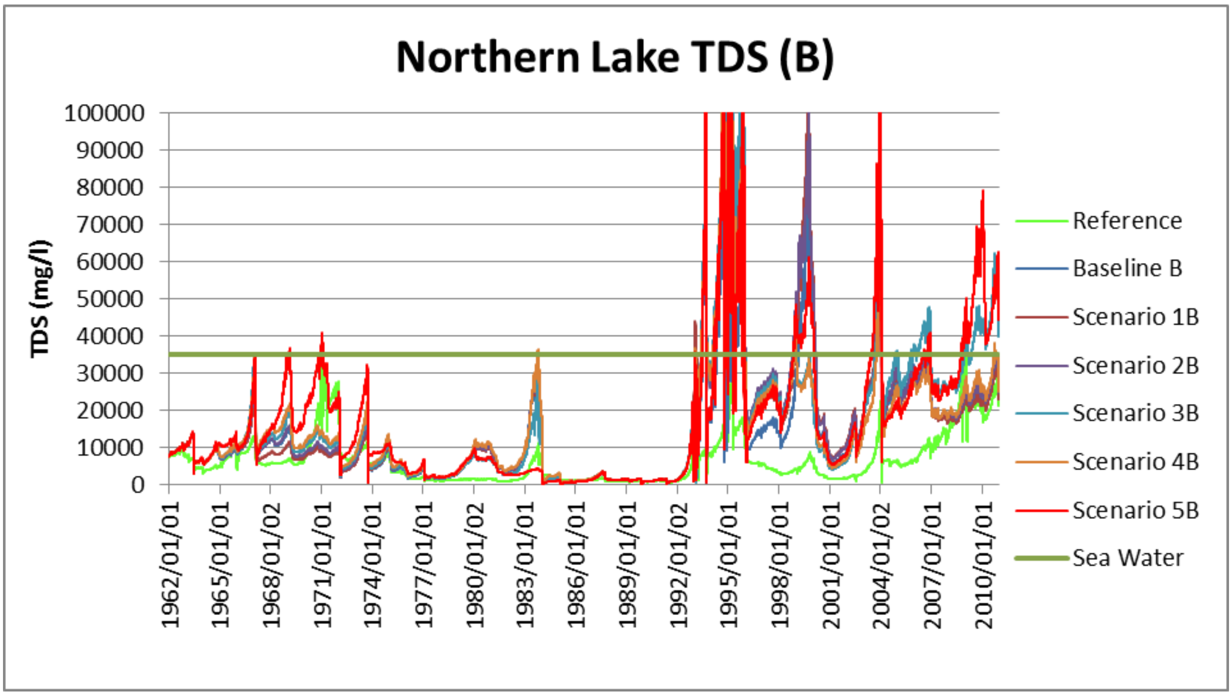


Figure 4.2.6-4 **Simulated TDS at Northern Lake - One-Mouth Scenario B**

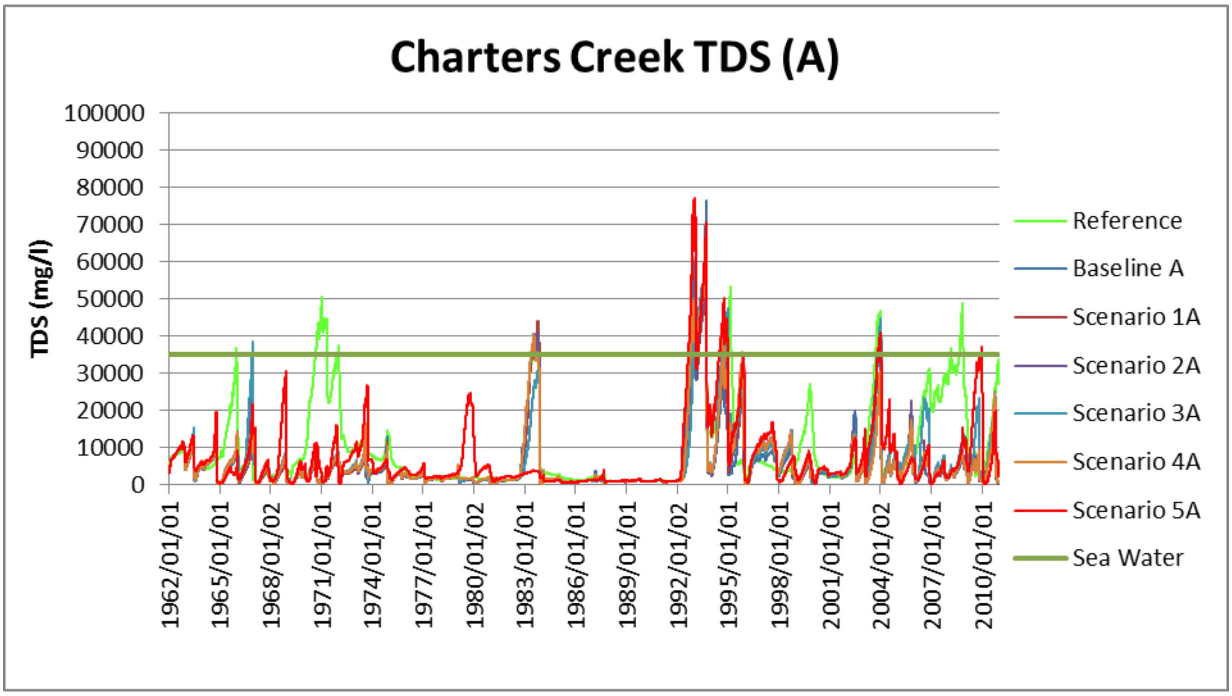


Figure 4.2.6-5 **Simulated TDS at Charters Creek - One-Mouth Scenario A**

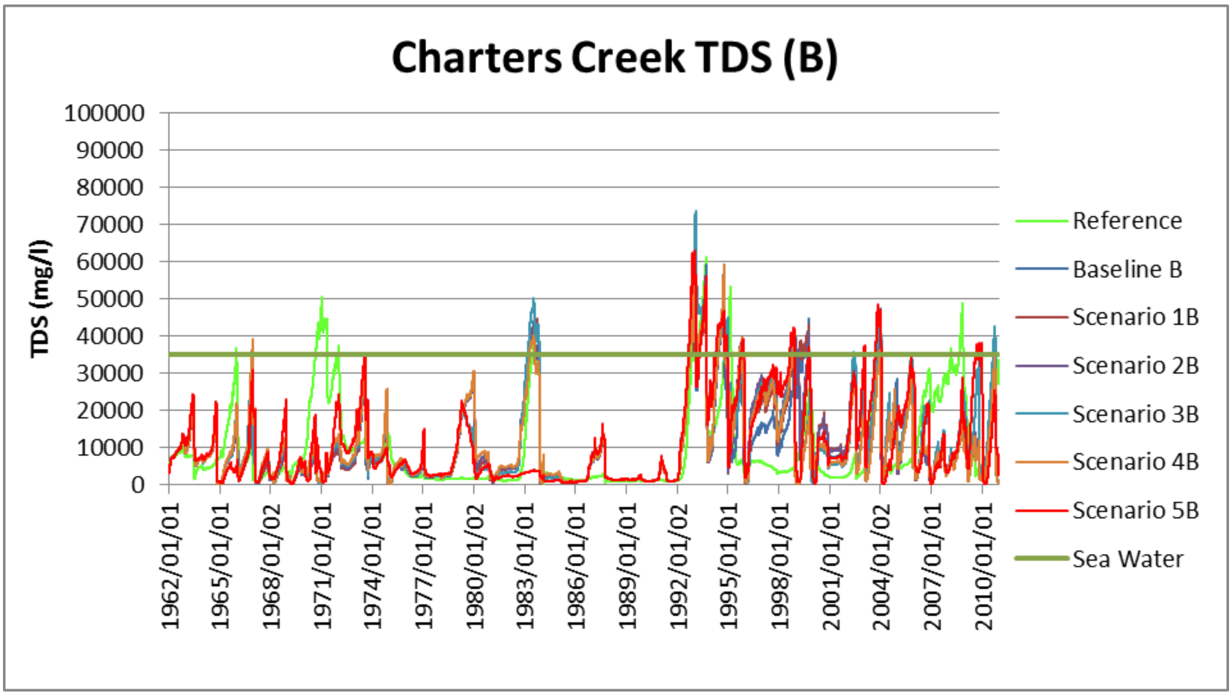


Figure 4.2.6-6 **Simulated TDS at Charters Creek - One-Mouth Scenario B**

Table 4.2.6.1 provides a summary of the Lake TDS simulations with exceedance statistics. TDS values above a concentration of 35 000 mg/l have been highlighted. The following are key observations from the table:

a) For mouth condition A, the Baseline TDS scenario at Lister's Point and at the Northern Lake, and scenario 5A at Charter's Creek, are closest to the Reference scenario TDS median concentrations.
b) For mouth state B, scenario 1 simulates median TDS Lake concentrations closest to that of the Reference scenario in the Lake.
c) When considering TDS values exceeded 10% of the time for mouth state A, scenarios 3A, 2A and 5A are closest to the Reference scenario TDS values at Lister's Point, Northern Lake and Charters Creek, respectively.
d) For TDS values exceeded 10% of the time for mouth state B, the Baseline scenario, scenario 4 and scenario 5 are closest to the Reference scenario TDS values at Lister's Point, Northern Lake and Charters Creek, respectively.
e) In mouth state A TDS peaks based on 10% of time exceedance are below 35000 mg/l, but in mouth state B, scenarios 3B and 5B the TDS values exceed 35000 mg/l.

In general the mouth state B works best at Charters Creek to get the Lake salinity relatively high similar to the Reference condition, but then the TDS at Lister's Point and the Northern Lake are too high (compared to Reference) because the freshwater inflow in the northern Lake are too low in current scenarios. Therefore mouth state A TDS values in the Northern Lake and False Bay are closer to the Reference scenario TDS concentrations, because the seawater flow to the Lake is throttled at the small spillway channel at the beach berm. Mouth state A spillway channel will however probably silt up as happened recently and the Lake salinity will then not behave as simulated. Therefore mouth state B with the proposed larger dredged spillway channel is the recommended scenario to assess in the EWR study, with the recommendation that fresh water river inflows to False Bay and the Northern Lake are supplemented to reduce the TDS at Lister's Point and at the Northern Lake (Refer to the iSimangaliso (2015) study for possible mitigation measures).

The effect of different berm heights on TDS in the St Lucia Lake was investigated by simulating closed berm crest levels of 2.95 m and 3.45 m MSL for the Baseline Scenario A (iSimangaliso, 2015). The results were compared to the 2.45 m MSL berm crest level used in all other simulations that were based on the 2013 survey data.

For the One mouth scenario the Lake TDS also decreases with increasing berm height, to about half of the concentration for the 3.45 m MSL berm compared to the 2.45 m MSL berm crest level. In general, however, it is considered likely that under Current conditions, the berm crest level would remain at 2.45 m MSL and this was used in all of the simulations with results summarized in Table 4.2.6.1 above. If higher berm crest levels are used under current conditions, the general effect, based on 10% exceedance data, is a lowering of the TDS concentrations in the Lake. The selected berm crest level used in the TDS scenarios will therefore yield conservatively high salinity concentrations (iSimangaliso, 2015).

Table 4.2.6.1 Summary of simulated scenario TDS statistics (mg/l)

Scenario	Stats description	One Mouth - A			One Mouth - B		
		Lister's Point	Northern Lake	Charters	Lister's Point	Northern Lake	Charters
Baseline	10% of time exceedance	13746	13084	10754	31491	29913	25647
	20% of time exceedance	10330	9772	6461	23384	21519	15414
	50% of time exceedance	5835	5520	2484	9499	9300	6396
	Average	9473	7060	5430	16096	13530	9965
Scenario 1	10% of time exceedance	15280	14304	10682	32011	31014	26651
	20% of time exceedance	11689	11025	7190	24257	23239	17967
	50% of time exceedance	5972	5637	2731	9062	8857	6309
	Average	10270	7889	5370	17201	15663	10298
Scenario 2	10% of time exceedance	15927	15210	12188	33253	31839	27897
	20% of time exceedance	12446	11699	7505	26331	25049	18488
	50% of time exceedance	6384	6096	2915	9962	9741	6803
	Average	10477	8475	5690	17227	15882	10598
Scenario 3	10% of time exceedance	21768	19173	14050	40726	37872	27584
	20% of time exceedance	14387	13353	8412	29471	27568	18785
	50% of time exceedance	6809	6313	2975	9867	9544	6659
	Average	11687	8579	6168	18762	16730	10952
Scenario 4	10% of time exceedance	15133	14512	11853	30132	29128	24998
	20% of time exceedance	12009	11507	7475	24886	23784	16679
	50% of time exceedance	6624	6395	2912	11014	10619	6728
	Average	11347	8579	5741	16792	15013	10152
Scenario 5	10% of time exceedance	27737	22988	17915	45571	40477	28895
	20% of time exceedance	17008	14808	10401	29232	27479	20388
	50% of time exceedance	8517	7477	3704	11298	10649	6776
	Average	15352	10598	7434	21104	17228	11157
Reference	10% of time exceedance	19938	16032	29034			
	20% of time exceedance	10950	9316	16486			
	50% of time exceedance	5853	5234	4691			
	Average	7597	6494	9619			

Note: Coloured values: above 35 000 mg/l

5 SEDIMENT TRANSPORT DYNAMICS OF THE ST LUCIA SYSTEM

5.1 Background

This section provides information on model boundary conditions (sediment inflows), sediment characteristics, and re-entrainment of deposited fine sediment due to changes in lake levels and river inflows, as well as the effect of wind.

The key sediment related aspect of the study in this section includes simulation of suspended sediment concentrations in Lake St Lucia system. This is a function of flow and wind waves, with the latter very important in this relatively shallow lake system. The output was needed as daily data for the 1962 to 2010 period for the ecological model.

5.2 Modelling of long term suspended sediment concentrations in the Lake system

5.2.1 Background

The ecological model used in this study requires daily suspended sediment concentrations in Lake St Lucia, in the Narrows and in the lower uMfolozi for all the simulation scenarios for the period 1962 to 2010. Although a two dimensional hydrodynamic model with sediment transport module was set up for the Lake St Lucia, the Narrows and the uMfolozi, the runtime of this model is such that it was impossible to simulate all the scenarios within the timeframe of this project (iSimangaliso, 2015). For the longer term simulations it was therefore decided to simulate the suspended sediment concentrations using the one dimensional hydrodynamic model which was calibrated for the salinity modelling. The cohesive sediment module was used in the model setup, with the key parameters shown in Table 5.2.1.1.

Table 5.2.1.1 1D cohesive module key parameters for turbulent sediment transport

Description	Parameter
• Critical bed shear stress for re-entrainment of the upper layer of the cohesive bed (N/m^2)	0.2
• Sediment (dry) density of the bed (kg/m^3)	1070

5.2.2 Sediment yields and loads

Sediment yields from the catchments were determined based on a methodology for ungauged catchments revised for South Africa during 2010 (WRC, 2012). It is recommended that local data be used wherever available and reliable, while the WRC method should be used for other ungauged catchments. Based on the records of DWS (2013) and the estimated reservoir sediment trap efficiency, the observed sediment yield at the Hluhluwe

Dam on the Nsimane River is 203 t/km^2.a (Table 5.2.2.1). Other regionally observed sediment yields are generally much higher than that of the Hluhluwe Dam. This is in agreement with the WRC (2012) calculation for the same catchment of 252 t/km^2.a, for a 50% confidence band. The sediment yields of the other sub-catchments in this study were then calculated using the WRC (2012) methodology, as shown in Table 5.2.2.2. The 50% confidence band sediment yields were used in this study.

Table 5.2.2.1 Observed regional sediment yields

Dam	DWA No.	Sediment yield (t/km^2.a)
Pongolapoort	W4R001	1038
Midmar	U2R001	931
Hazelmere	U3R001	714
Jericho	W5R001	245
Hluhluwe	W3R001	203

Table 5.2.2.2 Sediment yields and loads (based on historical land use to date)

River	Confidence Band	Sediment load (million t/a)	Effective catchment area (km^2)	Sediment yield (t/km^2.a)
uMfolozi	50% Confidence Band	2.189	10 299	213
	80% Confidence Band	3.16	10 299	307
	90% Confidence Band	4.14	10 299	402
uMsunduzi	50% Confidence Band	0.071	505	141
	80% Confidence Band	0.10	505	203
	90% Confidence Band	0.13	505	265
uMkhuze	50% Confidence Band	1.219	5 981	204
	80% Confidence Band	1.76	5 981	294
	90% Confidence Band	2.30	5 981	385
Mzinene	50% Confidence Band	0.138	728	190
	80% Confidence Band	0.20	728	274
	90% Confidence Band	0.26	728	358
Nsimane incremental downstream of dam*	50% Confidence Band	0.047	185*	252
	80% Confidence Band	0.07	185	364
	90% Confidence Band	0.09	185	475
Nyalazi	50% Confidence Band	0.280	1 923	146
	80% Confidence Band	0.40	1 923	210
	90% Confidence Band	0.53	1 923	275

Note: * incremental due to 97% trap efficiency of dam

Previous studies obtained sediment yields for the uMfolozi River as indicated below:

- Rooseboom (1975): 233 t/km^2.a
- Lindsay et al., (1996): 122 t/km^2/a
- Middleton & Bailey (2008): 161 t/km^2.a
- Grenfell & Ellery (2009): 61 t/km^2.a
- Maro (2012): 156 t/km^2.a
- This study (2016): 213 t/km^2.a

The Grenfell & Ellery (2009) study was based on turbidity measurements that were converted to suspended sediment concentration and loads undertaken from 2000 to 2006, which was during a drought period. Lindsay *et al*. (1996) estimated the sediment yield based on sampling on one day only! (In South Africa daily sediment samples should be taken for a period of at least 5 years to obtain a reliable long term sediment yield). Rooseboom (1975) used a combination of regional river suspended sediment sampling and reservoir surveys to determine the sediment yield. Maro (2012) derived suspended sediment data indirectly from turbidity measurements taken at the Mtubatuba water treatment works for the period 2000–2010. In the filtration laboratory tests used by Maro to obtain the suspended-sediment concentration versus turbidity relationship, the full samples were not used which could have resulted in an underestimation of the concentrations. Typically when only part of the sample is filtered, the sediment concentration is underestimated because of the difficulty to mix the sample while drawing off a part of the sample. In reality, a turbidity-suspended sediment concentration relationship at a site would also have much more scatter if the relationship was determined for every turbidity measurement taken due to the hydrology and sediment loads generated in different parts of the catchment which affects the turbidity meter readings. In general, it seems that the sediment yield calculated for the uMfolozi River catchment in this study is realistic and conservatively high compared to previous estimates.

The hydrological model ACRU was used in the hydrological task to simulate daily sediment transport. The ACRU generated mean annual sediment yields for the historical scenario were scaled to the values in Table 5.2.2.2. The cohesive fraction sediment transport at the model boundaries was assumed to be 80% and the non-cohesive (sand) fraction 20% of the total inflow load into the model domain, which is typical for South African rivers. In the one dimensional model, only the cohesive fraction suspended sediment transport was simulated as required by the ecological model.

The swamp on the uMkhuze River upstream of St Lucia Lake traps sediment. The two dimensional hydrodynamic model was used to simulated the sediment trapping capacity of this wetland and it was found that 46% of the sediment could be trapped during floods in the swamp (iSimangaliso, 2015). The swamp’s sediment trap efficiency was considered in generating the boundary conditions for the uMkhuze River.

The mean annual sediment loads for these different hydrological scenarios are shown in Table 5.2.2.3. An in-channel dam was considered in scenarios 3 and 5, which was assumed would trap 97% of the sediment load. For scenario 3 the dam has a catchment area of 9174 km^2, and the average sediment load at the dam site is 0.072 million t/a. With reservoir sedimentation, the average sediment load reaching the uMfolozi River bifurcation is 0.11 million t/a.

Table 5.2.2.3 Mean annual sediment loads at the model boundaries for the scenarios (million t/a)

River	Refer-ence	Baseline	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
uMfolozi*	0.441	1.341	1.341	1.341	0.110	1.341	0.628
uMsunduzi*	0.008	0.024	0.024	0.024	0.024	0.024	0.024
uMkhuze**	0.217	1.043	1.043	1.043	1.043	1.043	1.043
Mzinene	0.032	0.098	0.098	0.098	0.098	0.098	0.098
Nsimane	0.007	0.031	0.031	0.031	0.031	0.031	0.031
Nyalazi	0.024	0.160	0.160	0.160	0.160	0.160	0.160

Notes: * Upstream of the bifurcation and diversion on the uMfolozi River;
** Upstream of the uMkhuze swamp

For scenario 5 the dam has a catchment area of 5314 km^2, and the average sediment load at the dam site is 0.74 million t/a. With reservoir sedimentation, the average sediment load reaching the uMfolozi River bifurcation is 0.63 million t/a.

Scenario 4 has a proposed large off-channel dam with a river abstraction works. It was assumed that with proper design of the river abstraction works the abstracted sediment loads would be limited and for this study it was assumed that no sediment is abstracted in scenario 4.

5.2.3 Sediment re-entrainment due to wind

Lake St Lucia is shallow and wind plays an important role in re-suspending fine sediment due to orbital bed velocities caused by wind generated waves on the lake. For the purpose of deriving time series of bed orbital velocities for the long term modelling period of 1962-2010, wind data and wind fetch lengths at different lake water levels and at three locations in the lake were required. Available wind data over the period required for the long term modelling (i.e. 1962 to 2010) is limited. The only available long term wind data base at St Lucia which covers the required period was the mean daily wind direction and velocity hindcast data generated by the global atmospheric model of the USA National Centre for Environmental Prediction (NCEP). The NCEP data used was the so-called Re-analysis mean daily wind data which is available for the period 1948 to 2013 at a global grid spacing of 2.5 x 2.5 degrees. The NCEP wind data was extracted for a location central to the St Lucia Lakes i.e. at 28˚S; 32.5˚E. The time plot of wind velocities for the period 1948-2013 is presented in Figure 5.2.3-1 below and the mean annual wind rose (wind directions are for wind blowing *from* directions shown) for the period 1962 to 2010 is presented in Figure 5.2.3-2 below.

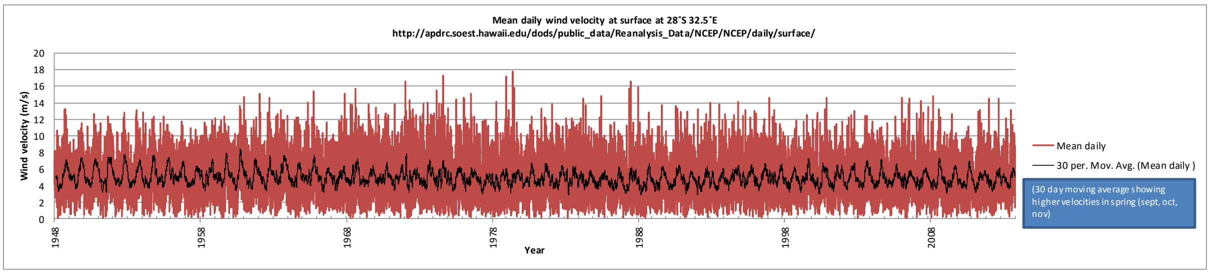


Figure 5.2.3-1 Mean daily wind data at St Lucia Lake (NCEP Re-analysis hindcast data (1948-2013)

The dominant wind direction for the Lake St Lucia is towards the SSW or from the NNW. The winds with the higher velocities are towards the northern sector or from the southern sector.

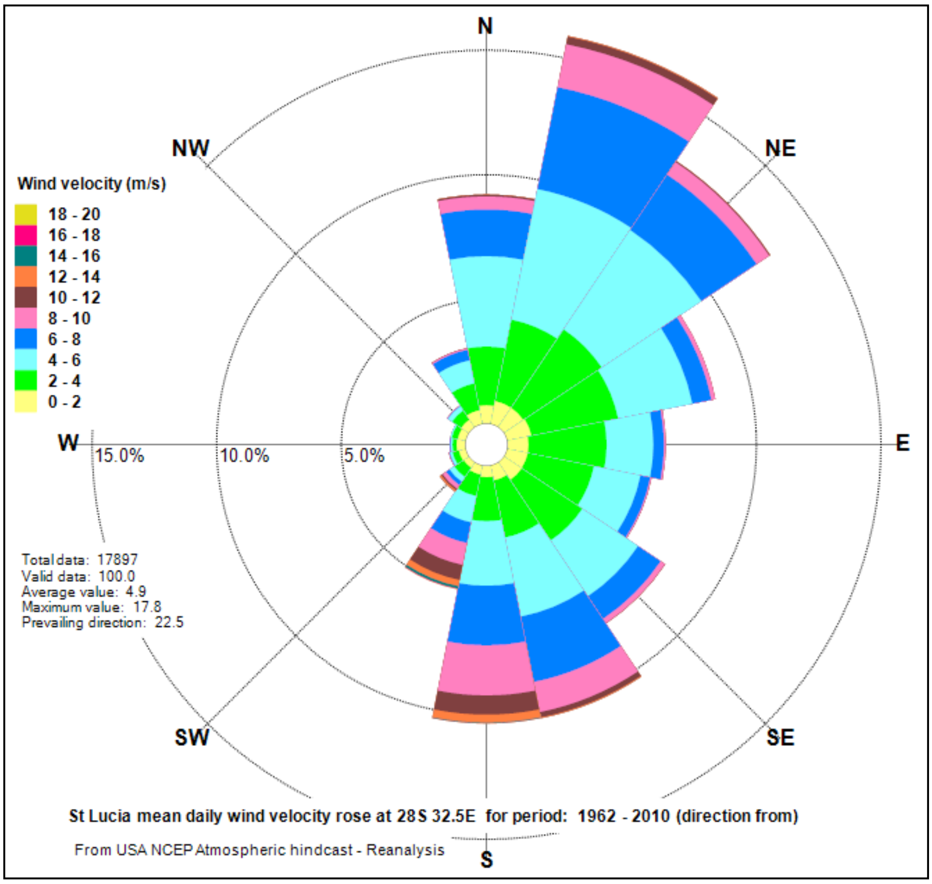


Figure 5.2.3-2 Mean annual wind rose based on mean daily data at Lake St Lucia (28˚S; 32.5E) for the period 1962 to 2010 (directions from)

Since the NCEP Re-analysis wind data is modelled hindcast data, a regional comparison of wind data on the coast between Durban and Kosi Bay was done to check the suitability of the NCEP data for this study. The relevant data from different sources as presented in Figure 5.2.3-3 below, are:

- Recorded data at:

- Durban (King Shaka Airport by SAWS for period 2011-2014)
- Richards Bay (Richards Bay Airport by the SAWS "long term data base")
- St Lucia Town (From ARC-ISCW Agro Climatology programme for period 2011-2013)
- Kosi Bay (From ARC-ISCW Agro Climatology programme for period 2011-2013)

- Hindcast data:
  - Vortex wind roses at Durban, Richards Bay, St Lucia Lake, and Kosi Bay (data based on hourly average hindcast data by the National Center for Atmospheric Research (NCAR) in USA; 1992-2011 at level 80 m above surface).
  - NCEP wind rose at St Lucia Lake (mean daily wind data for period 1962-2010).

The evaluation of the available data indicated good agreement between recorded and hindcast (modelled) data at Durban and Richards Bay. However, the available recorded data (both velocity and direction) at St Lucia compared to hindcast data is poor. The comparison between NCEP and Vortex data is considered acceptable. Based on the findings of the latter described evaluation, it was decided to use the data which is considered the best available for this study i.e. the NCEP daily mean data.

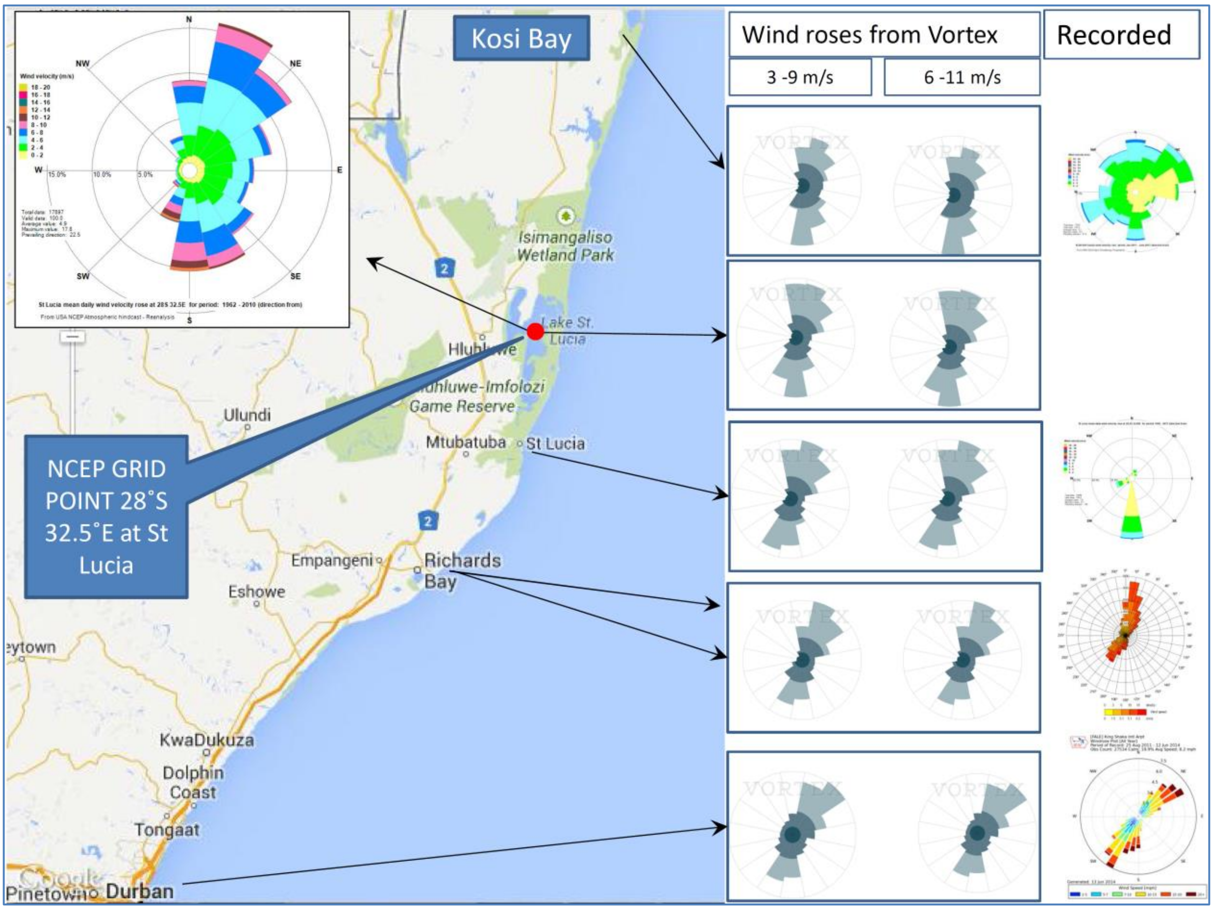


Figure 5.2.3-3: Comparison of wind roses on the Kwazulu Natal north coast between Durban and Kosi Bay

During the field work carried out in March 2013 (iSimangaliso, 2015), the wind speed was on average 4 m/s and created waves at the water level recorder north west of Lister's Point as shown in Figure 5.2.3-4.

Figure 5.2.3-4 Waves in False Bay north of Lister's Point as observed during the field work of 15 March 2013

Wind fetch lengths in the Lake were measured for all possible Lake water levels and wind directions as shown in **Appendix F**. The measurements were taken using the survey data from this study.

For each of the modelling scenarios with single mouth conditions, daily wind speed, water level and water depth data observed/simulated opposite Lister's Point, Northern Lake and opposite Charters Creek, were used to calculate a near-bed flow velocity caused by the wind. The wave heights where calculated with the method as described in Chapter 2 of Part II (p44-47 including Figure II-2-1) of the Coastal Engineering Manual (CEM, 2008) where the mean daily wind velocities were adjusted as a function of the available fetch length (Figure II-2-1 of CEM) and wave heights were limited due to wave breaking as a function of water depth and wave steepness. Also, wave periods were limited as a function of water depth. Using the derived significant wave height for each day, the resulting maximum horizontal orbital velocity on the bed was calculated by applying linear wave theory. The daily near bed velocities (based on the latter derived maximum horizontal orbital velocities) were converted to bed shear stress. From the 1D hydrodynamic model with sediment transport module, a bed shear stress–suspended sediment concentration rating was developed for each of the three locations in the Lake. The critical condition for re-entrainment of cohesive sediment from the bed was based on a bed-shear stress of 0.2 Pa. Perissinotto et al. (2013) measured turbidity in the Lake versus bed shear stress calculations and they found that at the specific location the re-entrainment of bed sediment started at bed shear stress values between 0.1 to 0.2 Pa. Daily times series of wind generated waves which re-entrain suspended sediment could therefore be calculated for all the simulation scenarios. Wind generated waves and associated local sediment concentrations and flow generated suspended sediment concentrations could therefore be investigated separately. Table 6.2.3.1 gives a summary of the simulation results. Figures generated from these simulated time series data are shown in **Appendix G**.

5.2.4 Suspended sediment simulation results

Re-suspension by wind generated waves of fine sediment in the Lake is the dominant mechanism affecting the suspended sediment concentrations. The highest concentrations generated by flow occur in the Northern Lake originating from the uMkhuze River, downstream of the swamp. The flow-generated suspended sediment concentrations are generally quite small, but some high concentrations are present for short periods when lake levels are low.

The Reference scenario total suspended sediment concentrations are, on average, very similar to the concentrations for the scenarios 1B at Lister's Point and the Northern Lake, and for the Baseline scenario B and scenario 4B at Charters Creek.

Although the simulated sediment concentration differences in the Lake are not large, the highest concentrations are generally found at Charters Creek, followed by the Northern Lake. The highest mean total suspended sediment concentrations are simulated for scenario 5A and 2B.

Table 5.2.3.1 Simulated average suspended sediment concentrations opposite Lister's Point (centre of False Bay), the Northern Lake and opposite Charters Creek at the centre of the Southern Lake, for the period 1962 to 2010, for One- and Two-Mouth Scenarios (Scenario A)

Scenario	Location in Lake	Flow generated mean suspended sediment concentration (mg/l)		Wind wave generated mean suspended sediment concentration (mg/l)		Total mean suspended sediment concentration (mg/l)	
		Single mouth A	Single mouth B	Single mouth A	Single mouth B	Single mouth A	Single mouth B
Baseline	Lister's Point	1	1	666	673	667	674
	Northern Lake	21	20	727	710	748	730
	Charters Creek	1	0.7	956	988	957	988
Scenario 1	Lister's Point	1	1	645	588	646	589
	Northern Lake	22	20	720	671	742	691
	Charters Creek	1	0.7	952	986	953	987
Scenario 2	Lister's Point	1	1	644	776	645	777
	Northern Lake	22	20	707	821	729	840
	Charters Creek	1	0.7	964	1222	965	1222
Scenario 3	Lister's Point	1	1	784	630	785	631
	Northern Lake	25	22	827	711	852	732
	Charters Creek	0.3	0.2	1048	1030	1049	1030
Scenario 4	Lister's Point	1	1	712	594	713	595
	Northern Lake	22	20	760	685	781	705
	Charters Creek	1.1	0.7	1003	992	1003	993
Scenario 5	Lister's Point	2	1	891	757	893	759
	Northern Lake	27	20	884	803	911	823
	Charters Creek	1	0.5	1098	1067	1099	1067
Reference	Lister's Point	0		510		510	
	Northern Lake	16		611		627	
	Charters Creek	1		997		998	

Figures showing the daily time series of suspended sediment concentrations are shown in **Appendix G**. Drawing comparison with observed historical data is problematic because of the range of turbidity-suspended sediment concentration relationships that are available. These relationships were developed for specific sites only but are also depended on the suspended sediment characteristics which could vary from low flows to floods and between floods at a specific site. Turbidity data obtained from Cyrus (2014) for this study for the period 2005 to 2012 was converted to suspended sediment concentrations in this study using the various relationships published for the St Lucia system. Table 5.2.4.1 shows that there is quite a large variation in "observed" sediment concentrations for the same data. Figure 5.2.4-1 shows the locations of observed sampling positions in the Lake (Cyrus *et al.* 2011).

Table 5.2.4.1 Comparison of simulated and observed suspended sediment concentrations at St Lucia Lake (iSimangaliso, 2015)

Location	Average/ Maximum Concentration	Observed suspended sediment concentration data (Cyrus, 2014) (mg/l) converted from turbidity meter data by using one of three relationships (data record 2005 to 2012)			iSimangaliso (2015) study simulated concentrations for the Current scenario & One-Mouth (1962 to 2010)****
		Cyrus & Blaber (1988)	Carrasco (2007)	Maro ***(2012)	(mg/l)
Northern Lake	Average	81	130	38	1 007
	Maximum	268	505	149	3 550*
Fanie's Island	Average	84	137	40	**
	Maximum	278	526	155	**
Charters Creek	Average	137	242	71	1 111
	Maximum	1 610	3200	945	3 736*
Catalina Bay	Average	151	271	80	1 111
	Maximum	969	1 913	565	3 736*

Notes: * 5% exceedance of the time

**simulated but not part of the output for the ecological model.

*** Maro (2012) developed his relationship for the river and not the lake, but was added here to show prediction differences in the same system.

**** locations in this study are at centre of North Lake and South Lake, not near banks as in observed data.

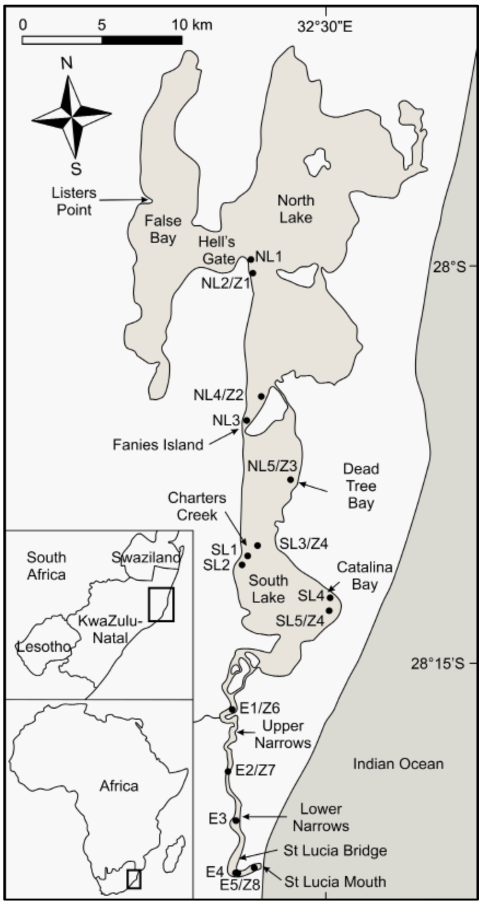


Figure 5.2.4-1 Sediment sampling locations in St Lucia Lake (Cyrus *et al*., 2011)

Cyrus and Blaber (1988) published results on sampling from 1980 to 1983, with average and maximum lake suspended sediment concentrations of 102 and 1 346 mg/l (converted from NTU), respectively. MacKay (2010) reported on maximum North Lake and South Lake suspended sediment concentrations of 806 and 3199 mg/l (converted from NTU), respectively.

Perissinotto et al. (2013) presented recorded turbidity versus bed shear stress (calculated from wave heights and periods) in the South Lake, with water depths of 0.5 to 1.2 m. They found critical bed shear stress conditions for re-entrainment of 0.1 to 0.2 Pa, which compare well with the 0.2 Pa value used in this study. The observed suspended sediment concentrations varied from about 470 to 2600 mg/l, compared to the average and maximum simulated concentrations of this study for the period 1962 to 2010, of 1111 and 3736 mg/l respectively.

Based on the data in Table 5.2.4.1 the simulated concentrations in the Lake seem high at the Northern Lake, but this could be ascribed to the sampling location near the bank in the observed data, while the simulated data is in the middle of the Northern Lake. The Southern Lake data is more in agreement with the simulated data, especially when the maximum observed data is considered. The locations of the simulated data in the Lake will always have longer wind fetch lengths for the prevailing winds than the observed data sampling points near the banks of the Lake available during this study.

Suspended sediment concentrations were also obtained from the 1D hydrodynamic modelling at Honeymoon Bend and in the Narrows. Table 5.2.4.2 provides the average simulated sediment concentrations for the period 1962 to 2010. There are a number of aspects related to the data shown in Table 5.2.4.2 that require clarification. The uMfolozi and uMsunduzi River concentration (combined) data is given upstream of the tidal zone. This data is based on the WRC (2012) report which was used to derive the sediment yields of the uMfolozi River and iMsunduzi River. This sediment yield also agrees with the observed sediment yield at the Hluhluwe Dam. The daily data used in the model for the Baseline and scenarios 1 to 5 is not based on the ACRU model daily sediment loads because these loads are erosion potential loads and do not take into account sediment storage in the catchment. The ACRU model therefore overestimates the sediment yield compared to the WRC (2012) regional method based on observed data. In this study, daily ACRU simulated sediment loads were never used in any of the scenarios. Daily sediment loads were calculated for this study by calibrating the selected sediment load-discharge rating to obtain the current scenario WRC (2012) based sediment yields. The ACRU generated sediment loads were only used to calculate relative differences between the various scenarios which were then used to scale the WRC current sediment yields to other scenarios.

Table 5.2.4.2 Simulated average suspended sediment concentrations on the uMsunduzi and uMfolozi Rivers, at Honeymoon Bend and at the Narrows

Scenario	uMfolozi and uMsunduzi Rivers combined average TSS concentration (mg/l)*		Honeymoon Bend average TSS concentration (mg/l)		Upper Narrows average TSS concentration (mg/l)	
	mouth A	mouth B	mouth A	mouth B	mouth A	mouth B
Baseline	75	76	45	50	34	30
Scenario 1	75	74	44	50	34	30
Scenario 2	75	75	45	50	34	30
Scenario 3	21	21	9	11	7	7
Scenario 4	74	73	44	49	34	30
Scenario 5	62	63	28	36	20	18
Reference	20		11		6	

The data for Honeymoon Bend in Table 5.2.4.2 could be affected by tidal flow through a single mouth and sediment from the southern rivers, large flood flow through the western channel and floodplain flow entering at Honeymoon Bend, and/or flow out of the Lake.

The key findings are:

a) The simulated average TSS concentrations are relatively small.
b) The average sediment concentration at the Upper Narrows is less than at Honeymoon Bend, due to sediment deposition in the Narrows.
c) Comparison with observed historical data is problematic because of various turbidity-suspended sediment concentration relationships that are available. Turbidity data obtained from Cyrus (2014) for this study for the period 2005 to 2012 was converted to suspended sediment concentrations using the various relationships published for the Lake St Lucia system. Table 5.2.4.3 shows that there is a large variation in "observed" sediment concentrations for the same data. The simulated data from the iSimangaliso (2015) study seems to give realistic concentrations in the Narrows and Honeymoon Bend, especially if one considers that the simulation data does not include the effect of wind wave sediment re-entrainment and transport, and the poor reliability of the observed data when converting turbidity data to TSS concentrations.

Table 5.2.4.3 Comparison of average simulated and observed suspended sediment concentrations at the Narrows and Honeymoon Bend (iSimangaliso, 2015)

Location	Observed suspended sediment concentration (Cyrus, 2014) (mg/l) converted from turbidity meter data using one of three relationships (data for 2005 to 2012)			iSimangaliso (2015) study simulated concentration Current scenario A with single mouth (1962 to 2010)
	Cyrus & Blaber (1988)	Carrasco (2007)	Maro (2012)*	(mg/l)
Upper Narrows	70	107	32	32
Middle Narrows	66	99	29	33
Lower Narrows	135	239	71	37
Honeymoon Bend	62	91	27	42

Note: *Maro (2012) developed his relationship for the uMfolozi River, but was added here to show prediction differences in the same system.

Table 5.2.4.4 shows the simulated total TSS concentrations averaged for the period 1962 to 2010 in the Lake and Narrows, for mouth states A and B. In the Narrows, scenarios 3A and 3B have average TSS concentrations similar to the Reference scenario probably due to the proposed large dam in the uMfolozi River catchment which traps sediment. The other scenarios, however, all have relatively small TSS average concentrations in the Narrows of 50 mg/l or less.

Table 5.2.4.4 Simulated average suspended sediment concentrations opposite Lister's Point (centre of False Bay), the Northern Lake and opposite Charters Creek at the centre of the Southern Lake, and narrows, for the period 1962 to 2010, for One Mouth Scenarios A and B

Scenario	Location	Total mean suspended sediment concentration Scenario A single mouth (mg/l)	Total mean suspended sediment concentration Scenario B single mouth (mg/l)
Baseline	Lister's Point	667	674
	Northern Lake	748	730
	Charters Creek	957	988
	Upper narrows	34	30
	Lower Narrows	45	50
Scenario 1	Lister's Point	646	589
	Northern Lake	742	691
	Charters Creek	953	987
	Upper Narrows	34	30
	Lower Narrows	45	50
Scenario 2	Lister's Point	645	777
	Northern Lake	729	840
	Charters Creek	965	1222
	Upper Narrows	34	30
	Lower Narrows	45	50
Scenario 3	Lister's Point	785	631
	Northern Lake	852	732
	Charters Creek	1049	1030
	Upper Narrows	7	7
	Lower Narrows	9	11
Scenario 4	Lister's Point	713	595
	Northern Lake	781	705
	Charters Creek	1004	993
	Upper Narrows	34	30
	Lower Narrows	44	49
Scenario 5	Lister's Point	893	759
	Northern Lake	911	823
	Charters Creek	1099	1067
	Upper Narrows	20	18
	Lower Narrows	28	36
Reference	Lister's Point	510	
	Northern Lake	627	
	Charters Creek	998	
	Upper Narrows	6	
	Lower Narrows	11	

Note: TSS in the Lake includes wind wave generated and flow driven TSS concentrations

6 CONCLUSIONS AND RECOMMENDATIONS

Hydrodynamic modelling was carried out in this task on hydraulics, salinity (TDS) and suspended sediment (TSS) dynamics, to evaluate different scenarios and long terms trends in the St Lucia estuarine lake system. The study investigated single (combined) mouth conditions without artificial breaching of the mouth, for the period 1962 to 2010. Open or closed mouth conditions were simulated based on empirical rules in a one dimensional (1D) hydrodynamic model which was calibrated successfully against historical water level and salinity data in the Lake, considering the reliability of the daily flow data generated in the hydrology task, the TDS data reliability of especially the earlier records and the TDS sampling during droughts from the banks in some locations (iSimangaliso, 2015). Long-term water level and TDS concentrations were simulated in this study for the Reference (Acocks land cover and agricultural use of 1920), Baseline (current) and five possible development scenarios. The daily flow hydrology for this study differs from the hydrology of the iSimangaliso (2015) study in that rainfall input data was scaled in this study (which is scientifically more correct), to calibrate the ACRU model flows against the Pitman model, while in the iSimangaliso (2015) study the simulated daily flows were scaled.

Suspended sediment transport was simulated in Lake St Lucia, the Narrows, and the uMfolozi River, considering the bed sediment grading, the sediment yields, floodplain flow during large floods, open and closed mouths, for a single mouth system which is not breached artificially when closed, and wind wave re-suspension of sediment in the Lake. The simulated suspended sediment concentrations were validated against limited available observed data and were found to be in the same order of magnitude (iSimangaliso, 2015). Long term simulations including land use and water use change impacts were simulated and compared.

This report assumed that the mouth is never breached artificially. If the mouth is allowed to breach when the water spills over the berm at a high level, this could inundate farmland or cause drainage problems, but breaching at a high water level ensures flushing of sediment and creation of a relatively large mouth (width and depth) with more tidal flow. The berm lowest crest level could typically be at about 2.5 m MSL to 3.0 m MSL and flooding to these elevations during low river flow conditions when the mouth could close have to be considered for future land use planning.

A mouth state “A”, based on the 2013 topographical survey (iSimangaliso, 2015), with a small spillway channel excavated parallel with the beach berm to link the Mfolozi River estuary with the Lake estuary, as well as a mouth state with a larger first phase spillway channel based on the dredging contract of iSimangaliso (2016) (state B), were used in the hydrodynamic model simulations. Note that for mouth state B the spillway channel in this study differs from the state B of the iSimangaliso (2015) study, because the 2015 study proposed removal of the north eastern end of the dredged spoil dump while the iSimangaliso 2016 dredge contract proposes a channel parallel with the beach berm (used in this study).

The Reference scenario setup at the mouth of this study differs from the iSimangaliso (2015) study in that the single mouth in this study was placed opposite the Lake estuary, with the uMfolozi River extended to downstream of Honeymoon Bend, based on a survey of 1905 and an aerial photo of 1937.

The key findings of this study are:

- The lowest mean Lake level is simulated in scenario 5B at Lister's Point. For mouth state B, the mean Lake levels corresponding closest to the Reference condition are found with the **Baseline** scenario. **Scenario 1B** minimum Lake levels are found to agree the closest to those of the Reference scenario.
- Under Reference conditions the lake water levels dropped to below 0.1 m MSL about 16 % of the time (such a low Lake level is one of the triggers to close the mouth if the uMfolozi River flow is also low). The **Baseline B** scenario percentage of time below 0.1 m MSL is the closest to that of the Reference scenario in general. The percentage of time the water level is below 0.1 m MSL for Lister's point and the Northern Lake for **scenarios 1B and 3B** are also close to those of the Reference values.
- The net flow in the Narrows for all the scenarios are out of the Lake. All the scenarios (baseline and future) however differ significantly from the Reference scenario, with the latter having a significantly larger Lake outflow due to larger Lake river inflows.
- The Lake estuary tidal prism mean annual flows for the **Baseline B and scenarios 1B and 2B** were found closest to that of the Reference condition. On the river estuary the **scenarios 2B and 4B** gave tidal prism results similar to those of the Reference condition. This does not mean that scenarios 2B and 4B are better or should be implemented, because the tidal prism statistics are determined by many factors. For example the Lake inflow from rivers under Reference conditions were much more than under all other scenarios and this decreased the net tidal prism calculated as flow up the Narrows for the Reference scenario.
- Under Reference conditions the mouth was open for 84 % of the time. The **Baseline scenario B** (61.8 % open) is the closest to the Reference condition, followed closely by **scenario 1B** (61.6 % open) and then **scenario 2B** (61.2 % open). Scenario B mouth conditions improves the percentage of time the mouth is open by about 3 % to 6% of the time compared to mouth state A scenarios. Scenario 5 causes a drastic decrease in the percentage of time the mouth is open compared to all other scenarios.
- TDS: For mouth condition A, the **Baseline A** TDS concentrations at Lister's Point and at the Northern Lake, and of **scenario 5A** at Charter's Creek, are closest to the Reference scenario TDS median concentrations. For mouth state **B, scenario 1** simulates median TDS Lake concentrations closest to that of the Reference scenario in the Lake. When considering TDS values exceeded 10 % of the time for mouth **state A, scenarios 3A, 2A and 5A** are closest to the Reference scenario TDS values at Lister's Point, Northern Lake and Charters Creek, respectively. For TDS values exceeded 10 % of the time for mouth **state B, the Baseline scenario, scenario 4B** and scenario 5B are closest to the Reference scenario TDS values at

Lister's Point, Northern Lake and Charters Creek, respectively. In mouth state A, TDS peaks based on 10 % of time exceedance are below 35000 mg/l, but in mouth state B, for scenarios 3B and 5B the TDS values exceed 35000 mg/l.

In general the mouth state B works best at Charters Creek to get the Lake salinity relatively high similar to the Reference condition, but then the TDS at Lister's Point and the Northern Lake are too high (compared to Reference) because the freshwater inflow in the northern Lake is too low in current scenarios. Therefore mouth state A TDS values in the Northern Lake and False Bay are closer to the Reference scenario TDS concentrations, because the seawater flow to the Lake is throttled at the small spillway channel at the beach berm. Mouth state A spillway channel will however probably silt up as happened recently and the Lake salinity will then not behave as simulated. Therefore mouth state B with the proposed larger dredged spillway channel is the recommended scenario to assess in the EWR study, with the recommendation that fresh water river inflows to False Bay and the Northern Lake are supplemented to reduce the TDS at Lister's Point and at the Northern Lake (Refer to the iSimangaliso (2015) study for possible mitigation measures).

- TSS in the Lake: Re-suspension by wind generated waves of fine sediment in the Lake is the dominant mechanism affecting the suspended sediment concentrations. The highest concentrations generated by flow occur in the Northern Lake originating from the uMkhuze River, downstream of the swamp. The flow-generated suspended sediment concentrations are generally quite small, but some high concentrations are present for short periods when lake levels are low. The Reference scenario total suspended sediment concentrations are, on average, very similar to the concentrations for the **scenarios 1B** at Lister's Point and the Northern Lake, and also similar to the **Baseline scenario B and scenario 4B** at Charters Creek. Although the simulated sediment concentration differences in the Lake are not large, the highest concentrations are generally found at Charters Creek, followed by the Northern Lake. The highest mean total suspended sediment concentrations are simulated for scenarios 5A and 2B.
- TSS in the Narrows: The simulated average TSS concentrations are relatively small. The average sediment concentration at the Upper Narrows is less than at Honeymoon Bend, due to sediment deposition in the Narrows. In the Narrows, **scenarios 3A and 3B** have average TSS concentrations similar to the Reference scenario probably due to the proposed large dam in the uMfolozi River catchment which will trap most of the Upper catchment sediment. The other scenarios, however, all have relatively small TSS average concentrations in the Narrows of 50 mg/l or less.

In general it seems that the **Baseline B scenario followed by scenarios 1B and 2B** have hydrodynamic, TDS and TSS characteristics more similar to the Reference scenario than the other scenarios. This is expected since the uMfolozi and Msunduzi combined river flows for these three scenarios are 95%, 94% and 93% of the Reference MARs respectively. Scenarios 3B, 4B and 5B have combined uMfolozi and Msunduzi River MARs of 88 %, 89 %

and 38 % respectively of the Reference scenario, and therefore are much more affected by possible development.

In all current or future possible development scenarios it is important to note that:

- Lake local river inflows should not be decreased in future but should rather be increased by deforestation.
- The mouth closes when the river flow averaged over 30 days is less than 1.5 m^3/s at the uMfolozi River DWS gauging station W2H032 and the water level in Lake at Charters Creek (Southern Lake) is less than 0.35 m MSL. The EWR of the uMfolozi River should consider the minimum uMfolozi River flow requirement so that the mouth stays open most of the time as under Reference conditions. Note that the DWS flow gauging station on which the 1.5 m^3/s minimum flow is based is inaccurate and it is recommended that the EWR rather consider a minimum Mfolozi River flow of 3.0 m^3/s which triggers mouth closure. This should be monitored in the field against actual mouth closure with accurate flow measurement in future.
- As part of the EWR the mouth should never be breached artificially and should be allowed to dam water in the river and Lake estuaries to typically 2.5 m MSL or even 3.0 m MSL, depending on the closed beach berm height. This will allow more river flow north through the Narrows towards the Lake during droughts and when breaching occurs naturally it will open up a large mouth with a large tidal flow.
- Mouth state B scenarios in this study assumed a dredged equilibrium beach channel parallel with the beach berm as proposed by the iSimangaliso (2016) dredging contract. The dredging of the beach side of the dredged spoil dump should only be seen as a first phase, however, and to ensure the stability and equilibrium of the "spillway" channel between the estuaries, all of the dredged spoil dump should be removed eventually (refer to iSimangaliso, 2015, for more details).
- The EWR should mainly be based on the hydrodynamics and TDS of the Lake system, than on TSS. In the Lake and Narrows the flow transported suspended sediment concentrations are relatively small for all scenarios. The Lake is dominated by wind wave generated suspended sediment.
- It is proposed that the uMfolozi River EWR is based on the **Baseline B** scenario hydrology (and not scenarios 1 to 5) to try and improve especially the drought flow conditions in the river (which affect mouth closure and Lake levels), which are currently unnatural due to the existing upstream irrigation and potable water abstraction, especially during droughts.

7 MONITORING REQUIREMENTS TO IMPROVE THE HYDRODYNAMIC, SALINITY AND SEDIMENTATION KNOWLEDGE OF THE SYSTEM

7.1 Hydraulics and hydrology

a) Rehabilitate existing or construct new flow gauging stations (weirs) with accurate low flow and flood measurement on all rivers flowing into the Lake St Lucia as well as on the uMfolozi and uMsunduzi Rivers. Extend the rating curves for floods by using field measurements by ADCP and slope-area methods. Measure water levels upstream and downstream of the stations at 12 minute intervals. Determine the submergence impacts on the weir and recalibrate over time.

b) Survey the beach berm and channel (between the sea and estuary parallel with the berm) to obtain accurate berm crest levels and the mouth location by LiDAR and underwater survey on an annual basis at a grid spacing of 1 m, and vertical accuracy of 0.1 m or better.

c) Record wave heights in the Lake and local hydraulic conditions and hourly wind speeds, with suspended sediment sampling to obtain suspended sediment concentrations.

d) Lake evaporation is a major part of the mass balance and the pan factors for the current weather stations need calibration against actual year-round evaporation weather station measurements at say three locations inside the Lake. The current evaporation stations could be affected by vegetation and the measurement methods.

e) The existing rain gauges at the Lake should be calibrated against in-lake weather station data to make sure they are not affected by vegetation. Rain gauge data should be available at least 5 to 12 minute intervals and the raw data should be available to users, not only as mean hourly data.

f) Wind speed recorders are needed at the Lake in several locations with logging at 12 minute intervals similar to the existing DWA flow gauging stations.

g) The DWS tidal gauge at the St Lucia bridge should be maintained and is an important gauge. A location for a tidal gauge closer to the mouth at the ski boat club should also be investigated.

h) Water losses in the uMkhuze swamps should be quantified during a low flow period by flow measurement upstream and downstream of the swamp.

i) On the uMfolozi River there used to be a flow gauging station at the N2 Road bridge, but this station was washed away during the 1984 flood. The remaining station downstream of the bridge at DWS gauge W2H032 is a stable river section and this station is used to determine the required flow for mouth closure. The river at the gauge is not stable and bed levels change over time, which make it impossible to measure low flows accurately. It is therefore proposed that a new flow gauging station is established at the river bifurcation (which is stable) with flow measurement of the diverted flow as well. This would give the total uMfolozi River discharge (upstream of the diversion). A low weir for low flow conditions (say 0 to 20 m^3/s) may be considered in the bifurcation. Figure A-1 shows an aerial photo of the bifurcation and the diversion. The diversion weirs and bifurcation has a discharge rating based on a physical model study carried out by Stellenbosch University.

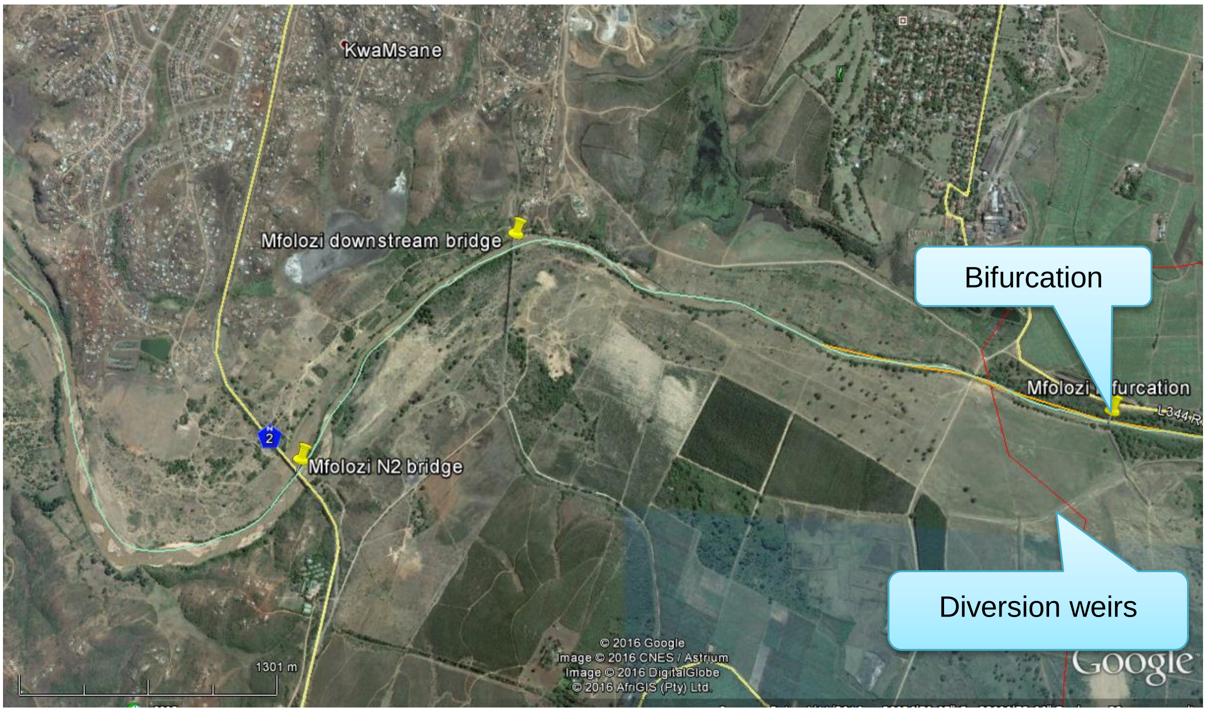


Figure A-1 Location of the bifurcation and diversion weirs on the uMfolozi River where a new flow gaging station should be established by DWS

It is important that the existing W2H032 gauging station and the proposed new one at the bifurcation measures flow for at least 5 years together in order to determine the accuracy of the historical recorded flows at W2H032.

7.2 Salinity

a) Regular (at least seasonal) measurement of TDS in the Lake, DWS gauging stations, the Narrows and estuary should be carried out by grab samples and analysis of the concentrations in the laboratory. The rivers flowing into the Lake and estuaries should also be sampled.

b) Salinity probes or other electronic methods should not be used alone since the accuracy in the long term could vary due to different methods/instruments used.

7.3 Sedimentation

a) Suspended sediment samples should be taken at the flow gauging stations at the Lake and in all influent rivers. The sampling should be carried out on a daily basis, at least during the flood season, using a standard USBR depth-integrated sampler with different nozzles for different flow conditions. The data is required to obtain sediment load-discharge relationships. Suspended sediment concentrations should be determined in a laboratory and not by turbidity meters in the field or laboratory. In the laboratory, the total sample volume of typically 0.5 l should be filtered. Larger samples of suspended sediment should also be collected from time to time for grading analysis (sieve and hydrometer).

b) Flood-season daily suspended sediment sampling should be carried out upstream and downstream of the uMkhuze and uMfolozi swamps, with discharge measurement, to obtain more data on the sediment trapping capacity of these swamps.

c) Turbidity probes should not be used for sampling since different instruments will give different results, and reliable conversion to suspended sediment concentration from NTU is almost impossible and will vary over time at a site as different sources of sediment from within a catchment will give different turbidity readings. Three turbidity-suspended sediment conversion relationships have been developed on the St Lucia system, which all provide very different concentrations for the same NTU value (Section 6.2.4).

d) Record wave heights in the Lake, local hydraulic conditions and hourly wind speeds, with suspended sediment sampling to obtain suspended sediment concentrations.

7.4 General

a) All sampling sites should be geo-referenced with hand held GPS to give x-y coordinates within 10 m accuracy or better. It is not good enough to say "Charters Creek" as was often done in the past.

b) The date and time (hh:mm) should be provided with all samples.

c) All sampling should be boat based and not taken from the bank.

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9 APPENDIX A HYDROLOGY OF THIS STUDY (AURECON, 2015)

MKUZE

Table A-1 presents the main land-use, water demands and operational features of the scenarios for EWR Site MK1. "It should be noted that Scenarios MK1-2 and MK1-5 were not analysed because the *ACRU* model has no facility for releasing the EWRs. This was discussed with the aquatic ecology team leader and it was decided that these two scenarios would be qualitatively assessed during the Estuary Workshop by contrasting the MK1-2 and MK1-5 streamflows with the EWR flows at MK1."

Table A-1: Main land-use, water demands and operational features of MK1 scenarios

Item	Baseline MK1-1	MK1-2	MK1-3	MK1-4	MK1-5
With EWRs	No	Yes	No	No	Yes
Domestic demand (10^6 m^3)	3.02	3.02	5.74 (2040)	5.74	5.74
Industrial demand (10^6 m^3)	2.33	2.33	5.16 (2040)	4.02 (2040 with 22% WDM savings)	4.02
Afforestation (km^2)	202.1	202.1	202.1	202.1	202.1
Domestic return flows (%)	35	35	35	35	35
Irrigation (km^2)	56.8	48.76	56.8	56.8	56.8
Irrigation effic. (incl. distrib. losses) (%)	75	85	75	85	85

Table A-2 presents the present-day land-use and water demands downstream of MK1 that were super-imposed on the natural *ACRU* configuration to form the Baseline Scenario MKE1-1 (sourced from Aurecon, 2014).

Table A-2: Baseline land-use and water demands for Scenario MKE1-1

Quaternary	Afforestation and IAPs (km^2)	Irrigation Area (km^2)	Domestic/Industrial Demands (10^6 m^3)	Dam Capacity (10^6 m^3)
W31J	0	1.0	0	0
W31K	0	0	0	0
W31L	0	1.2	0	0
W32A	0	0	0	0
W32B	29.7	2.5	0	0
TOTAL	29.7	4.7	0	0

No future development scenarios for the Mkuze downstream of MK1 were contained in the Scenario Report. Aurecon pointed out to the aquatic ecology team leader the fact that further water-use is present downstream of MK1 as well as notable losses in the Mkuze Swamp. Consequently, it was then decided to model the full Mkuze catchment with each of the MK1 scenarios in place upstream of MK1 (see Table A-1).

BLACK MFOLOZI

Table A-3: Main land-use, water demands and operational features of BM2 scenarios

Item	Baseline BM2-1	BM2-2	BM2-3	BM2-4	BM2-5
With EWRs	No	Yes	No	No	No
Domestic demand (10^6 m^3)	5.49 (Includes 22% excess losses)	3.85 (Basic human needs)	17.63 (2025 + 22% excess losses)	21.37 (2040 + 22% excess losses)	17.52 (2040 with 22% WDM savings)
Afforestation (km^2)	306.4	153.2	306.4	306.4	306.4
Domestic return flows (%)	25	25	25	25	25
Irrigation effic. (incl. distrib. losses) (%)	75	85	75	85	85
Vukwana Dam capacity (10^6 m^3)	6	6	20	0	0
New OCS capacity (10^6 m^3)	0	0	0	25	25

WHITE MFOLOZI

Table A-4: Main land-use, water demands and operational features of WM1 scenarios

Item	Baseline WM1-1	WM1-2	WM1-3	WM1-4	WM1-5	WM1-6
With EWRs	No	Yes	Yes	No	No	No
Domestic demand (10^6 m^3)	22.04	17.75 (Ulundi demand = 50%)	22.04 (Pipeline from Klipfontein Dam)	62.64 (2040) (No pipeline)	62.64 (2040) (No pipeline)	43.85 (2040 - Curtailed to basic human needs)
Dam storage ($10^6.m^3$)	24.83	23.40 (Mvunyana 50% silted)	21.96 (Mvunyana not used)	24.83	39.83 (Klipfontein raised 4m)	39.83 (Klipfontein raised 4m)
Domestic return flows (%)	25	25	25	25	25	25
Irrigation effic. (incl. distrib. losses) (%)	75	75	75	75	75	85
Gluckstadt I.S. (km^2)	2.5	1.25	0	2.5	2.5	0
New OCS capacity (10^6 m^3)	0	0	0	0	0	40

LOWER MFOLOZI

Table A-5: Main land-use, water demands and operational features of LMF1 scenarios for Mfolozi downstream of EWR sites BM2 and WM1#

Item	Baseline (LMF1-1)	LMF1-2	LMF1-3	LMF1-4	LMF1-5	LMF1-6	LMF1-7
With EWRs	No	Yes	No	No	Yes	No	No
Domestic demand (10^6 m^3)	7.4	7.4	7.4	17.7 (2040)	17.7 (2040)	17.7 (2040)	17.7 (2040)
Industrial demand (10^6 m^3)	11.0	11.0	11.0	12.6 (2040)	12.6 (2040)	12.6 (2040)	25.0 (>2040)
Dam Capacity (10^6 m^3)	6.0 (Richards Bay Minerals)	6.0 (RBM)	6.0 (RBM)	6.0 (RBM) 7.5 (OCS)	6.0 (RBM) 7.5 (OCS)	6.0 (RBM)	10.0 (RBM) 7.5 (OCS)
Afforestation (km^2)	65.0	65.0	49.8	65.0	65.0	65.0	65.0
Domestic return flows (%)	25	25	25	25	25	25	25
Irrigation (km^2)	39.0	39.0	39.0	39.0	39.0	39.0	39.0
Irrigation effic. and distribution losses (%)	75	75	75	75	75	75	75

#: It should be noted that the Baseline scenarios BM2-1 and WM1-1 were in place during the above LMF1 scenario modelling exercise.

Scenario LMF1-8: LMF1-6 plus an **in-channel dam of Operational Capacity = 90 million** m^3 and yield 66 million m^3/a in the Lower Mfolozi; 50% of the yield is used inside the Mfolozi catchment, leading to 25% return flows to the Mfolozi.
Scenario LMF1-9: LMF1-6 plus an **off-channel dam of Operational Capacity = 90 million** m^3 and yield 56 million m^3/a in the Lower Mfolozi; 50% of the yield is used inside the Mfolozi catchment, leading to 25% return flows to the Mfolozi.
Scenario LMF1–EWR: River EWR flows defined at BM2 and WM1, including larger floods (>1:2 yr RI) as well as current-day flows from the Lower Mfolozi, provided to the Estuary; current-day abstractions from the Lower Mfolozi curtailed to preserve the EWR flows.

HLUHLUWE

Table A-6: Main land-use, water demands and operational features of Hluhluwe scenarios

Item	Baseline HH1-1	HH1-2	HH1-3	HH1-4	HH1-5
With EWRs	No	No	Yes	No	No
Domestic demand (10^6 m^3)	3.1	3.1	3.1	6.02 (2040) (Transfer in = 6.10^6 m^3/a)	6.02 (2040) (Zero transfer in)
Afforestation (km^2)	13.9	0	0	13.9	0
Domestic return flows (%)	0	0	0	0	0
Irrigation (km^2)	13.8	13.8	13.8	13.8	13.8
Irrigation effic. and distrib. losses (%)	75	75	75	85	75

NYALAZI

Table A-7: Baseline land-use and water demands for Nyalazi Scenario NYAL-C

Quaternary Catchment	Afforestation and IAPs (km^2)	Irrigation Area (km^2)	Domestic/Industrial Demands (10^6 m^3)	Dam Capacity (10^6 m^3)
W32G	105.6	6.7	0	0
W32H	145.7	0	0	0

MSINENE

Table A-8: Baseline land-use and water demands for Msinene Scenario MSIN-C

Quaternary Catchment	Afforestation and IAPs (km^2)	Irrigation Area (km^2)	Domestic/Industrial Demands (10^6 m^3)	Dam Capacity (10^6 m^3)
W32C	18.2	21.6	0	0

10 APPENDIX B SURVEYED WATER LEVEL-AREA-VOLUME RELATIONSHIPS FOR LAKE ST LUCIA, THE NARROWS AND UMFOLOZI RIVER

St Lucia Lake				
BASE HEIGHT (m MSL)	FILL VOLUME (cubic meters)	FILL VOLUME (10^6 cubic meters)	FILL AREA (sq km)	FILL AREA_3D (sq km)
-1.90	0.18	0.00	0.000075	0.000075
-1.80	113.34	0.00	0.002975	0.002975
-1.70	646.83	0.00	0.008300	0.008300
-1.60	1835.96	0.00	0.016920	0.016930
-1.50	5418.48	0.01	0.130300	0.130300
-1.40	245726.80	0.25	5.435000	5.435000
-1.30	1187076.00	1.19	12.976000	12.976000
-1.20	2948391.00	2.95	22.588000	22.588000
-1.10	5924166.00	5.92	41.619000	41.619000
-1.00	11884872.00	11.88	78.050000	78.050000
-0.90	20934722.00	20.93	100.660000	100.660000
-0.80	32277728.00	32.28	127.050000	127.050000
-0.70	46326560.00	46.33	153.480000	153.480000
-0.60	62927642.00	62.93	177.770000	177.780000
-0.50	81810367.00	81.81	199.900000	199.900000
-0.40	102940728.00	102.94	222.660000	222.660000
-0.30	126269419.00	126.27	243.860000	243.860000
-0.20	151661074.00	151.66	263.800000	263.800000
-0.10	178907086.00	178.91	280.460000	280.460000
0.00	207535901.00	207.54	290.360000	290.360000
0.10	236781223.00	236.78	294.370000	294.370000

St Lucia Lake				
BASE HEIGHT (m MSL)	**FILL VOLUME (cubic meters)**	**FILL VOLUME (10^6 cubic meters)**	**FILL AREA (sq km)**	**FILL AREA_3D (sq km)**
0.20	266395187.00	266.40	297.780000	297.790000
0.30	296319519.00	296.32	300.650000	300.650000
0.40	326517008.00	326.52	303.310000	303.310000
0.50	357628850.00	357.63	313.170000	313.170000
0.60	389136843.00	389.14	317.060000	317.060000
0.70	421106908.00	421.11	322.830000	322.840000
0.80	453897831.00	453.90	334.170000	334.170000
0.90	488073755.00	488.07	349.270000	349.270000
1.00	523678411.00	523.68	362.950000	362.960000
1.10	560693579.00	560.69	377.100000	377.110000
1.20	599023672.00	599.02	389.150000	389.160000
1.30	638446019.00	638.45	398.730000	398.740000
1.40	678686640.00	678.69	405.760000	405.770000
1.50	719544642.00	719.54	411.110000	411.120000
1.60	760885250.00	760.89	415.720000	415.740000
1.70	802712774.00	802.71	420.960000	420.970000
1.80	845085086.00	845.09	426.540000	426.550000
1.90	888032305.00	888.03	432.420000	432.440000
2.00	931559409.00	931.56	438.110000	438.130000
2.10	975648277.00	975.65	443.610000	443.630000
2.20	1020268011.00	1020.27	448.690000	448.710000
2.30	1065369614.00	1065.37	453.240000	453.260000
2.40	1110886893.00	1110.89	457.020000	457.050000
2.50	1156759710.00	1156.76	460.380000	460.410000
2.60	1202950696.00	1202.95	463.380000	463.420000

St Lucia Lake				
BASE HEIGHT (m MSL)	**FILL VOLUME (cubic meters)**	**FILL VOLUME (10^6 cubic meters)**	**FILL AREA (sq km)**	**FILL AREA_3D (sq km)**
2.70	1249432549.00	1249.43	466.280000	466.310000
2.80	1296209064.00	1296.21	469.300000	469.330000
2.90	1343306073.00	1343.31	472.730000	472.770000
3.00	1390766236.00	1390.77	476.480000	476.520000
3.10	1438589395.00	1438.59	479.910000	479.950000
3.20	1486735644.00	1486.74	482.990000	483.040000
3.30	1535179823.00	1535.18	485.830000	485.890000
3.40	1583890095.00	1583.89	488.320000	488.380000
3.50	1632838525.00	1632.84	490.620000	490.680000
3.60	1682008485.00	1682.01	492.760000	492.830000
3.70	1731389690.00	1731.39	494.870000	494.940000
3.80	1780983842.00	1780.98	497.020000	497.090000
3.90	1830793202.00	1830.79	499.160000	499.230000
4.00	1880813533.00	1880.81	501.250000	501.330000
4.10	1931042928.00	1931.04	503.330000	503.410000
4.20	1981478112.00	1981.48	505.380000	505.460000
4.30	2032117120.00	2032.12	507.390000	507.480000
4.40	2082955763.00	2082.96	509.380000	509.470000
4.50	2133989407.00	2133.99	511.260000	511.360000
4.60	2185205348.00	2185.21	513.040000	513.140000
4.70	2236597573.00	2236.60	514.800000	514.900000
4.80	2288165390.00	2288.17	516.560000	516.660000
4.90	2339907768.00	2339.91	518.290000	518.400000
5.00	2391824622.00	2391.82	520.060000	520.170000

St Lucia Narrows				
BASE HEIGHT (m MSL)	**FILL VOLUME (cubic meters)**	**FILL VOLUME (10^6 cubic meters)**	**FILL AREA (sq km)**	**FILL AREA_3D (sq km)**
-2.00	13.50	0.00	0.000225	0.000225
-1.90	53.12	0.00	0.000525	0.000525
-1.80	137.09	0.00	0.001150	0.001150
-1.70	330.71	0.00	0.003475	0.003476
-1.60	988.01	0.00	0.010820	0.010830
-1.50	4121.24	0.00	0.051000	0.051000
-1.40	11286.01	0.01	0.104500	0.104500
-1.30	28086.26	0.03	0.237200	0.237200
-1.20	57475.25	0.06	0.350200	0.350300
-1.10	98355.01	0.10	0.477100	0.477100
-1.00	153767.00	0.15	0.635000	0.635000
-0.90	226464.50	0.23	0.814000	0.814000
-0.80	316359.00	0.32	0.985000	0.985000
-0.70	423659.80	0.42	1.160000	1.160000
-0.60	547853.40	0.55	1.324000	1.325000
-0.50	688649.20	0.69	1.490000	1.491000
-0.40	845779.20	0.85	1.652000	1.652000
-0.30	1019257.00	1.02	1.819000	1.819000
-0.20	1210081.00	1.21	2.005000	2.006000
-0.10	1419908.00	1.42	2.179000	2.180000
0.00	1644567.00	1.64	2.310000	2.311000
0.10	1882253.00	1.88	2.442000	2.443000
0.20	2130707.00	2.13	2.525000	2.527000
0.30	2387188.00	2.39	2.603000	2.604000

St Lucia Narrows				
BASE HEIGHT (m MSL)	FILL VOLUME (cubic meters)	FILL VOLUME (10^6 cubic meters)	FILL AREA (sq km)	FILL AREA_3D (sq km)
0.40	2651526.00	2.65	2.684000	2.686000
0.50	2923878.00	2.92	2.765000	2.766000
0.60	3204411.00	3.20	2.847000	2.849000
0.70	3560840.00	3.56	3.651000	3.653000
0.80	3933401.00	3.93	3.800000	3.802000
0.90	4321270.00	4.32	3.961000	3.963000
1.00	4731819.00	4.73	4.376000	4.378000
1.10	5239767.00	5.24	5.995000	5.997000
1.20	5962185.00	5.96	8.518000	8.521000
1.30	6931911.00	6.93	10.770000	10.773000
1.40	8077408.00	8.08	11.995000	11.998000
1.50	9314619.00	9.31	12.708000	12.711000
1.60	10613465.00	10.61	13.254000	13.258000
1.70	11966637.00	11.97	13.817000	13.820000
1.80	13379610.00	13.38	14.456000	14.460000
1.90	14859154.00	14.86	15.140000	15.144000
2.00	16407125.00	16.41	15.815000	15.820000
2.10	18020771.00	18.02	16.451000	16.456000
2.20	19694863.00	19.69	17.032000	17.036000
2.30	21430242.00	21.43	17.722000	17.727000
2.40	23244235.00	23.24	18.589000	18.594000
2.50	25159533.00	25.16	19.769000	19.774000
2.60	27200881.00	27.20	21.060000	21.066000
2.70	29370036.00	29.37	22.342000	22.349000
2.80	31674487.00	31.67	23.771000	23.778000

St Lucia Narrows				
BASE HEIGHT (m MSL)	**FILL VOLUME (cubic meters)**	**FILL VOLUME (10^6 cubic meters)**	**FILL AREA (sq km)**	**FILL AREA_3D (sq km)**
2.90	34126808.00	34.13	25.296000	25.303000
3.00	36742040.00	36.74	26.999000	27.006000
3.10	39528294.00	39.53	28.783000	28.791000
3.20	42497449.00	42.50	30.588000	30.596000
3.30	45654519.00	45.65	32.632000	32.641000
3.40	49021718.00	49.02	34.661000	34.670000
3.50	52566002.00	52.57	36.126000	36.135000
3.60	56236096.00	56.24	37.242000	37.252000
3.70	60010738.00	60.01	38.240000	38.249000
3.80	63883447.00	63.88	39.205000	39.215000
3.90	67850037.00	67.85	40.131000	40.141000
4.00	71910061.00	71.91	41.065000	41.075000
4.10	76057813.00	76.06	41.855000	41.866000
4.20	80276469.00	80.28	42.500000	42.511000
4.30	84557401.00	84.56	43.123000	43.134000
4.40	88900412.00	88.90	43.710000	43.721000
4.50	93295997.00	93.30	44.197000	44.208000
4.60	97738569.00	97.74	44.646000	44.658000
4.70	102224243.00	102.22	45.077000	45.089000
4.80	106755736.00	106.76	45.560000	45.572000
4.90	111337966.00	111.34	46.060000	46.073000
5.00	115962010.00	115.96	46.415000	46.428000

uMfolozi River				
BASE HEIGHT (m MSL)	**FILL VOLUME (cubic meters)**	**FILL VOLUME (10^6 cubic meters)**	**FILL AREA (sq km)**	**FILL AREA_3D (sq km)**
-2.20	12.81	0.00	0.000425	0.000426
-2.10	86.87	0.00	0.001225	0.001228
-2.00	240.56	0.00	0.001850	0.001854
-1.90	448.29	0.00	0.002300	0.002306
-1.80	694.44	0.00	0.002550	0.002557
-1.70	971.66	0.00	0.003200	0.003211
-1.60	1324.57	0.00	0.003800	0.003813
-1.50	1754.43	0.00	0.005020	0.005040
-1.40	2349.31	0.00	0.006820	0.006840
-1.30	3133.80	0.00	0.008920	0.008950
-1.20	4199.52	0.00	0.012420	0.012460
-1.10	5727.72	0.01	0.019750	0.019790
-1.00	8444.87	0.01	0.035600	0.035660
-0.90	12933.64	0.01	0.054100	0.054200
-0.80	19406.70	0.02	0.077100	0.077200
-0.70	28536.39	0.03	0.107500	0.107600
-0.60	40961.49	0.04	0.140700	0.140900
-0.50	56843.92	0.06	0.177300	0.177500
-0.40	76652.50	0.08	0.221400	0.221700
-0.30	101435.50	0.10	0.276200	0.276600
-0.20	131879.90	0.13	0.335600	0.336200
-0.10	168718.10	0.17	0.403700	0.404500
0.00	213680.10	0.21	0.501000	0.502000
0.10	268826.70	0.27	0.599000	0.600000
0.20	334497.60	0.33	0.696000	0.698000

uMfolozi River				
BASE HEIGHT (m MSL)	FILL VOLUME (cubic meters)	FILL VOLUME (10^6 cubic meters)	FILL AREA (sq km)	FILL AREA_3D (sq km)
0.30	406983.60	0.41	0.753000	0.754000
0.40	484963.30	0.48	0.806000	0.807000
0.50	568157.50	0.57	0.858000	0.859000
0.60	656589.90	0.66	0.912000	0.914000
0.70	750527.20	0.75	0.968000	0.970000
0.80	850122.50	0.85	1.024000	1.027000
0.90	955366.80	0.96	1.081000	1.084000
1.00	1066439.00	1.07	1.144000	1.148000
1.10	1186315.00	1.19	1.262000	1.266000
1.20	1321317.00	1.32	1.456000	1.460000
1.30	1483195.00	1.48	1.837000	1.841000
1.40	1700224.00	1.70	2.540000	2.545000
1.50	2002868.00	2.00	3.578000	3.583000
1.60	2426998.00	2.43	4.949000	4.955000
1.70	3012406.00	3.01	6.885000	6.892000
1.80	3827183.00	3.83	9.575000	9.582000
1.90	4968532.00	4.97	13.411000	13.418000
2.00	6522176.00	6.52	17.714000	17.723000
2.10	8520921.00	8.52	22.295000	22.304000
2.20	10992655.00	10.99	27.224000	27.234000
2.30	13974320.00	13.97	32.414000	32.425000
2.40	17465061.00	17.47	37.334000	37.347000
2.50	21425845.00	21.43	41.829000	41.842000
2.60	25817728.00	25.82	45.896000	45.911000
2.70	30582232.00	30.58	49.296000	49.311000
2.80	35656969.00	35.66	52.123000	52.139000

uMfolozi River				
BASE HEIGHT (m MSL)	**FILL VOLUME (cubic meters)**	**FILL VOLUME (10^6 cubic meters)**	**FILL AREA (sq km)**	**FILL AREA_3D (sq km)**
2.90	40992878.00	40.99	54.524000	54.541000
3.00	46551782.00	46.55	56.612000	56.629000
3.10	52308299.00	52.31	58.492000	58.510000
3.20	58247326.00	58.25	60.271000	60.290000
3.30	64360383.00	64.36	61.982000	62.002000
3.40	70641621.00	70.64	63.628000	63.649000
3.50	77083870.00	77.08	65.216000	65.237000
3.60	83685428.00	83.69	66.822000	66.844000
3.70	90450001.00	90.45	68.480000	68.503000
3.80	97379517.00	97.38	70.105000	70.129000
3.90	104469236.00	104.47	71.683000	71.707000
4.00	111714287.00	111.71	73.205000	73.230000
4.10	119109869.00	119.11	74.723000	74.749000
4.20	126659594.00	126.66	76.269000	76.296000
4.30	134361182.00	134.36	77.741000	77.769000
4.40	142203913.00	142.20	79.095000	79.123000
4.50	150178116.00	150.18	80.394000	80.424000
4.60	158280412.00	158.28	81.622000	81.652000
4.70	166499774.00	166.50	82.757000	82.788000
4.80	174830554.00	174.83	83.859000	83.891000
4.90	183271611.00	183.27	84.966000	84.999000
5.00	191826548.00	191.83	86.146000	86.180000

11 APPENDIX C EXTREME TIDAL LEVELS AND DATUM LEVELS

1. Probabilistic analysis of extreme tidal levels

A probabilistic analysis was carried out on the observed tidal levels at Richards Bay (Figure C-1). Table C.1 shows the proposed tidal levels for different recurrence intervals.

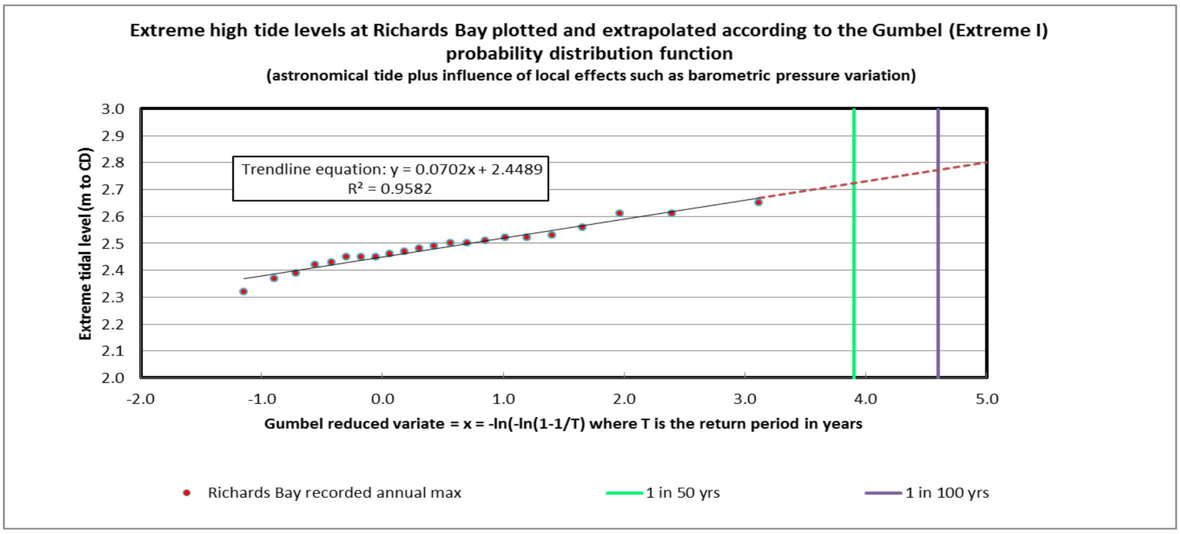

Figure C-1 Probabilistic analysis of tidal levels at Richards Bay

Table C.1 Recurrence interval tidal levels

Recurrence interval (years)	Tidal level (m to CD)	Tidal level (m MSL)
100	2.77	1.76 (2.26))*
50	2.72	1.71 (2.21)
10	2.61	1.59 (2.09)
1	2.29	1.28 (1.78)

Note: *Values in brackets with predicted sea level change by 2090 of 0.5 m added (see section 2 below).

2. Datums for St Lucia

Datums as interpreetd for this study are shown in Figure C-2.

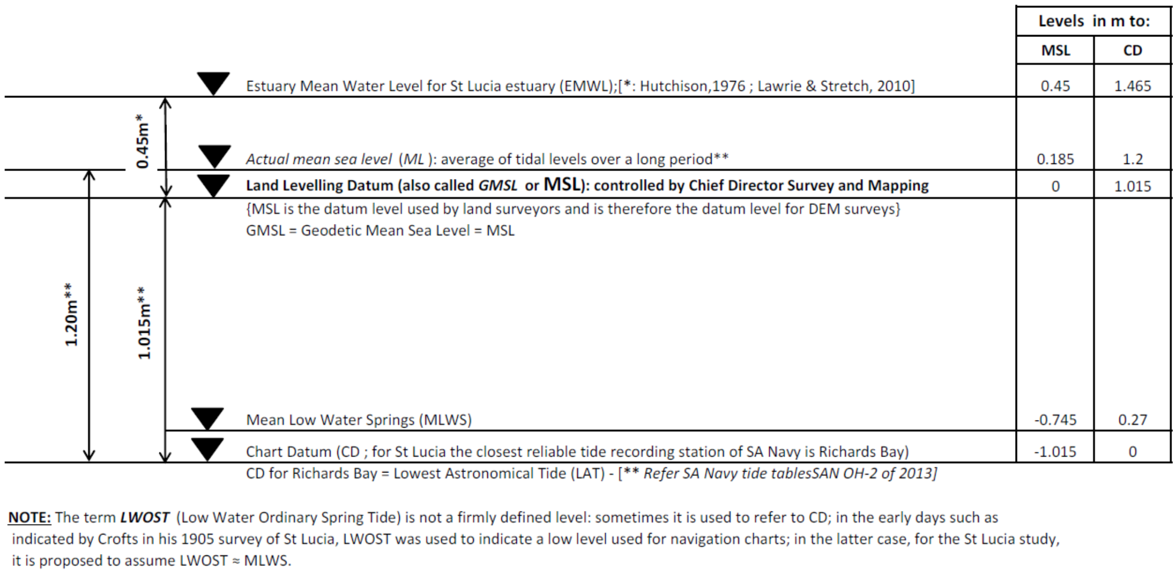

Figure C-2 **Datum levels for St Lucia as interpreted for this project**

12 APPENDIX D MOUTH CONDITION TIME SERIES GRAPHS

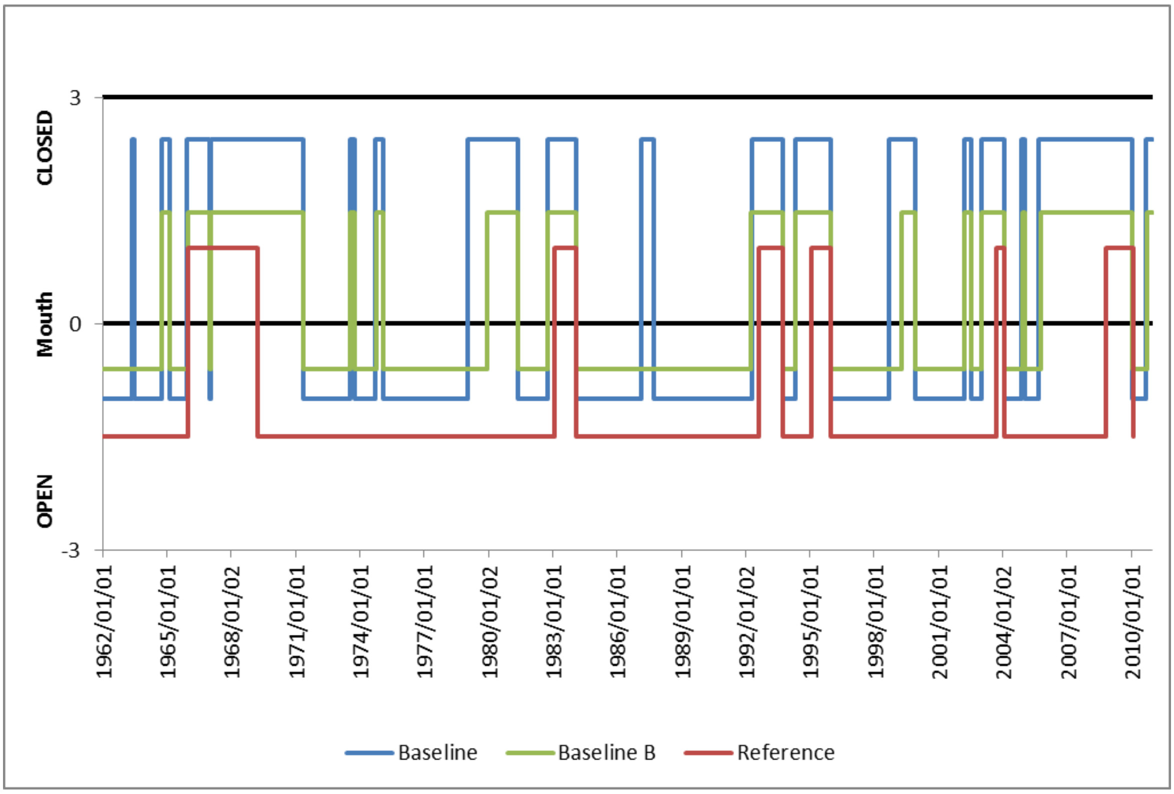

Figure D-1 **Baseline mouth conditions: Scenario A vs B**

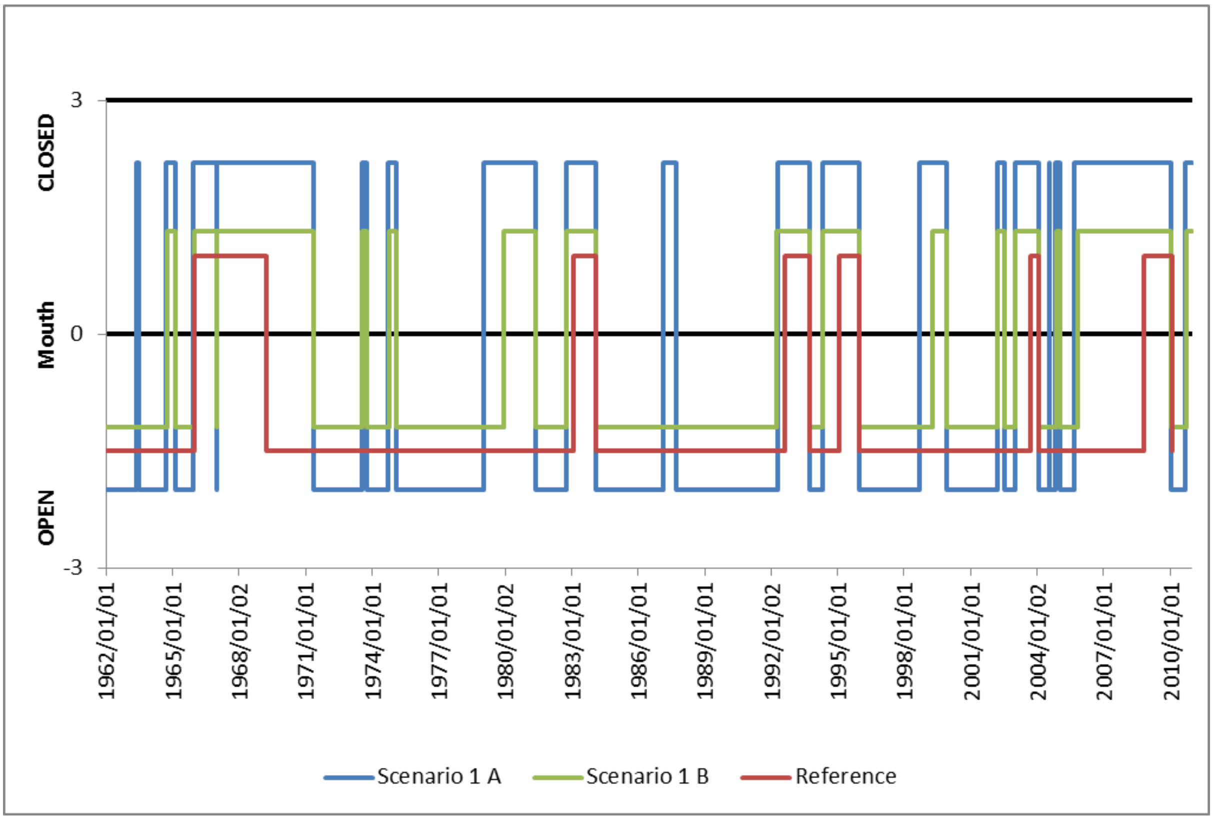

Figure D-2 **Scenario 1 mouth conditions: Scenario A vs B**

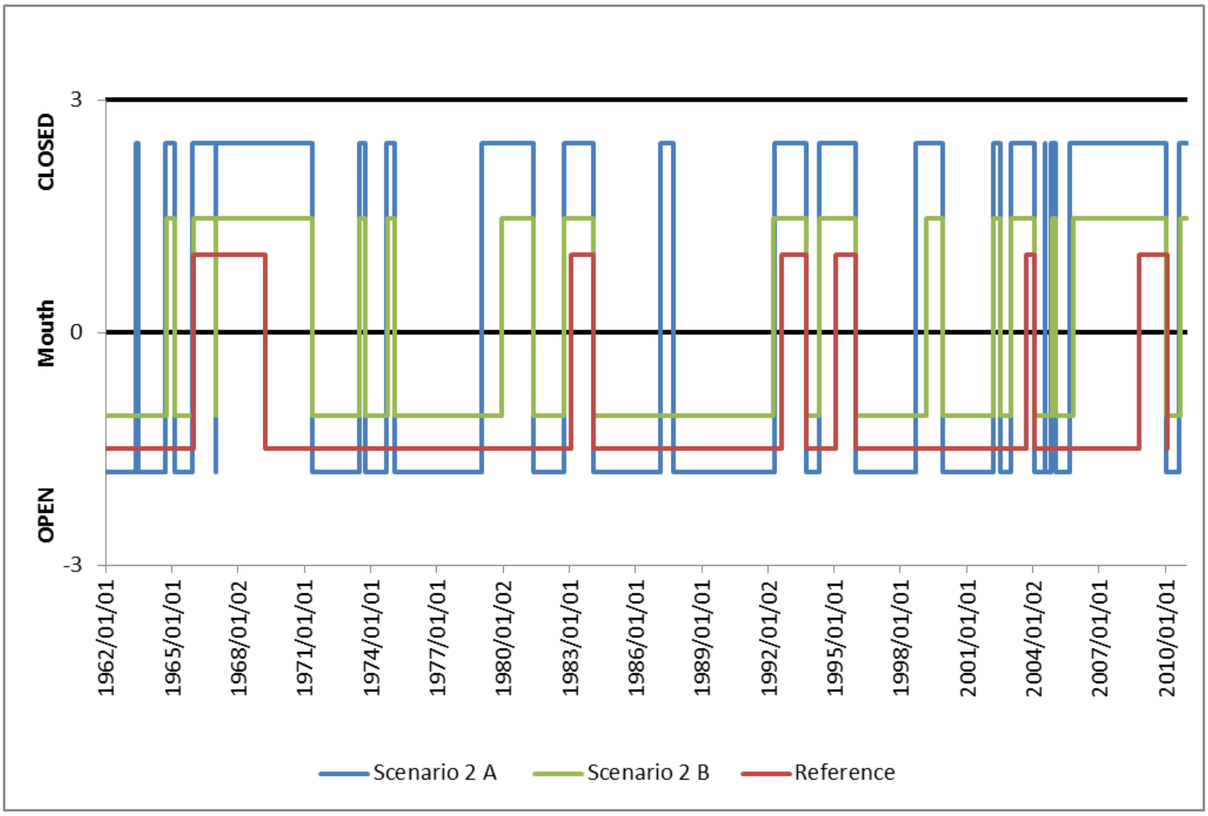

Figure D-3 **Scenario 2 mouth conditions: Scenario A vs B**

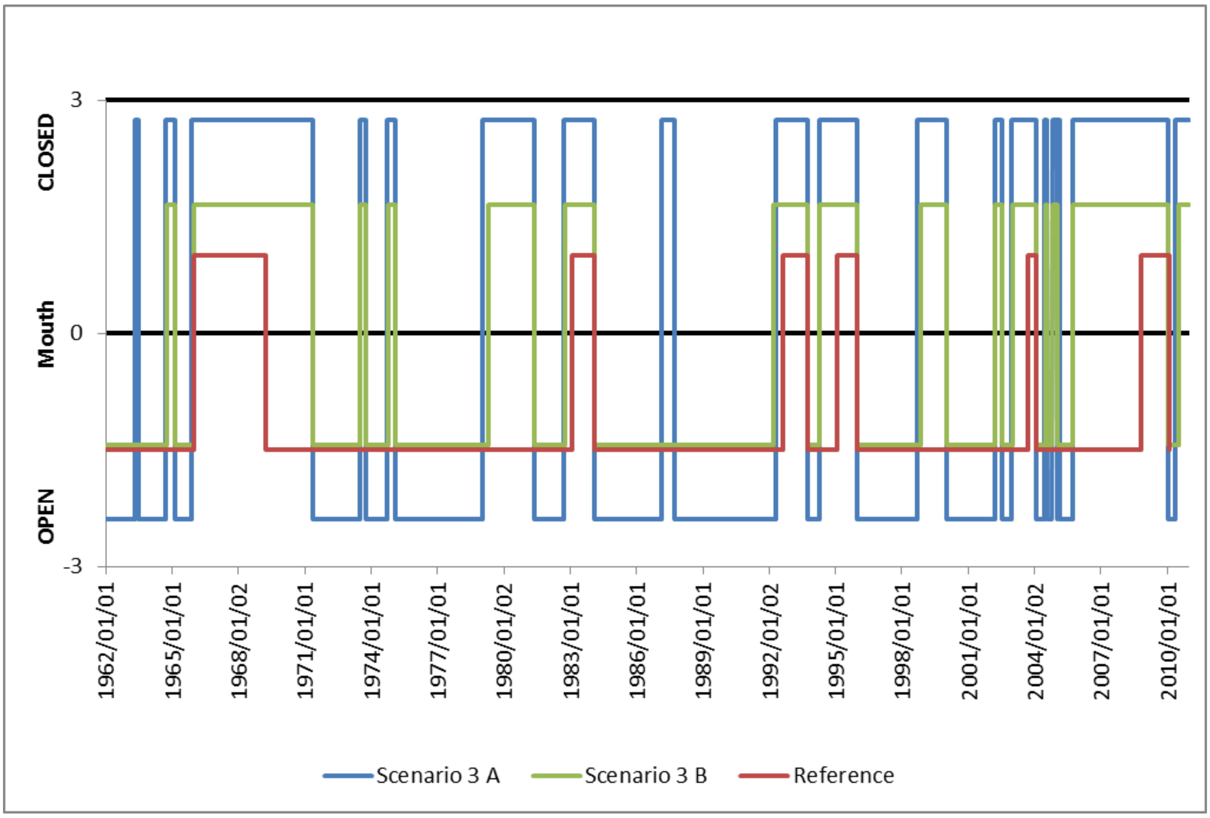

Figure D-4 **Scenario 3 mouth conditions: Scenario A vs B**

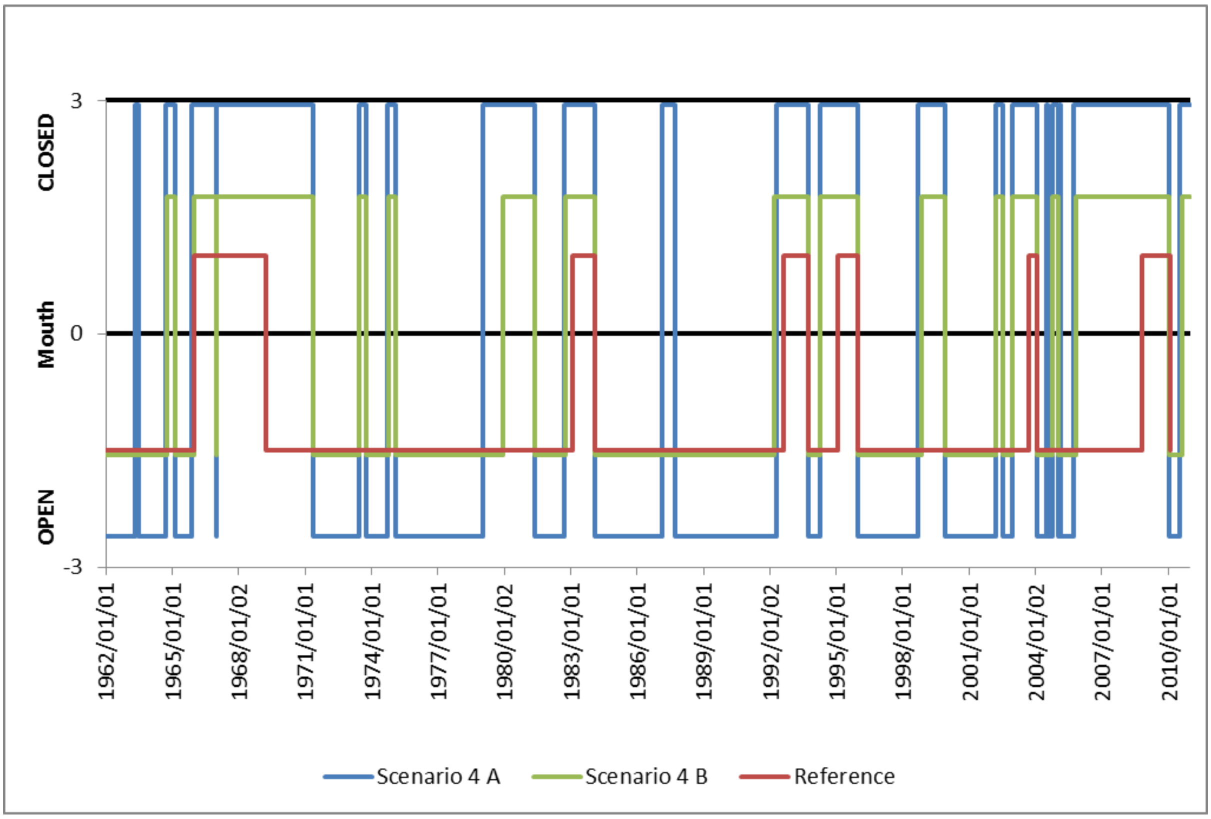

Figure D-5 **Scenario 4 mouth conditions: Scenario A vs B**

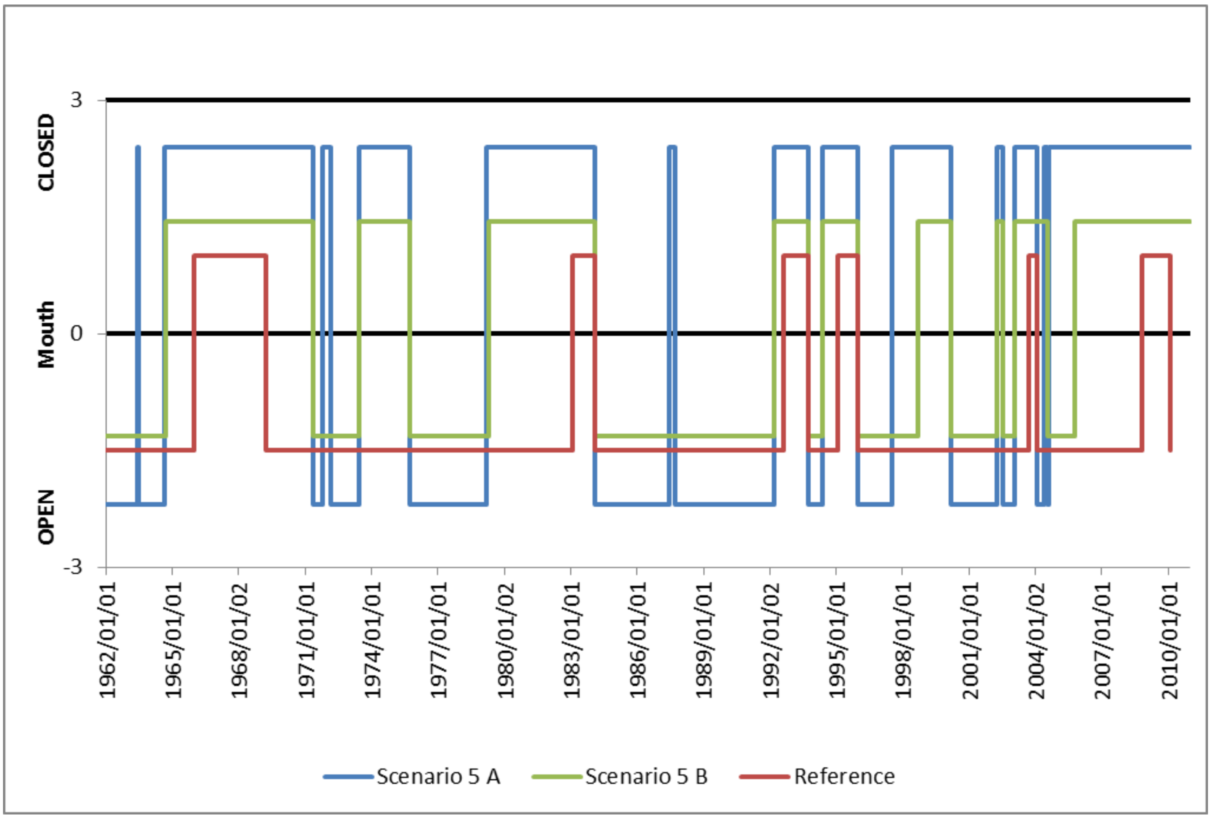

Figure D-6 Scenario 5 mouth conditions: Scenario A vs B

13 APPENDIX E SCENARIOS A AND B - SIMULATED WATER LEVEL AND TDS TIME SERIES GRAPHS AT LISTER'S POINT, NORTHERN LAKE AND CHARTERS CREEK (DAILY DATA PLOTTED) FOR THE PERIOD 1962 TO 2010 ALL FOR ONE MOUTH CONDITION

Locations of points in the lake

Site name	Lo 33		UTM
	X	Y	
Lister's Point	-59717	-3097313	36 J 440307 6903926
Northern Lake	-49968	-3089639	36 J 450052 6911597
Charters Creek	-55945	-3121740	36 J 444077 6879509

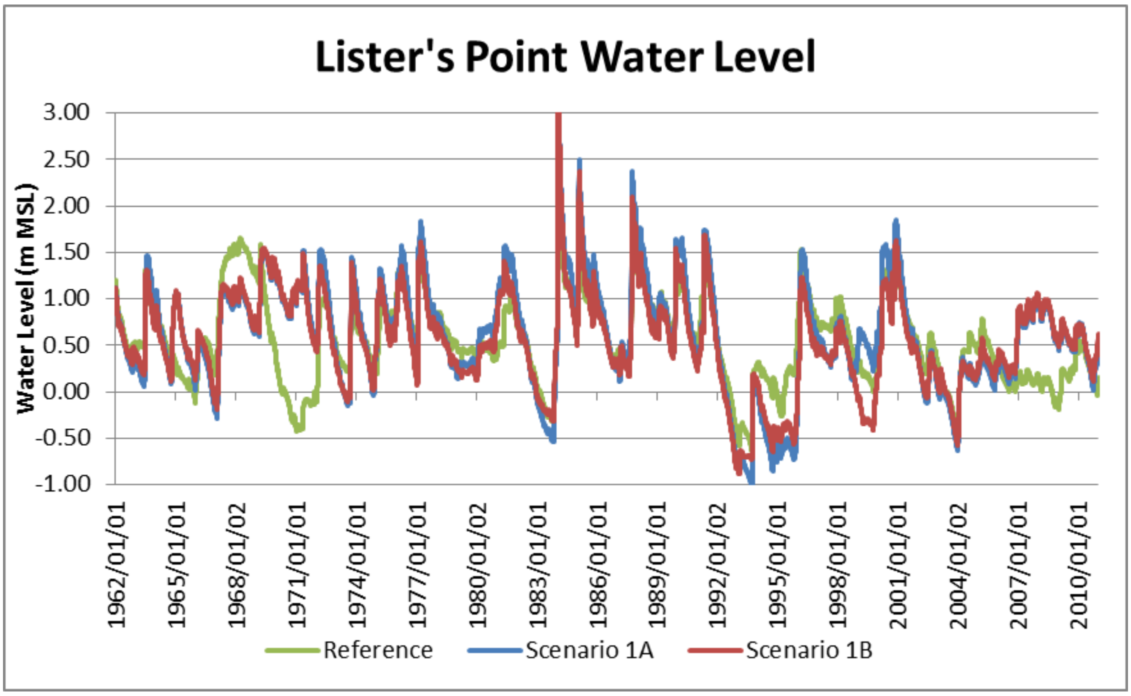

Figure E-1 Lister's Point Water Level (Baseline: One Mouth – A and B)

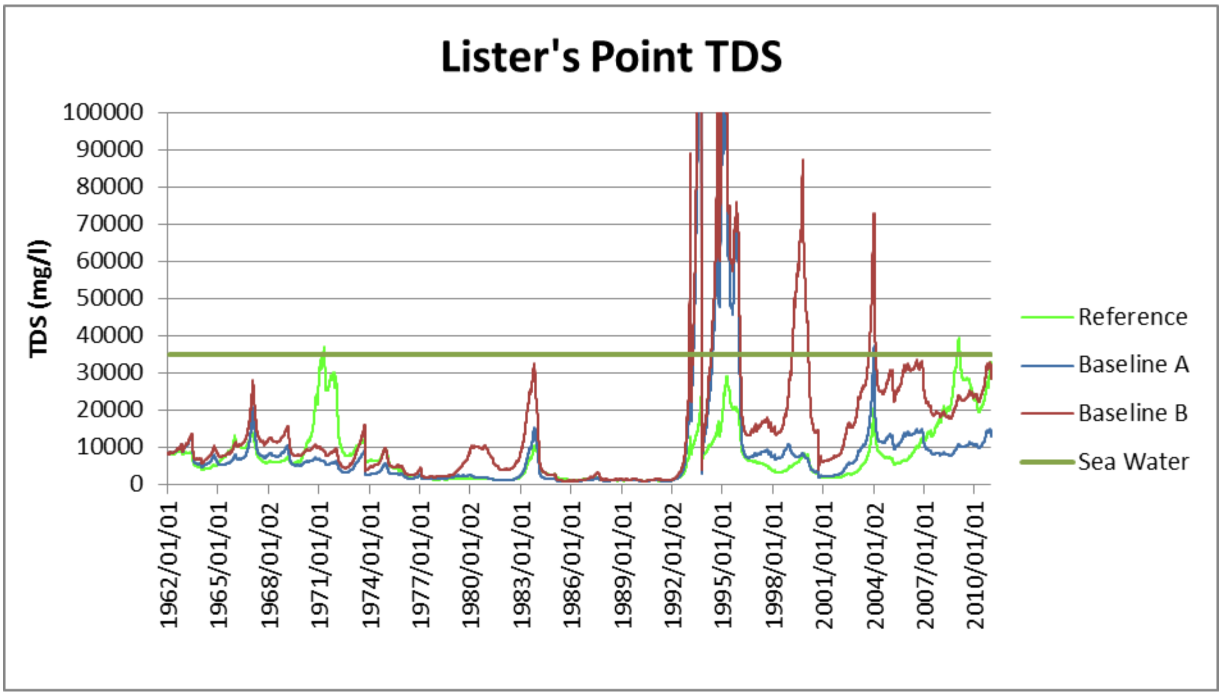

Figure E-2 Lister's Point TDS (Baseline: One Mouth – A and B)

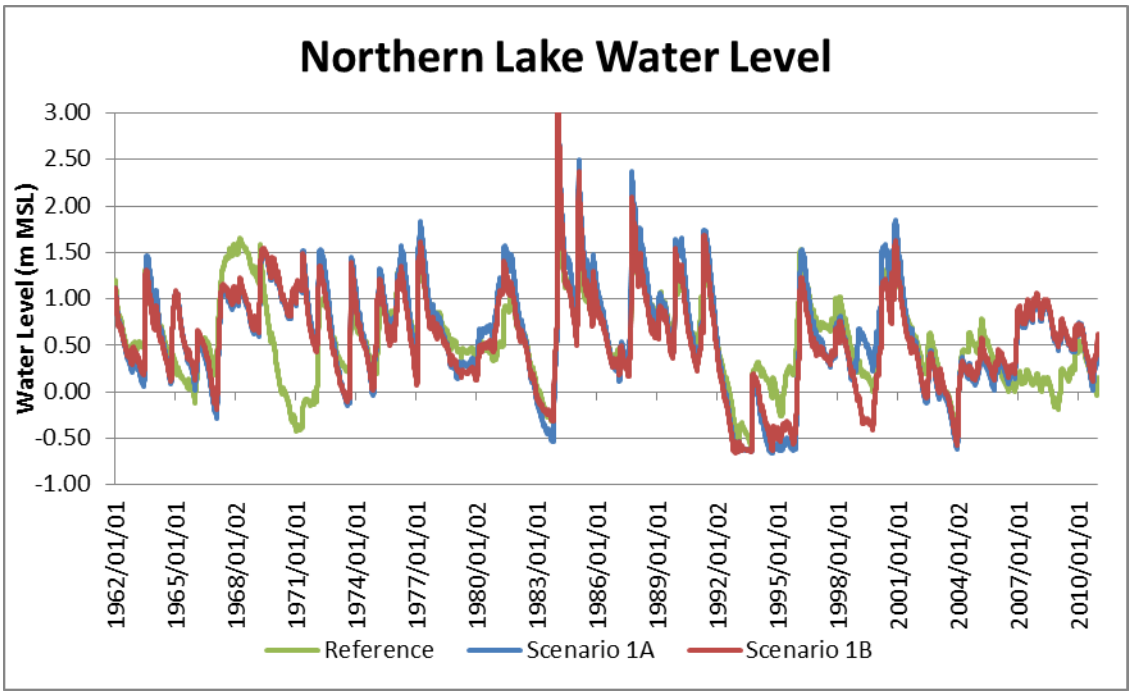

Figure E-3 Northern Lake Water Level (Baseline: One Mouth – A and B)

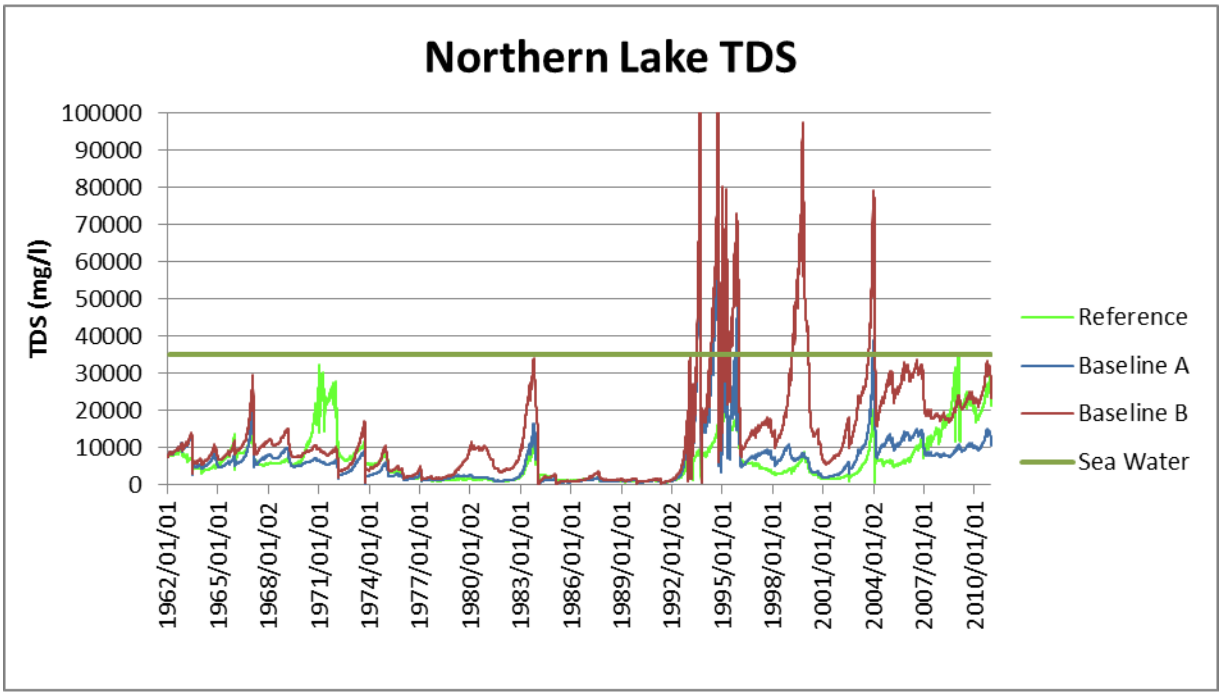

Figure E-4 Northern Lake TDS (Baseline: One Mouth – A and B)

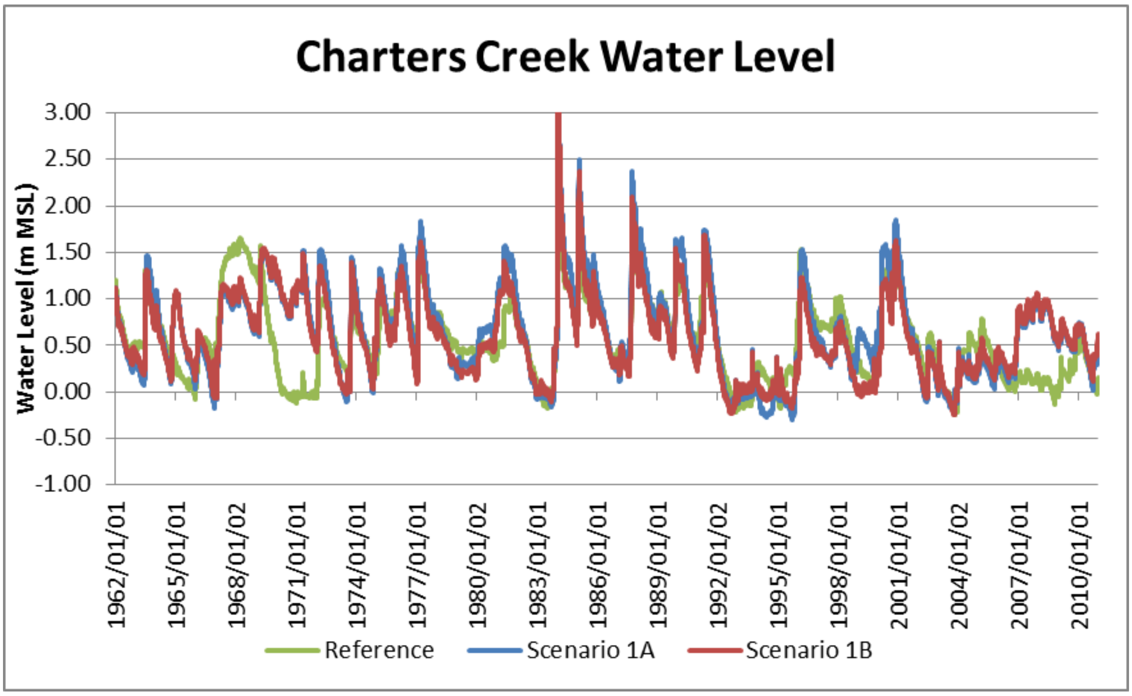

Figure E-5 Charters Creek Water Level (Baseline: One Mouth – A and B)

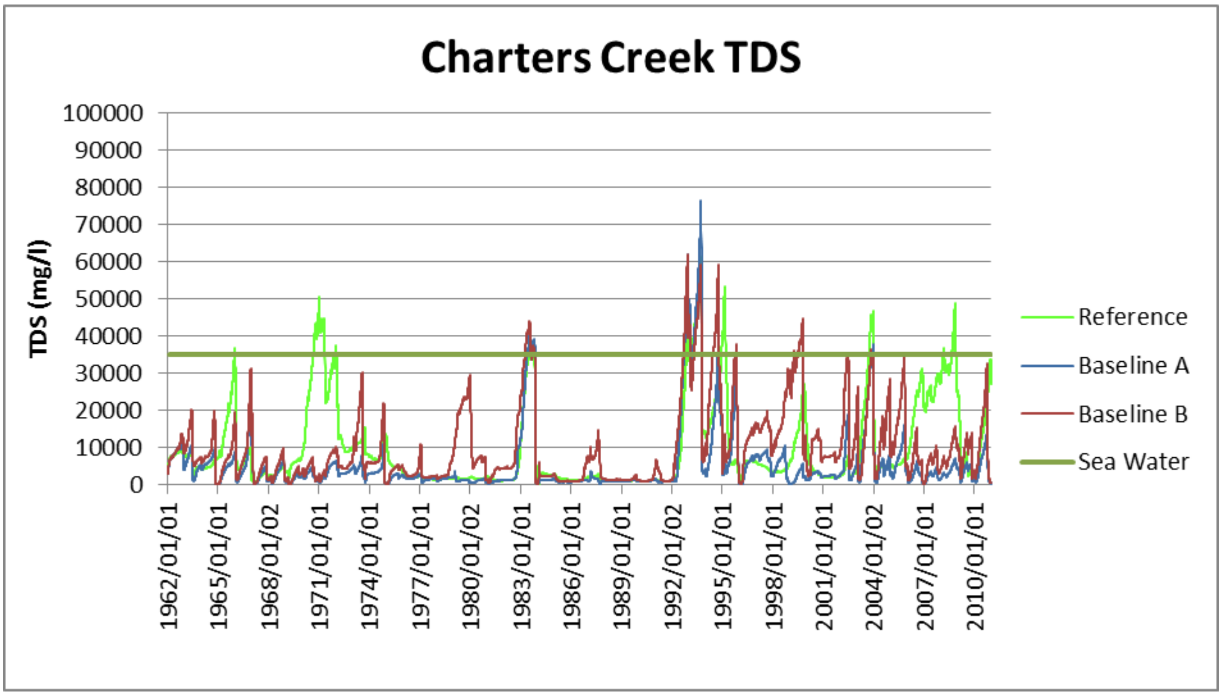

Figure E-6 Charters Creek TDS (Baseline: One Mouth – A and B)

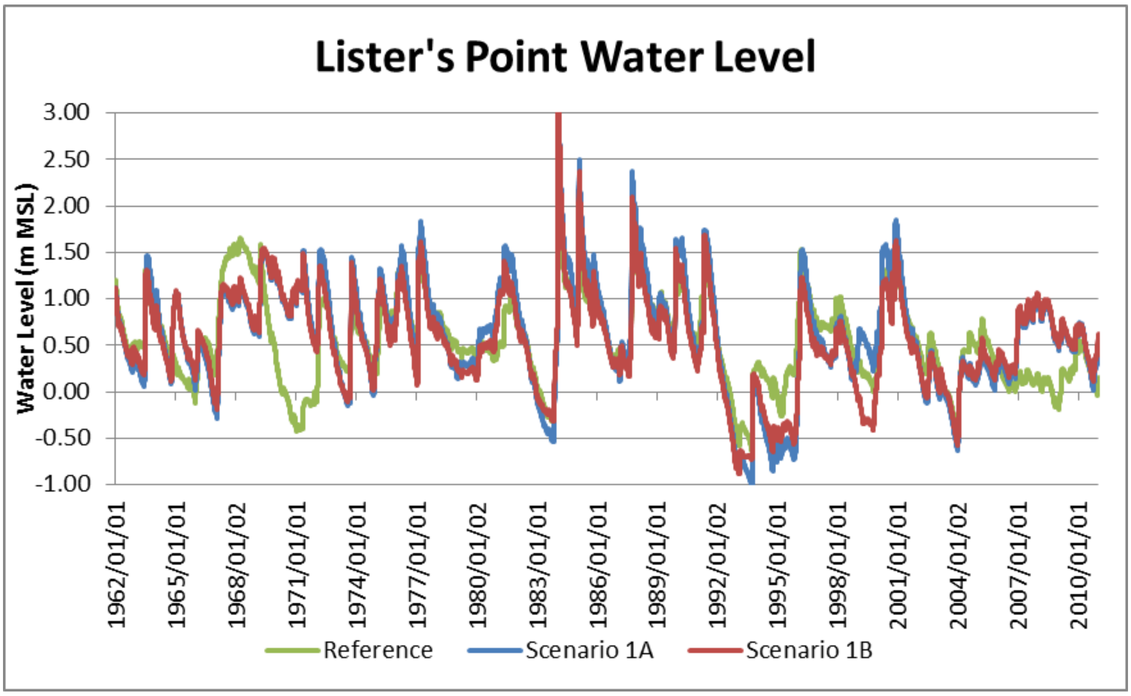

Figure E-7 **Lister's Point Water Level (Scenario 1: One Mouth – A and B)**

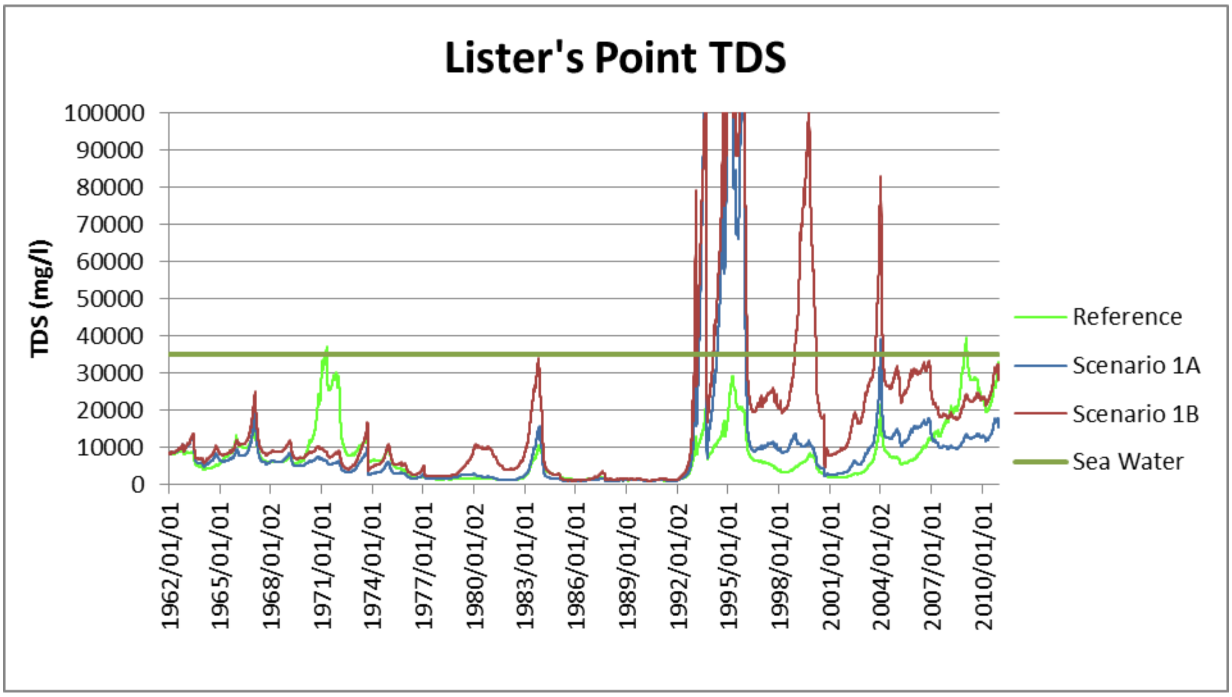

Figure E-8 **Lister's Point TDS (Scenario 1: One Mouth – A and B)**

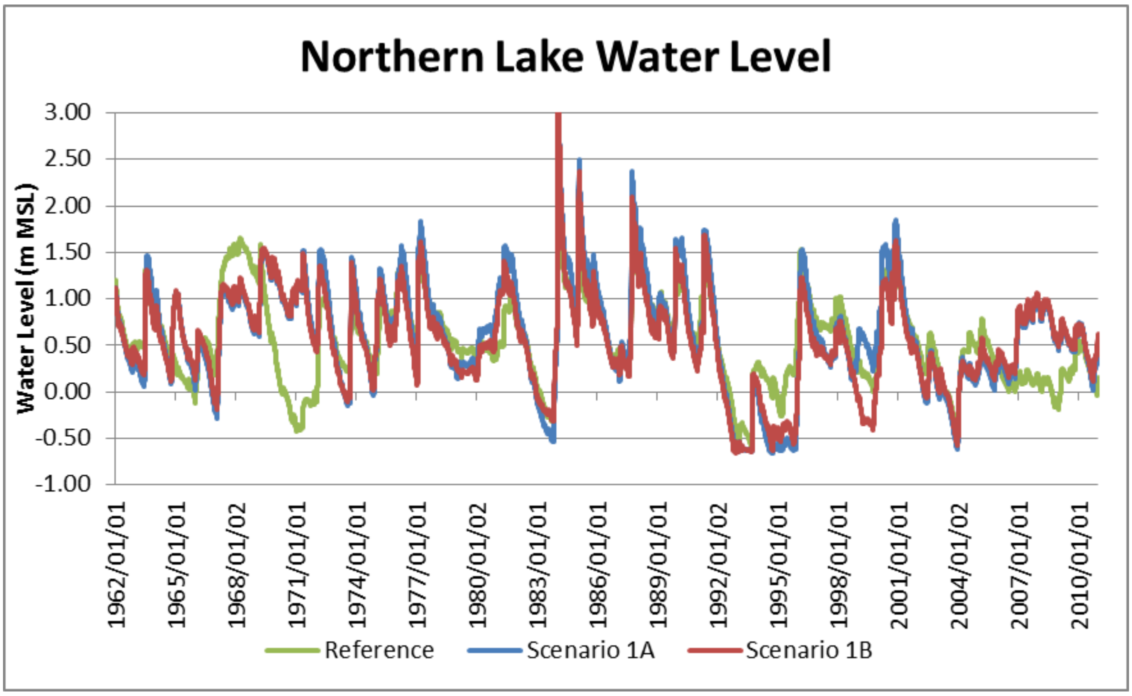

Figure E-9 **Northern Lake Water Level (Scenario 1: One Mouth – A and B)**

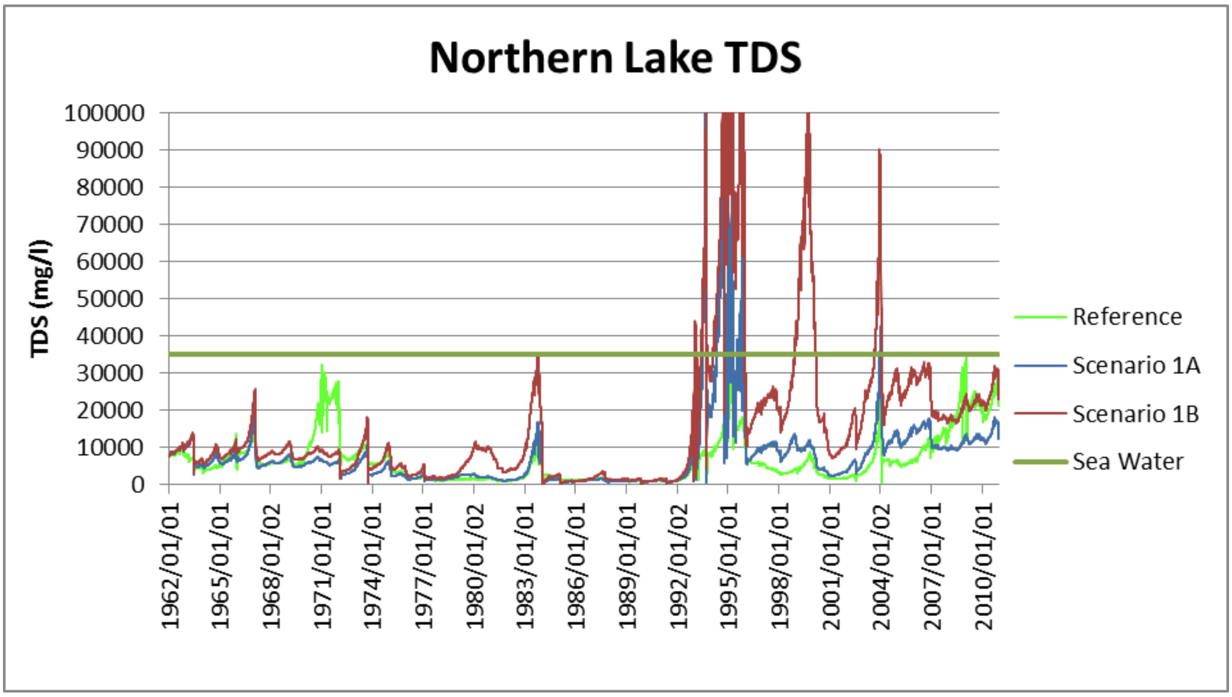

Figure E-10 **Northern Lake TDS (Scenario 1: One Mouth – A and B)**

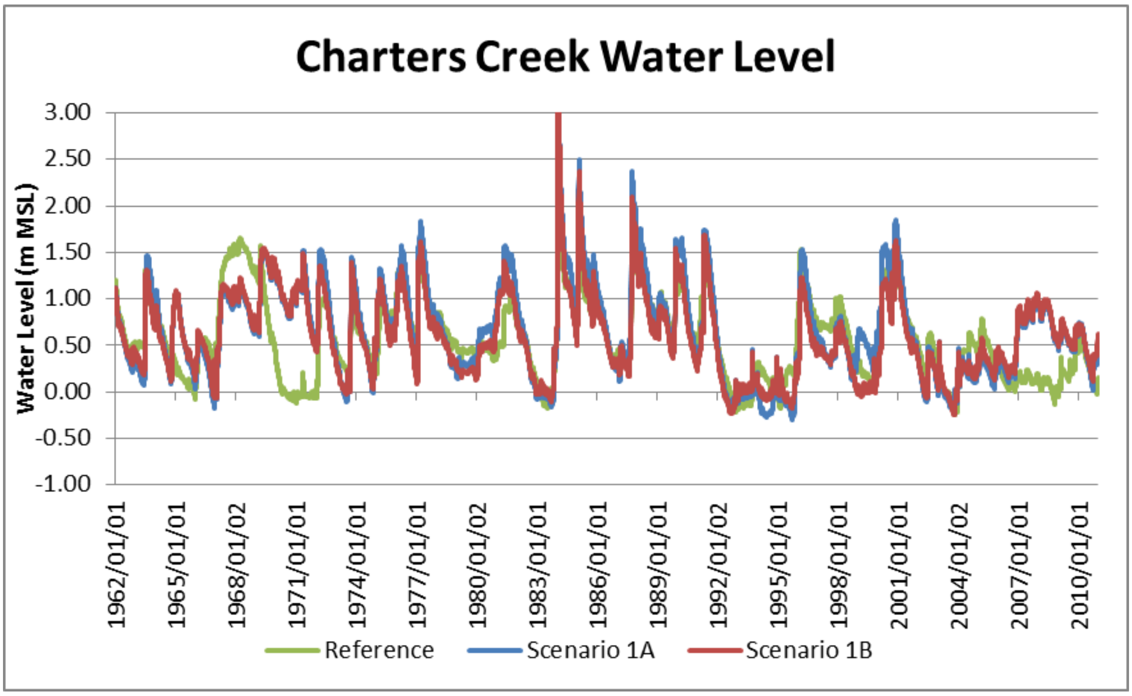

Figure E-11 Charters Creek Water Level (Scenario 1: One Mouth – A and B)

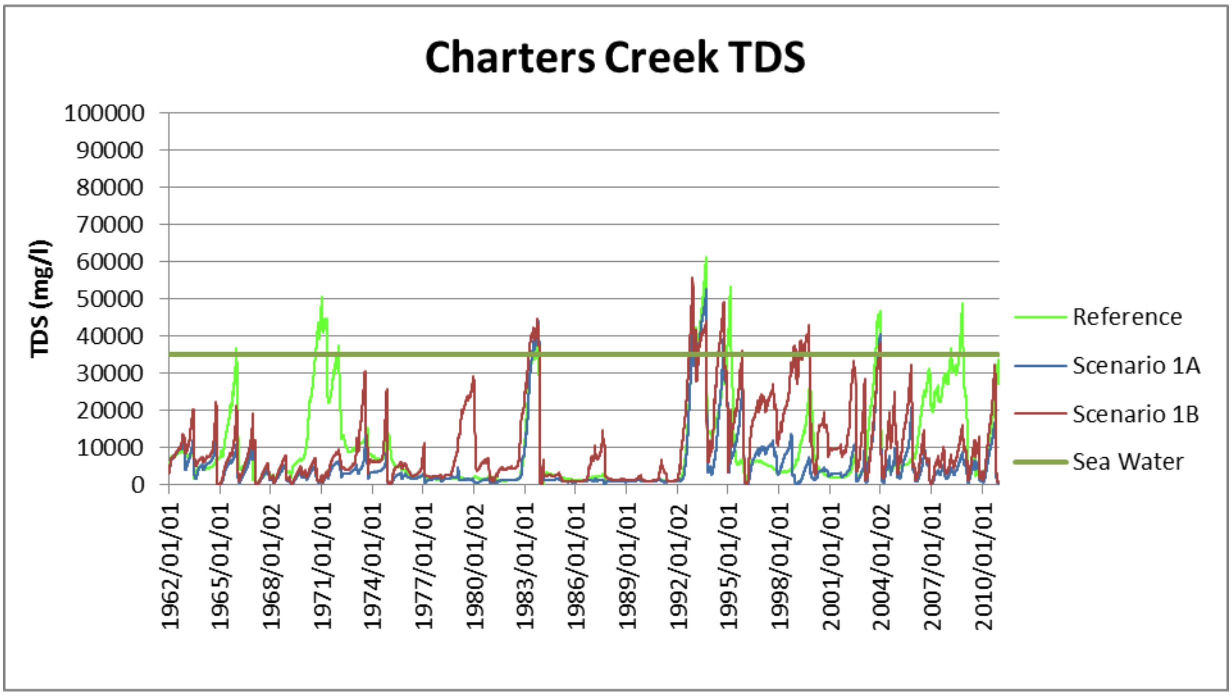

Figure E-12 Charters Creek TDS (Scenario 1: One Mouth – A and B)

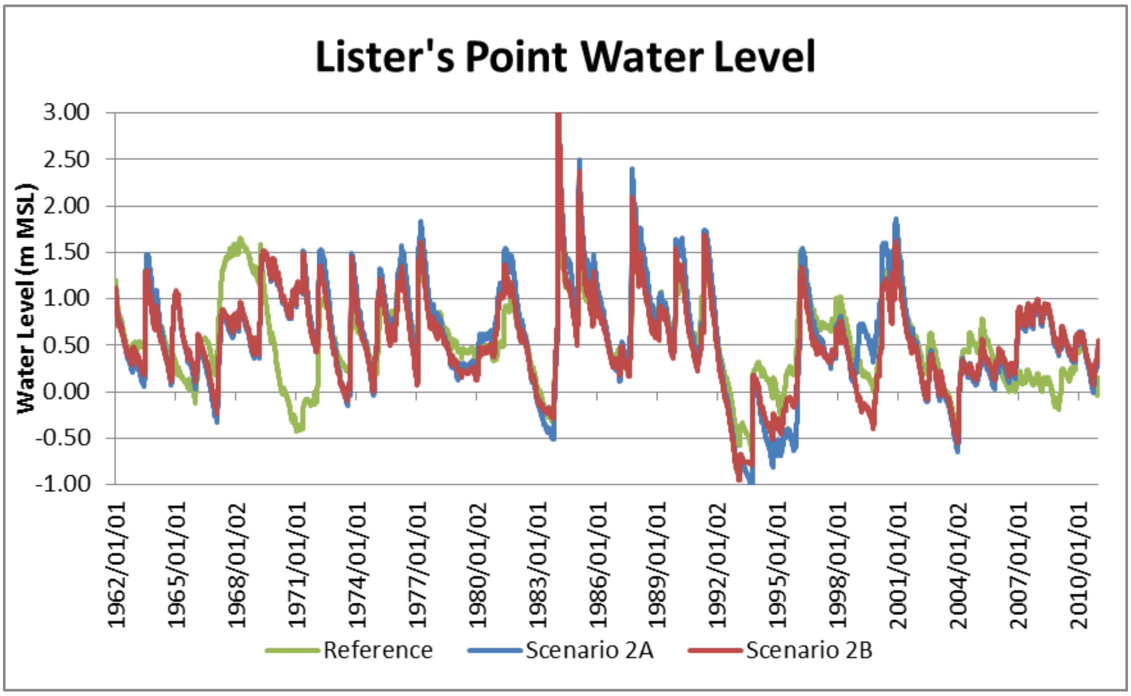

Figure E-13 Lister's Point Water Level (Scenario 2: One Mouth – A and B)

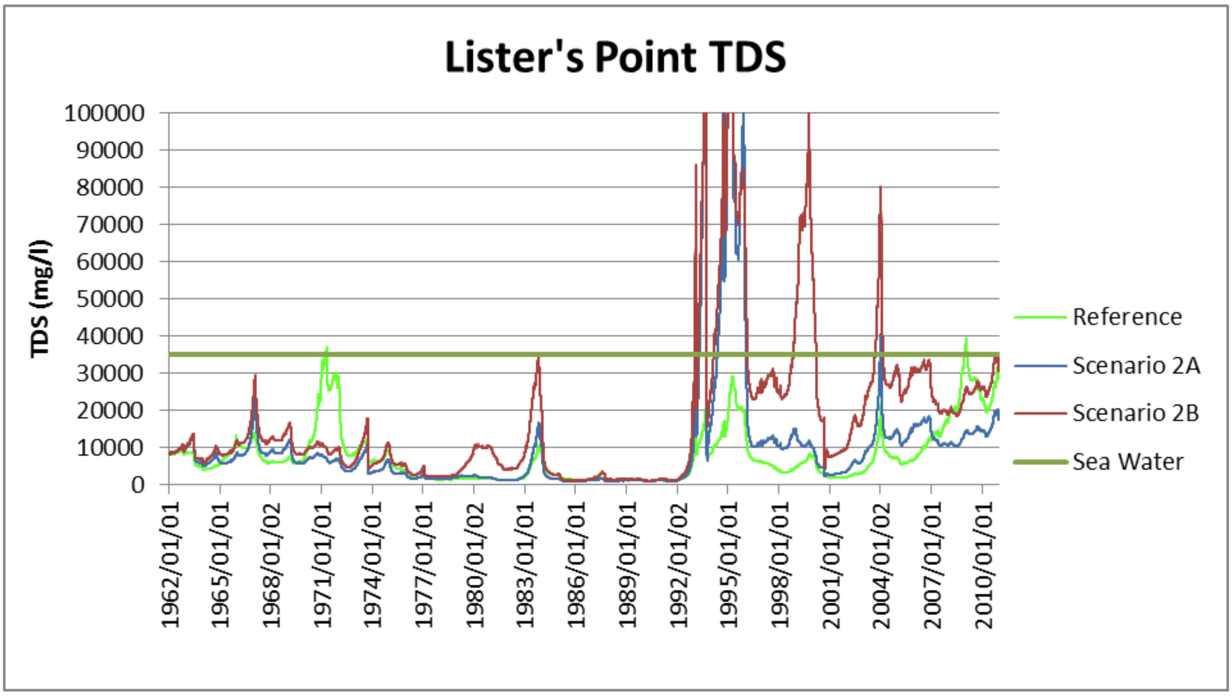

Figure E-14 Lister's Point TDS (Scenario 2: One Mouth – A and B)

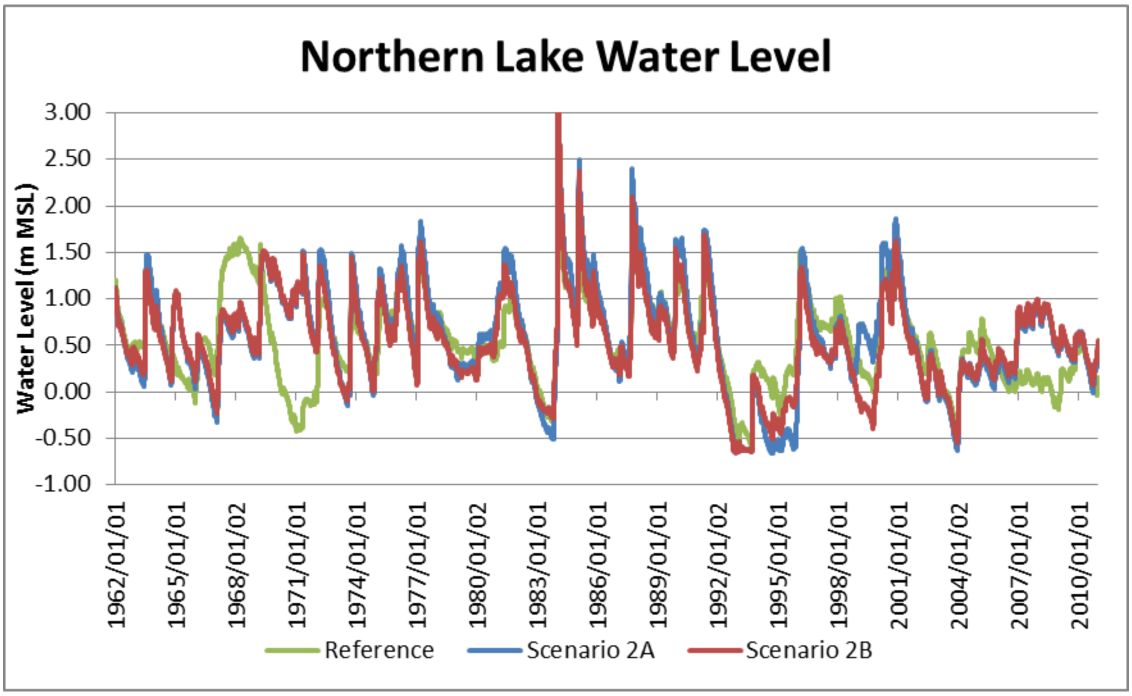

Figure E-15 Northern Lake Water Level (Scenario 2: One Mouth – A and B)

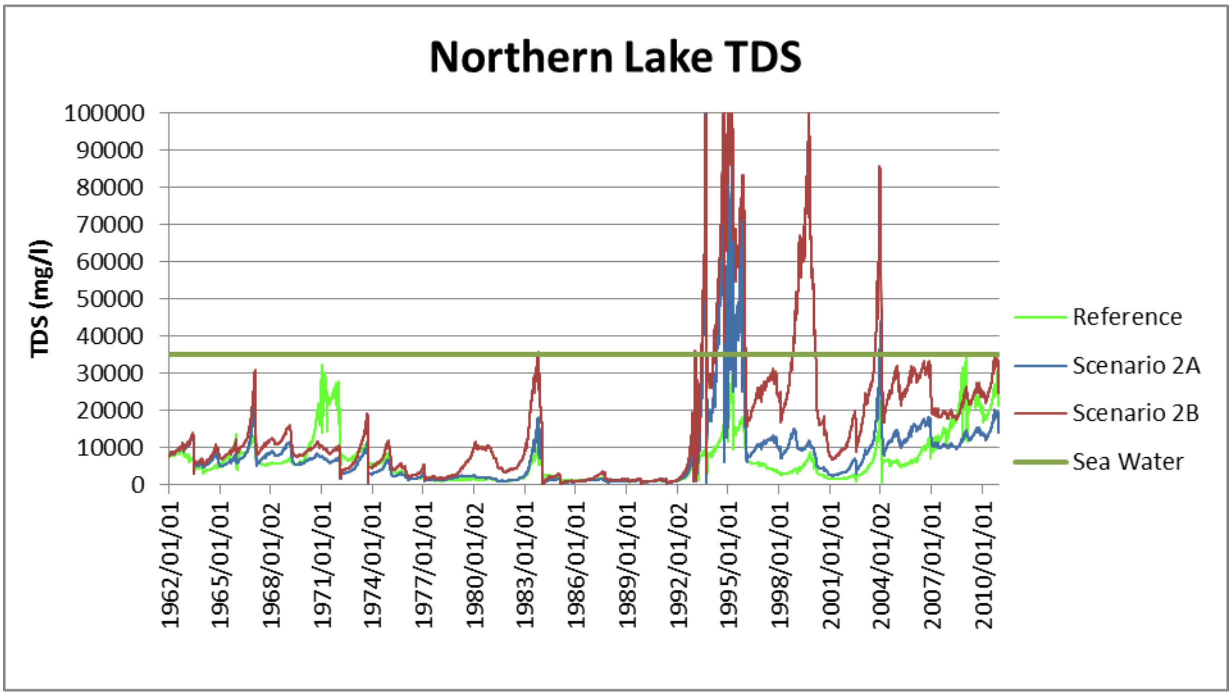

Figure E-16 Northern Lake Water Level (Scenario 2: One Mouth – A and B)

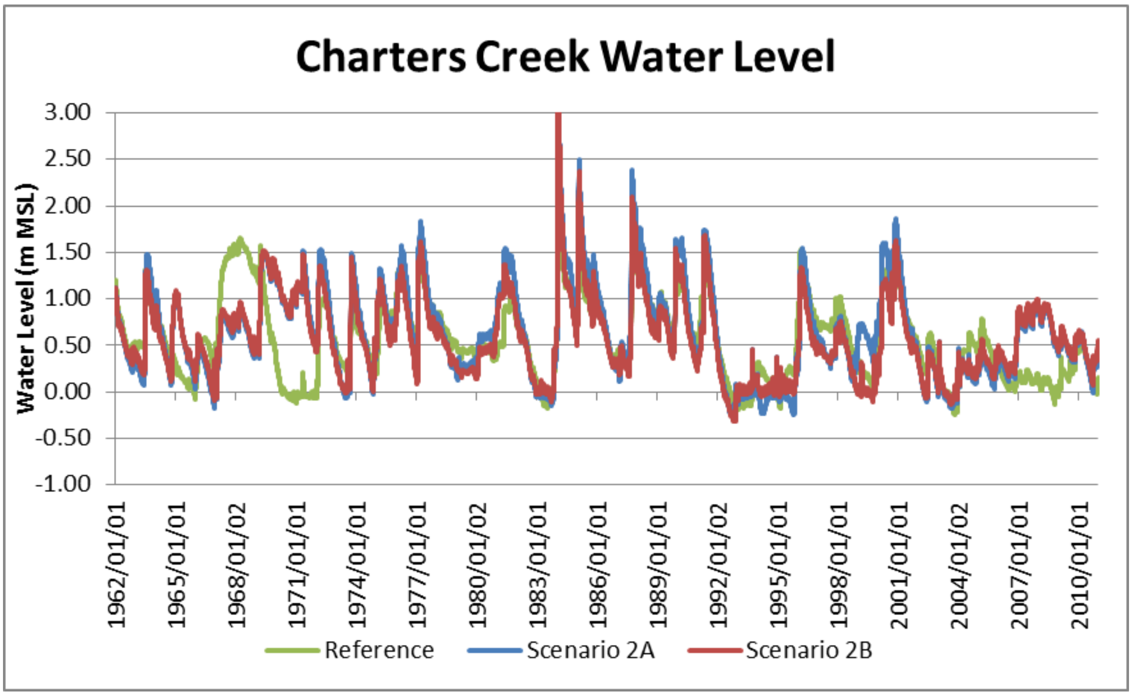

Figure E-17 Charters Creek Water Level (Scenario 2: One Mouth – A and B)

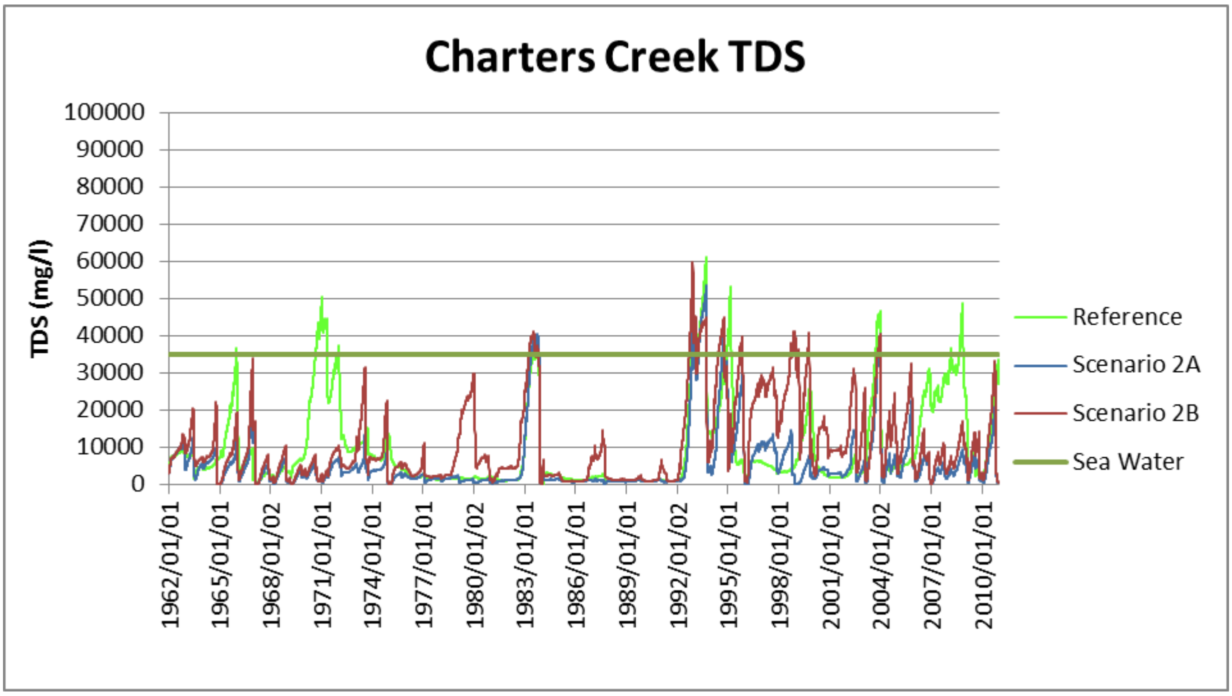

Figure E-18 Charters Creek TDS (Scenario 2: One Mouth – A and B)

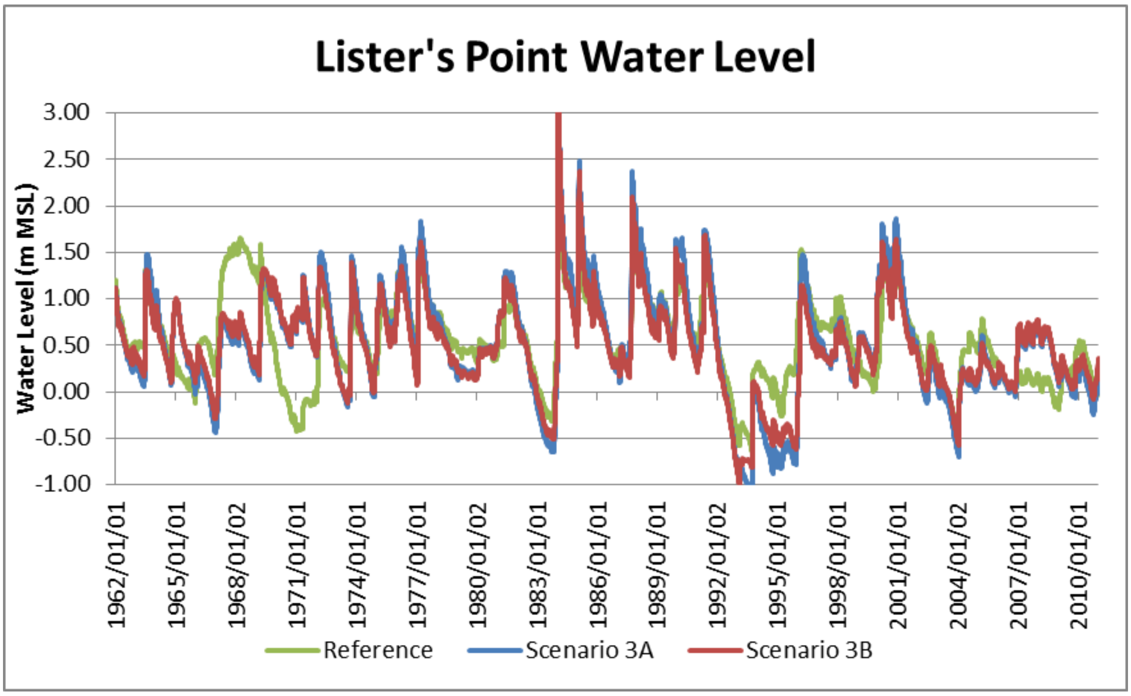

Figure E-19 Lister's Point Water Level (Scenario 3: One Mouth – A and B)

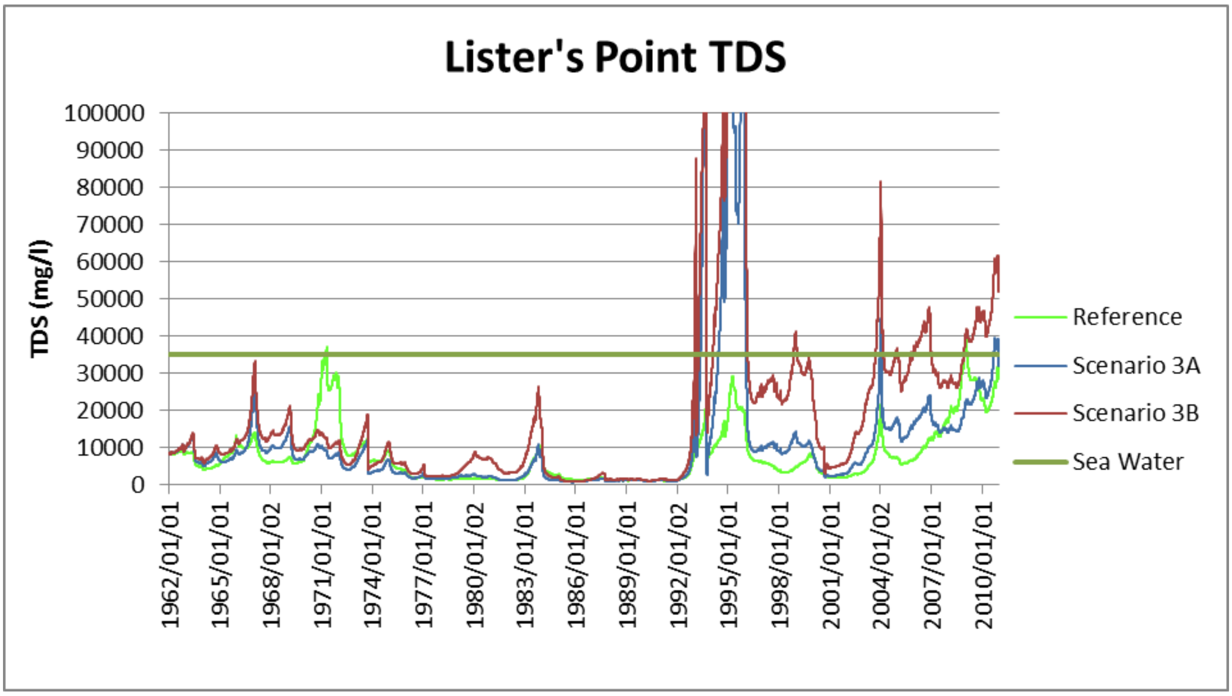

Figure E-20 Lister's Point TDS (Scenario 3: One Mouth – A and B)

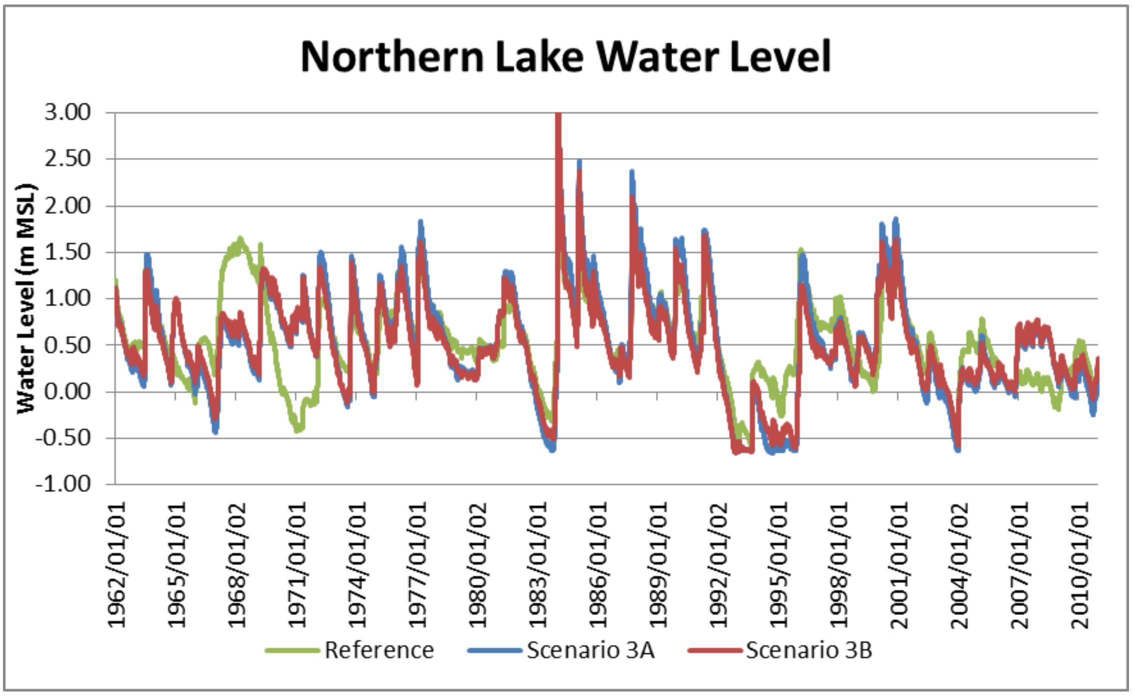

Figure E-21 Northern Lake Water Level (Scenario 3: One Mouth – A and B)

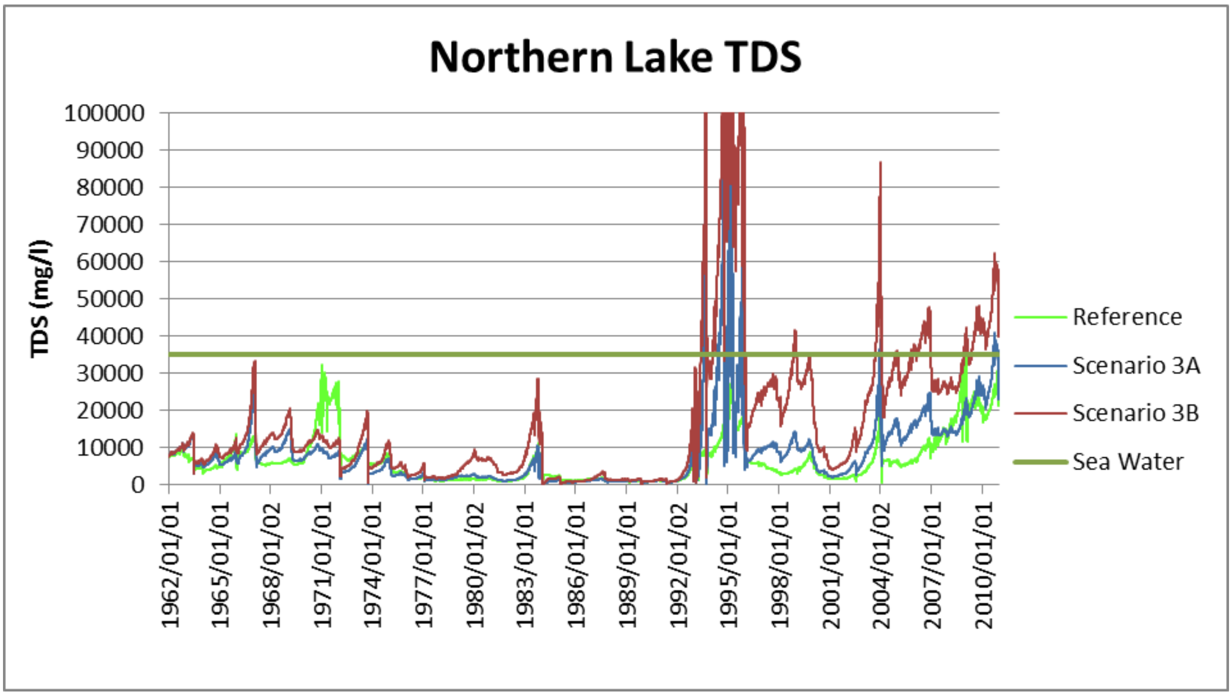

Figure E-22 Northern Lake TDS (Scenario 3: One Mouth – A and B)

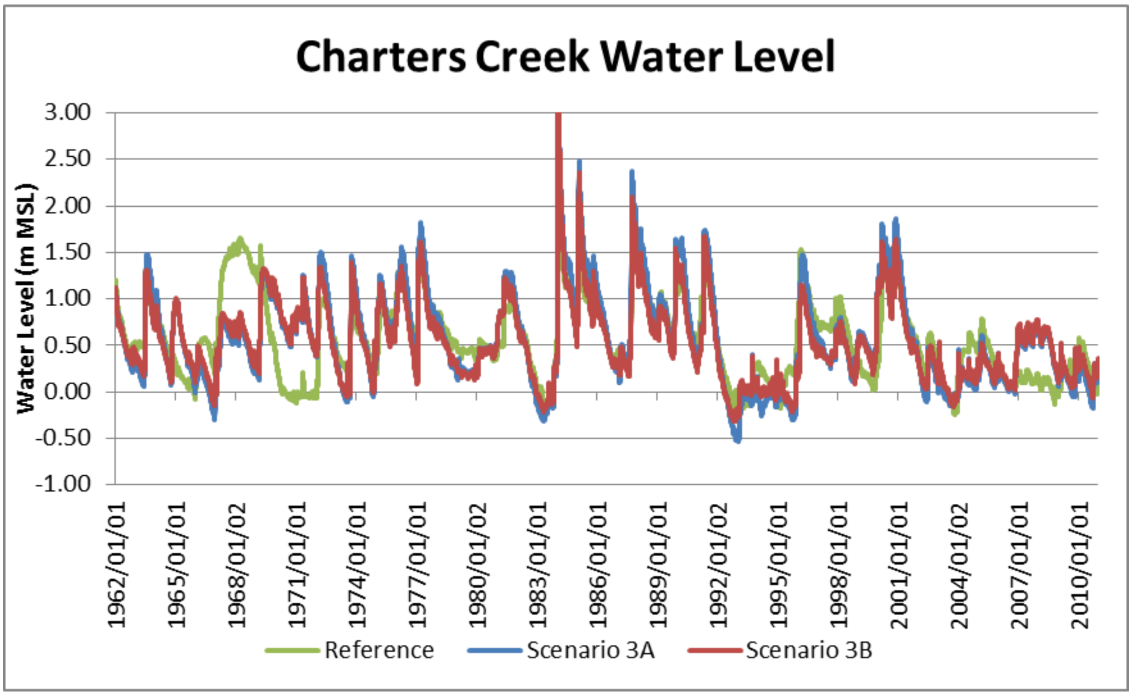

Figure E-23 Charters Creek Water Level (Scenario 3: One Mouth – A and B)

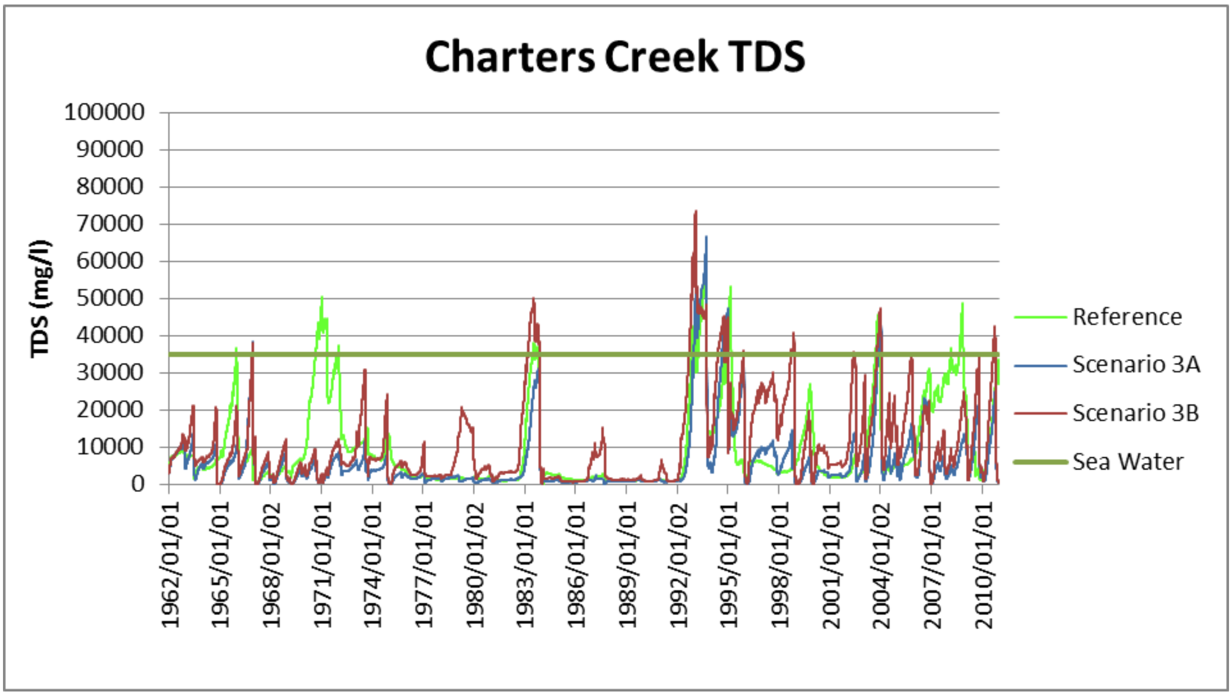

Figure E-24 Charters Creek TDS (Scenario 3: One Mouth – A and B)

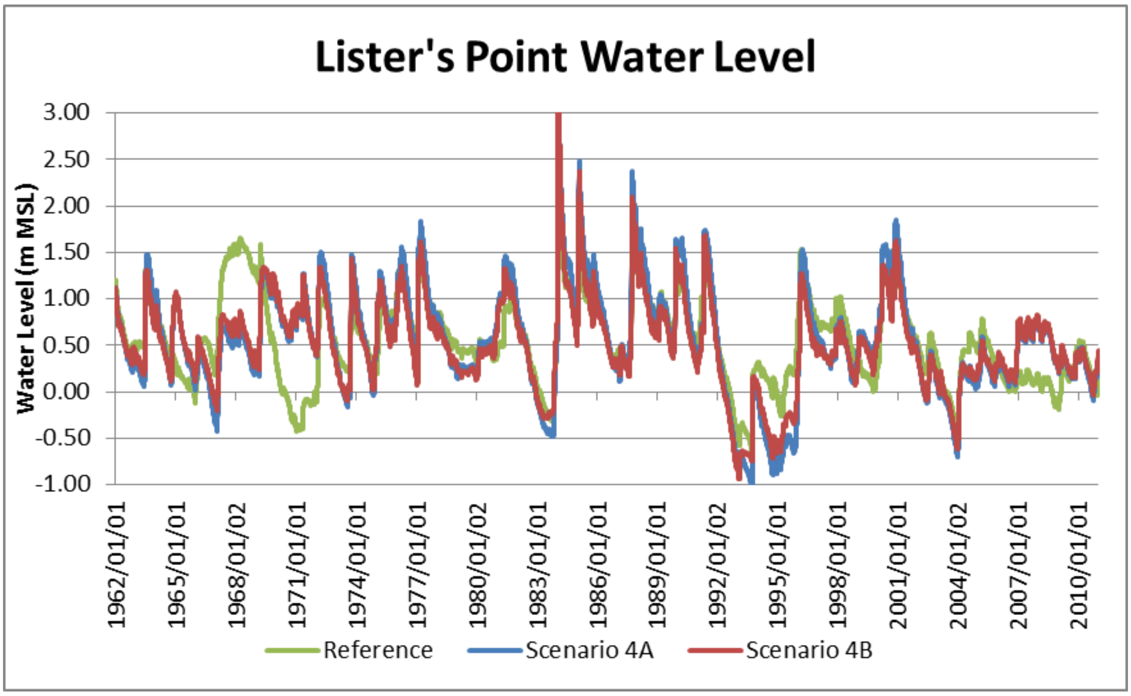

Figure E-25 Lister's Point Water Level (Scenario 4: One Mouth – A and B)

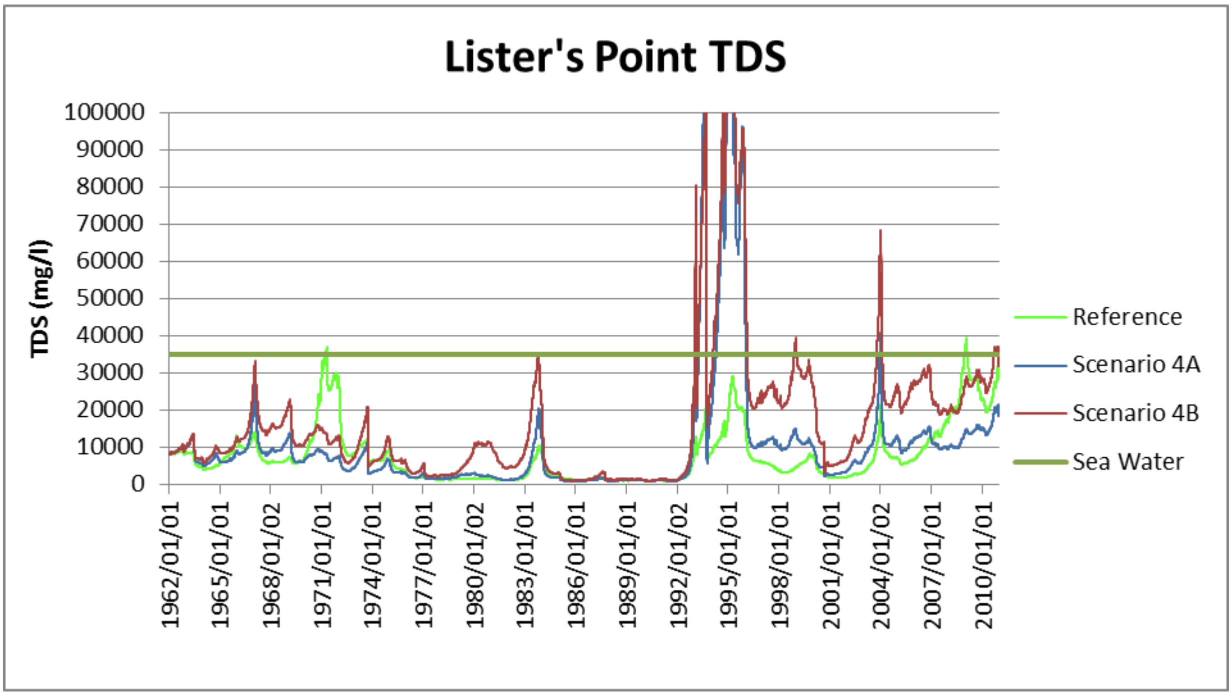

Figure E-26 Lister's Point TDS (Scenario 4: One Mouth – A and B)

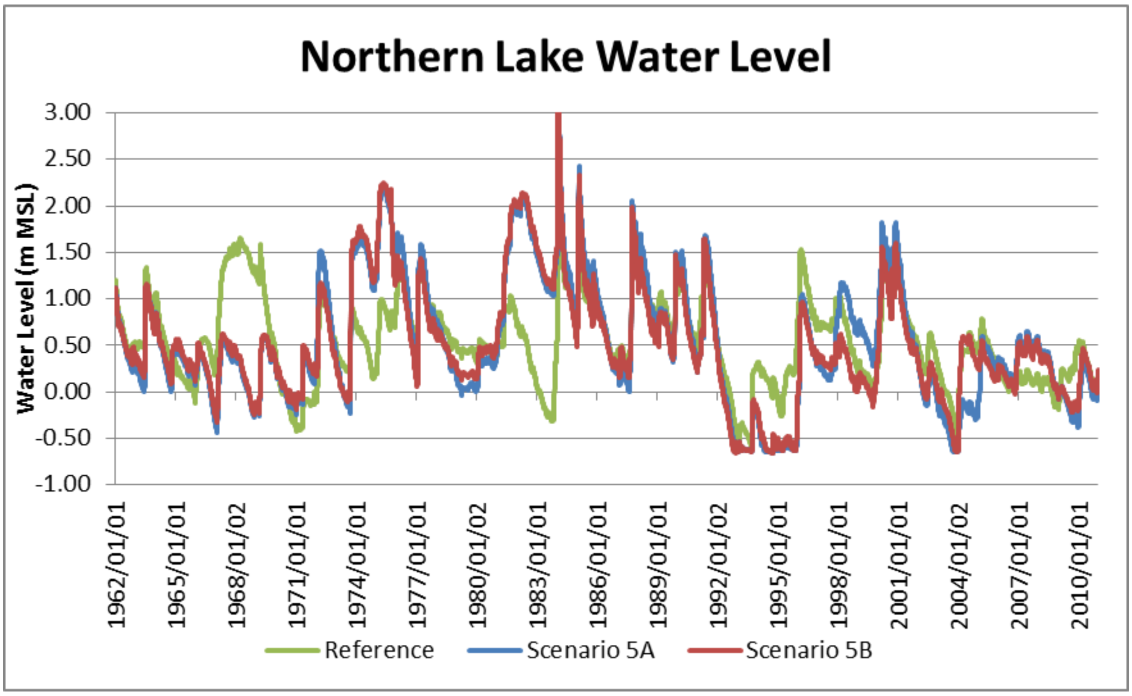

Figure E-27 **Northern Lake Water Level (Scenario 4: One Mouth – A and B)**

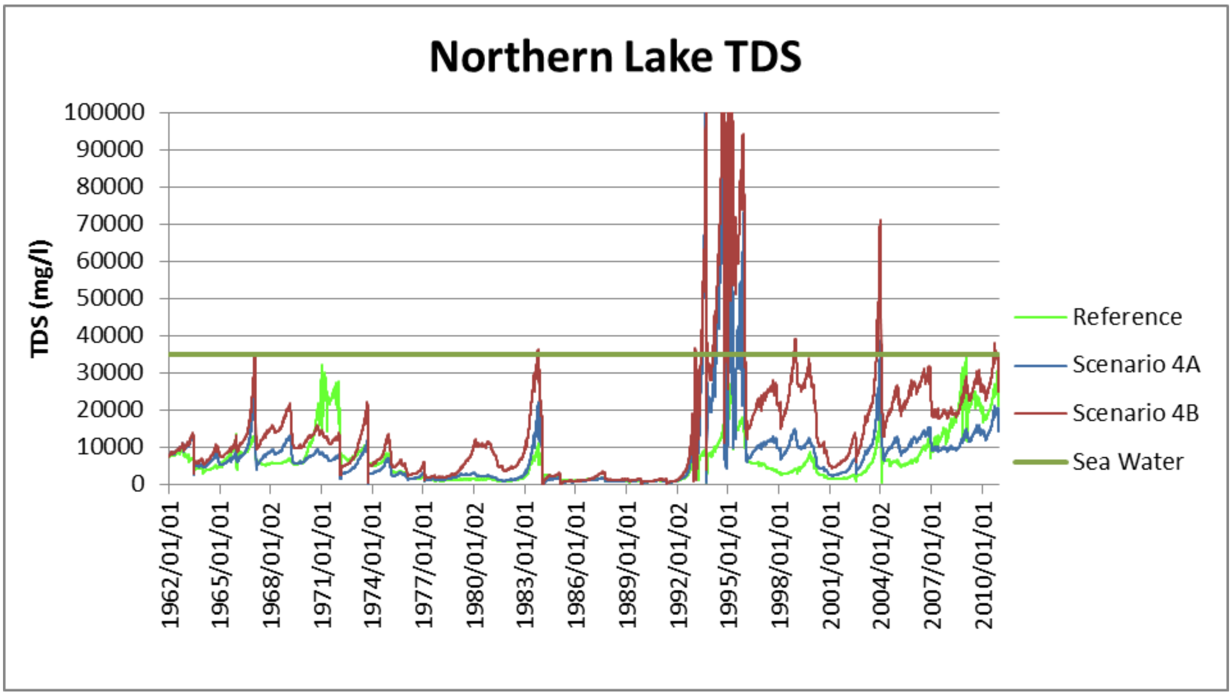

Figure E-28 **Northern Lake Water Level (Scenario 4: One Mouth – A and B)**

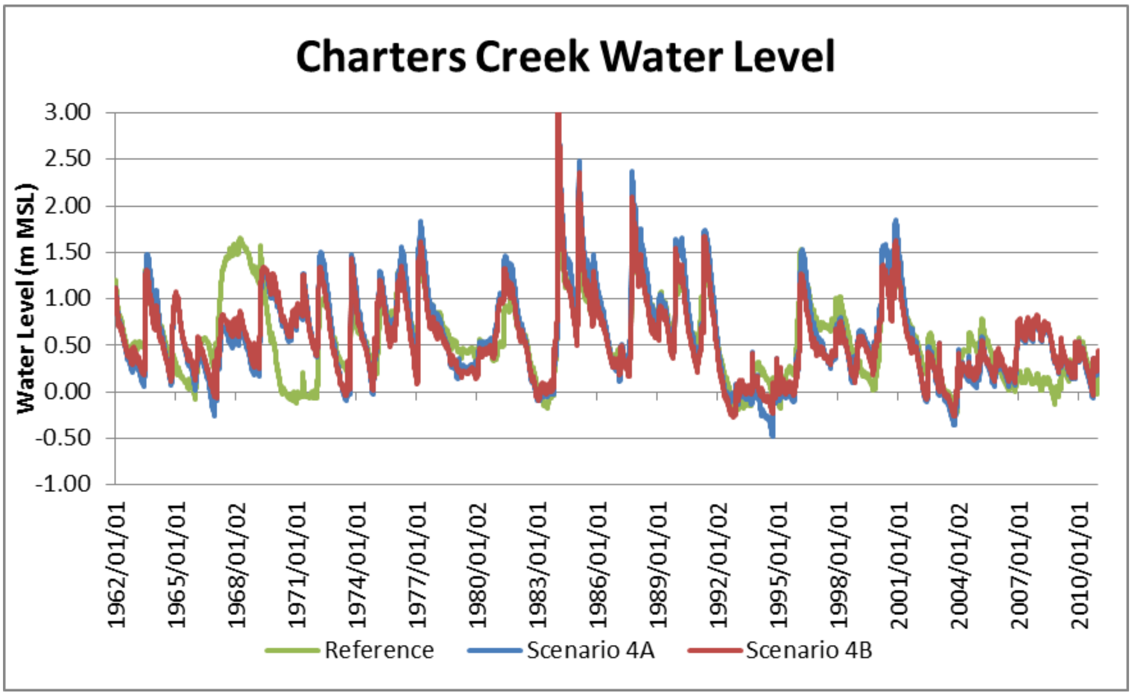

Figure E-29 **Charters Creek Water Level (Scenario 4: One Mouth – A and B)**

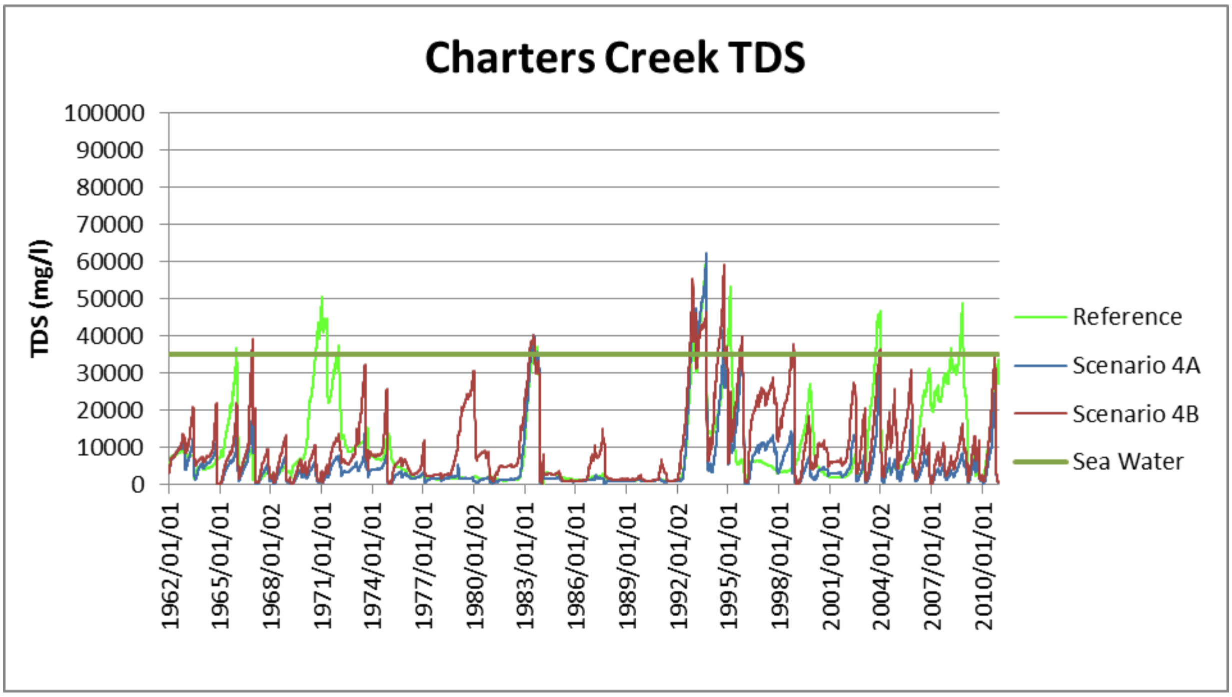

Figure E-30 **Charters Creek TDS (Scenario 4: One Mouth – A and B)**

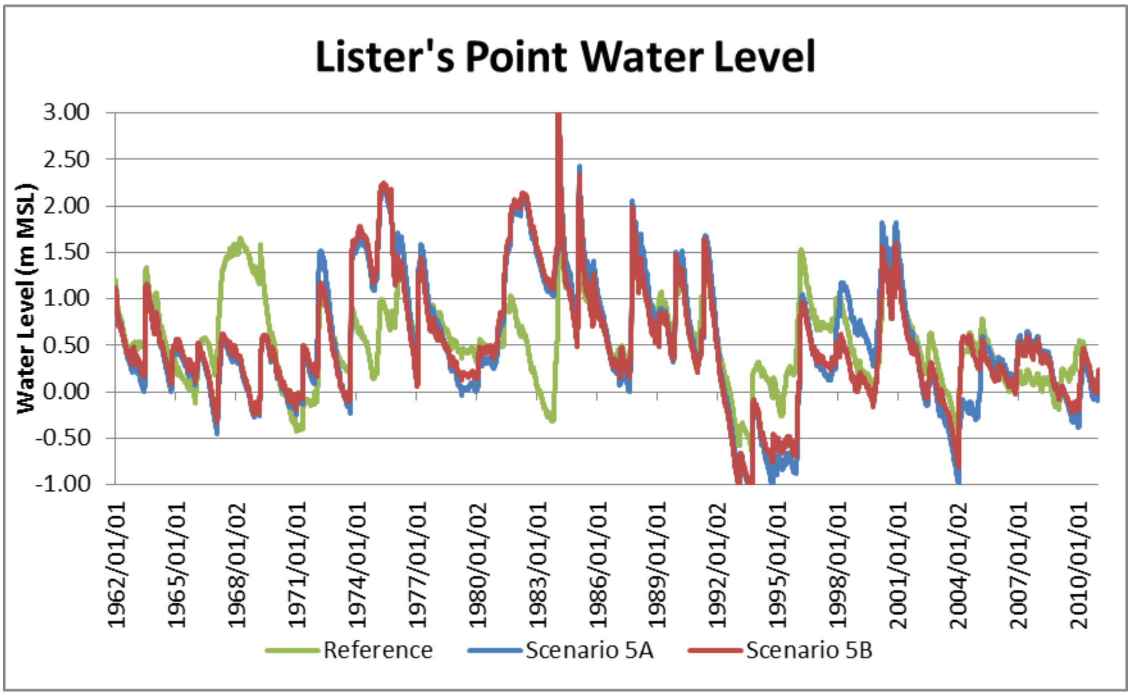

Figure E-31 Lister's Point Water Level (Scenario 5: One Mouth – A and B)

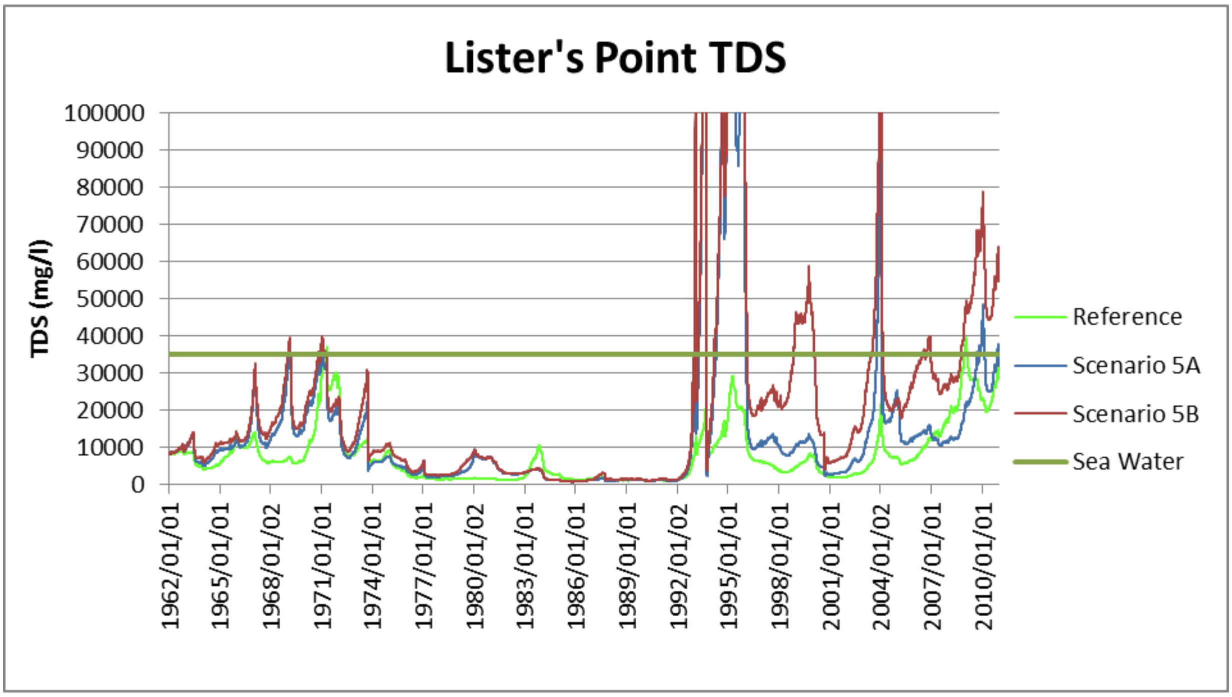

Figure E-32 Lister's Point TDS (Scenario 5: One Mouth – A and B)

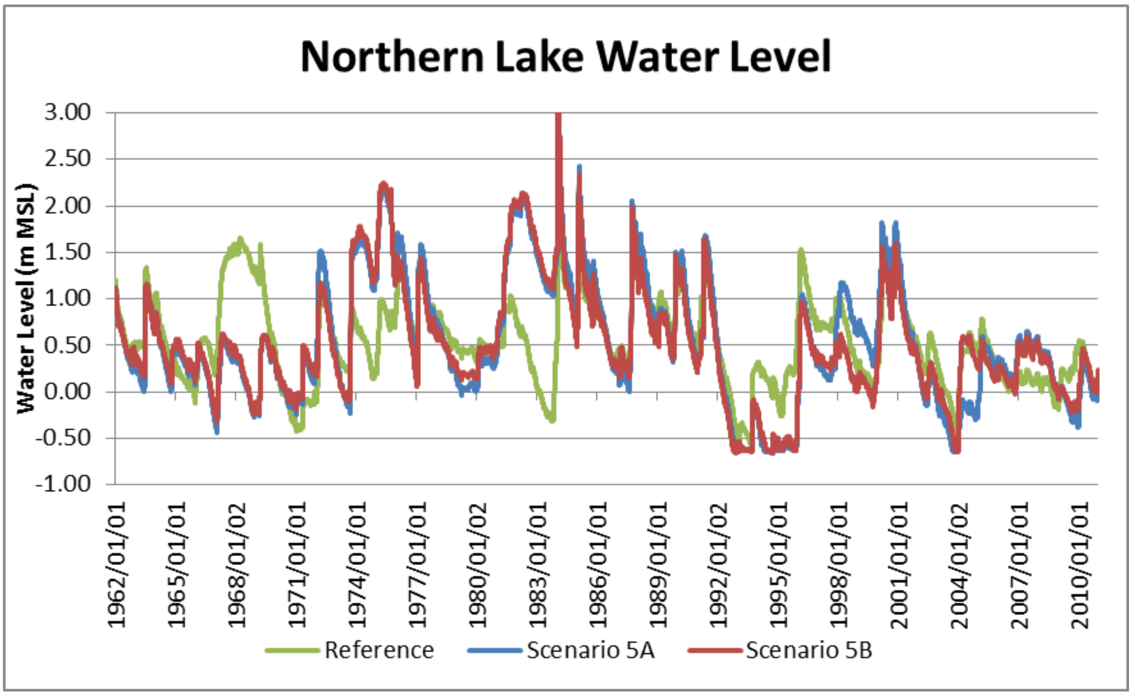

Figure E-33 Northern Lake Water Level (Scenario 5: One Mouth – A and B)

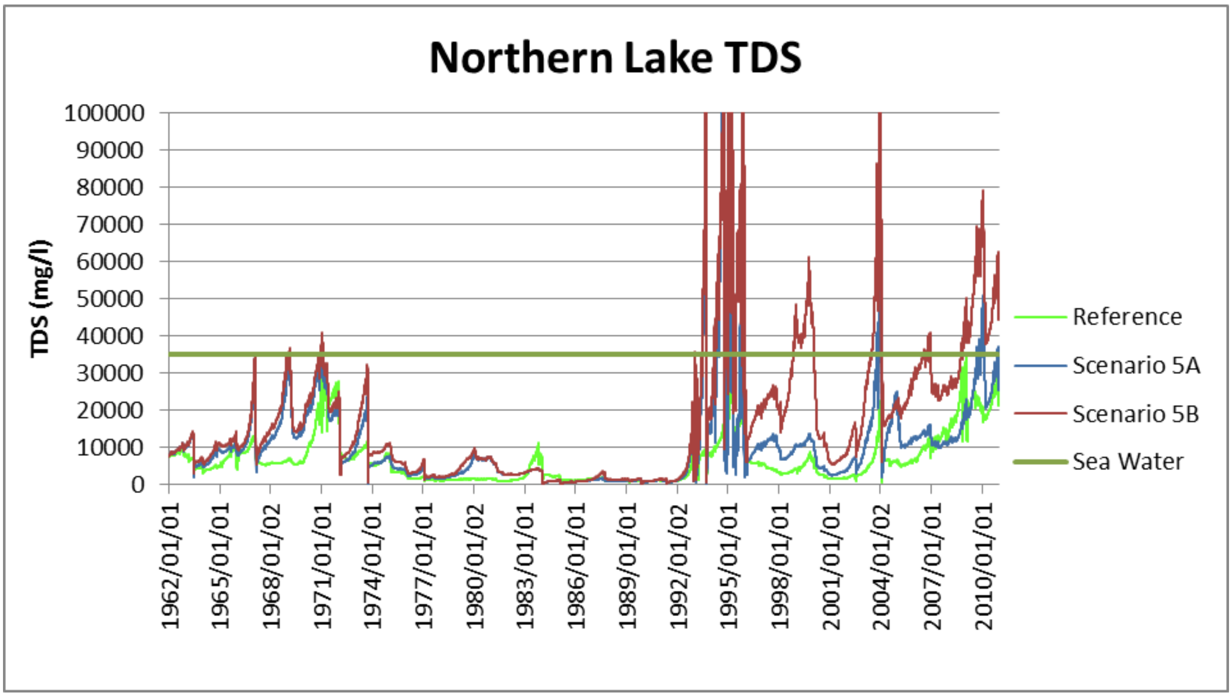

Figure E-34 Northern Lake TDS (Scenario 5: One Mouth – A and B)

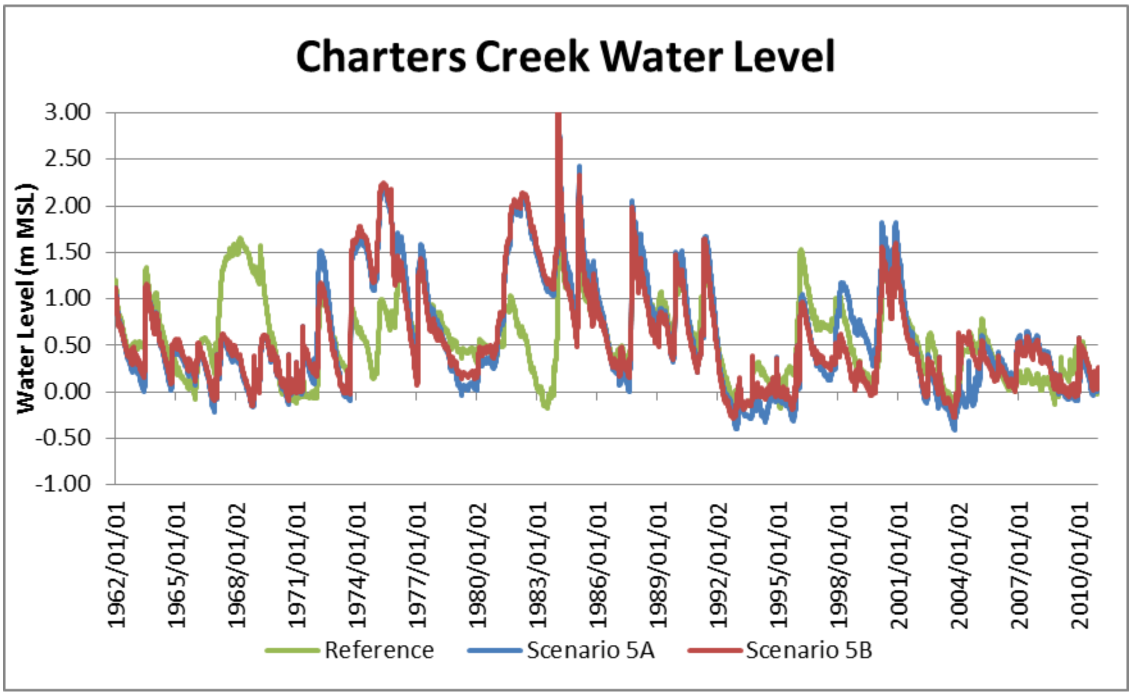

Figure E-35 **Charters Creek Water Level (Scenario 5: One Mouth – A and B)**

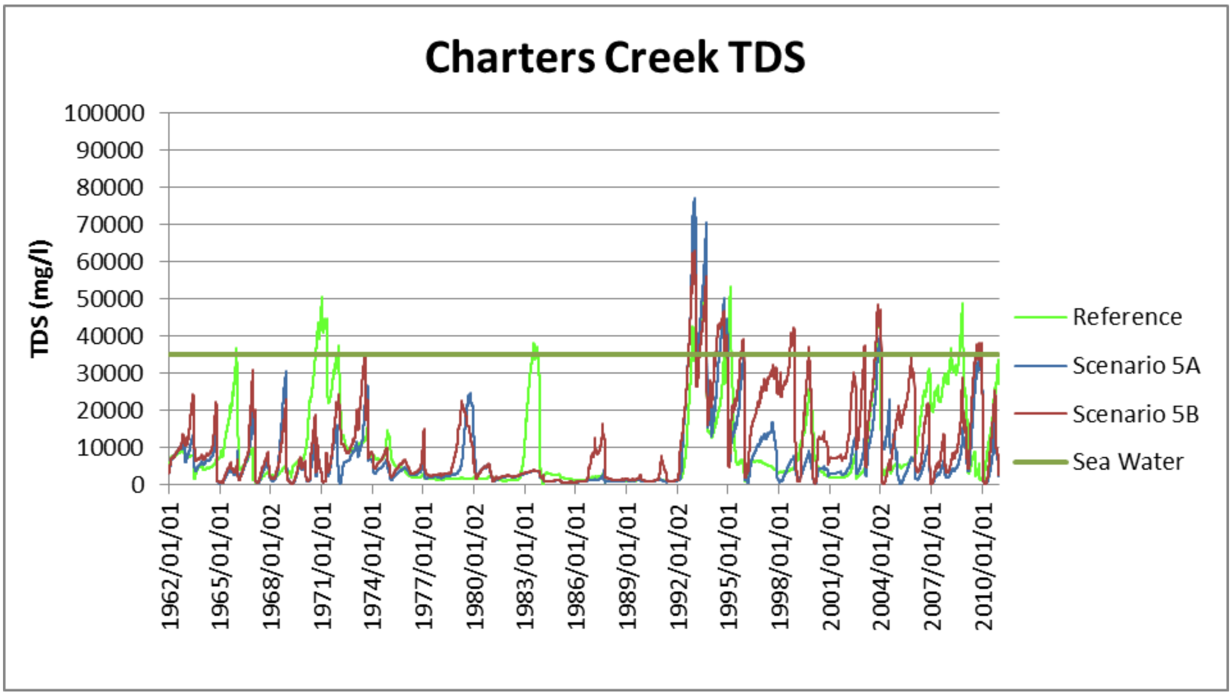

Figure E-36 **Charters Creek TDS (Scenario 5: One Mouth – A and B)**

14 APPENDIX F WIND FETCH LENGTHS IN LAKE ST LUCIA

Fetch lengths were determined at the following locations in the Lake:

a) Opposite Lister's Point in False Bay
b) Northern Lake
c) Opposite Charters Creek in the Southern Lake

Locations in the lake

Site name	**Lo 33**		**UTM**
	X	**Y**	
Lister's Point	-59717	-3097313	36 J 440307 6903926
Northern Lake	-49968	-3089639	36 J 450052 6911597
Charters Creek	-55945	-3121740	36 J 444077 6879509

Table F.1 Fetch lengths opposite Lister's Point (m)

	Water levels (m MSL)																
Wind directions	**-1.00**	**-0.75**	**-0.50**	**-0.25**	**0.00**	**0.25**	**0.50**	**0.75**	**1.00**	**1.25**	**1.50**	**1.75**	**2.00**	**2.25**	**2.50**	**2.75**	**3.00**
N	7433	8302	8634	8697	8727	8757	8844	8873									8979
NNE	4605	4979	5116	5223	5248												5302
NE	2814	3105	3150	3184	3215	3238	3318	3371									3409
ENE	1492	1645	1772	1915	1975	2011	2061										2238
E	1280	1623	1857	2250	2360	2424	2475										2508
ESE	1881	3155	5544	7258	8837	9027	9246	9396	9469	9546							11646
SE	2514	3950	4124	4476	4556	4592	4734	4886	4941	5001	5202						5557
SSE	1359	2818	3184	3362	3428	3465	3503	3568	3603								3678
S	1756	3698	4180	4679	4745	4840	4912	4952									5213
SSW	3900	5325	5638	6092	6171	6254	6338	6419	8694								8739
SW	1663	2101	2356	3504	3605	3639	3661	3693	3725	3761	3808	3832					3925
WSW	1431	2083	2431	2593	2684	2721	2751	2768									2836
W	1358	2027	2250	2516	2634	2674	2715	2740									2874
WNW	1398	2159	2332	2441	2495	2551	2598	2658									2739
NW	1464	2361	2476	2544	2599	2630	2668										2700
NNWN	1836	2112	2145	2191	3514												3884

Table F.2 Fetch lengths opposite Charters Creek (m)

	Water levels (m MSL)																
Wind directions	**-1.00**	**-0.75**	**-0.50**	**-0.25**	**0.00**	**0.25**	**0.50**	**0.75**	**1.00**	**1.25**	**1.50**	**1.75**	**2.00**	**2.25**	**2.50**	**2.75**	**3.00**
N	986	1251	1608	1889	1927	1957	2022	3454	3488	3818							6739
NNE	1007	1353	1603	2001	2034	2900	2919	2946	2967	3907							10347
NE	1345	1577	1836	2239	2423	2843	2877	2915	2938	2971	3019	3070	3099	3112	3135	3165	3208
ENE	1600	2155	2423	2817	2896	2962	2991	3027	3051	3082	3106						3176
E	2685	3145	3274	3771	3945	4018	4089	4191	4255	4309	4342	4367					4468
ESE	4851	5461	5832	5951	5997	6024											6070
SE	3088	3290	3591	3849	4357	4970	5330	5372	5409	5453	5602	5637	5673	5694			5746
SSE	1611	1975	2027	2313	2646	5111	5146	5874	6148	6181	6565	6613	6642				6674
S	836	1098	1446	1716	2197	3155	3183	3202	3559			3751	3799	3839	7160	7829	8069
SSW	836	1132	1465	1723	1756	1780	1795	1804	1811	1914	2041	2079	2371	2426			2827
SW	923	989	1263	1263													1669
WSW	875	952	1005	1079	1112												1182
W	141	272	314	998	1039	1064											1116
WNW	688	751	1155	1185	1211												1309
NW	725	1169	1233	1297	1354	1412	1719	1736									2039
NNW	820	1494	1803	1826	1857	1885	1906	1929	1950	1970							2129

Table F.3 Fetch lengths at Northern Lake (m)

	Water levels (m MSL)																
Wind directions	**-1.00**	**-0.75**	**-0.50**	**-0.25**	**0.00**	**0.25**	**0.50**	**0.75**	**1.00**	**1.25**	**1.50**	**1.75**	**2.00**	**2.25**	**2.50**	**2.75**	**3.00**
N			1639	2932	2983	4300	4343	4579	4621	4624	4789	7200	7194	7454	7504	7793	7862
NNE			1755	2041	2166	2267	2359	2440	2484	2752	2789	6005	6029	6051	6083	6099	6132
NE			1773	2002	2099	2128	2173	2223	2255	2294	2352	4502	6112	6636	6745	6820	6887
ENE			1428	1502	1532	1554	1584	1610	1681	6104	6938	7995	8283				8283
E			1376	1453	1533	1576	1641	1860	1927	2015	2114	2184	2255	2355			8551
ESE			5795	6350	6413	6461	6500	6539	9144	9207	9339						9374
SE		7581	8830	9354	9437	9489	9526	9582	9632	9744							9844
SSE		3022	265	3535	3566	3602	7721	8368	8416	8468	8512	8566	8616	8682	8759	8806	10485
S		2532	2899	3173	3499	3582	3661	3809	3842	3880	11356	11398	12039	19665	19693	19716	19746
SSW			2333	2941	3120	3146	11549										11772
SW		3845	4052	4217	4269												4457
WSW			2606	2803	2869	2905											2968
W			1800	2356	2418	2441	2481										2531
WNW			1503	2254	2332	2379	2405	2432	2457	2475							2547
NW			1451	2629	2689	2717	2756	2787	2810								2909
NNW			1745	2832	2882	2909	3614	3901									4167

15 APPENDIX G SIMULATED SUSPENDED SEDIMENT TIME SERIES GRAPHS AT LISTER'S POINT, NORTHERN LAKE AND CHARTERS CREEK IN LAKE ST LUCIA (DAILY DATA PLOTTED) – SCENARIO A

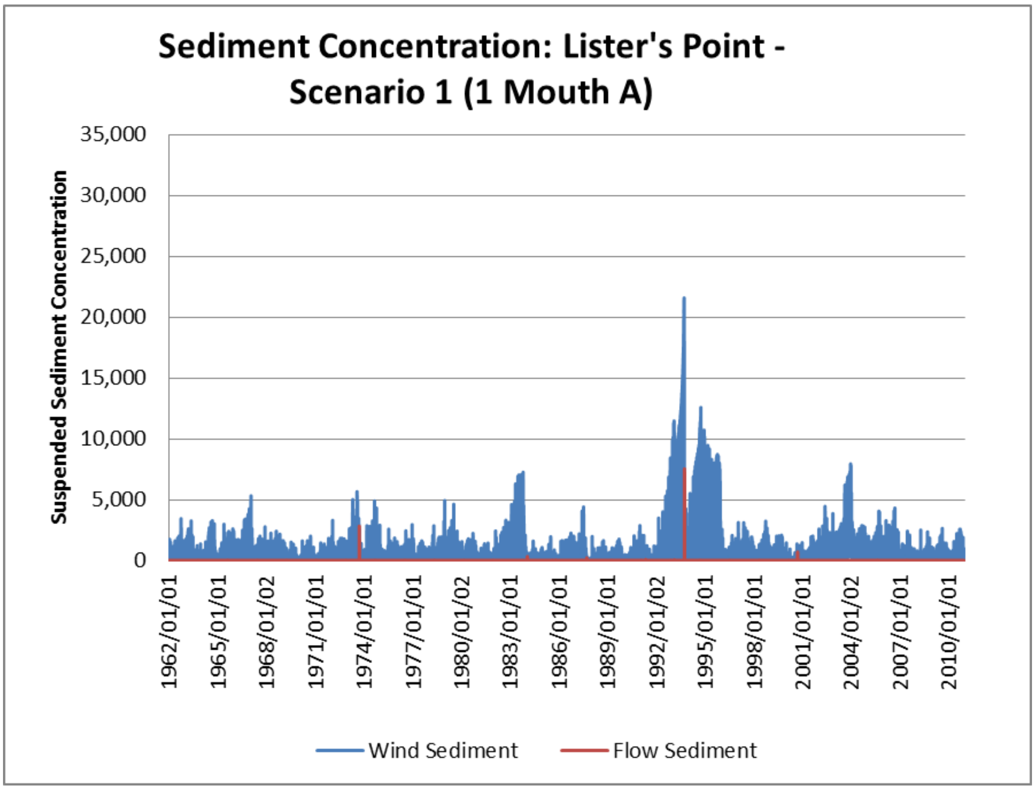

Figure G-1 **Suspended sediment concentration time series (daily data) at Lister's Point: Baseline A**

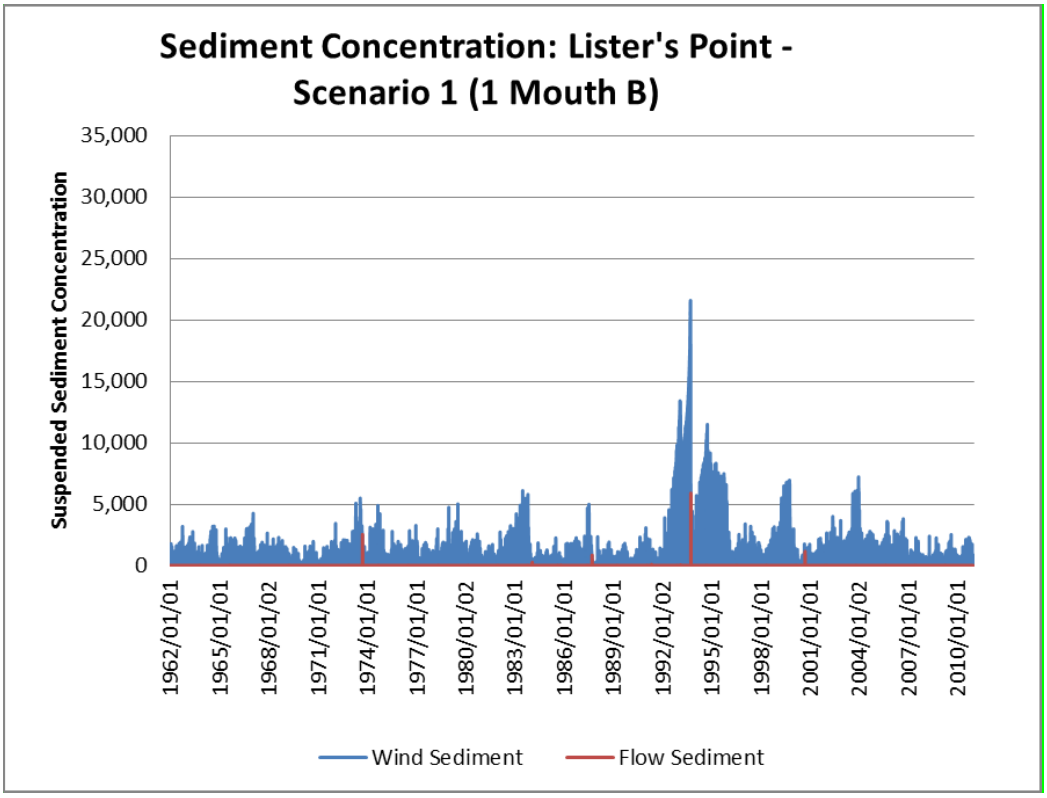

Figure G-2 Suspended sediment concentration time series (daily data) at Lister's Point: Baseline B

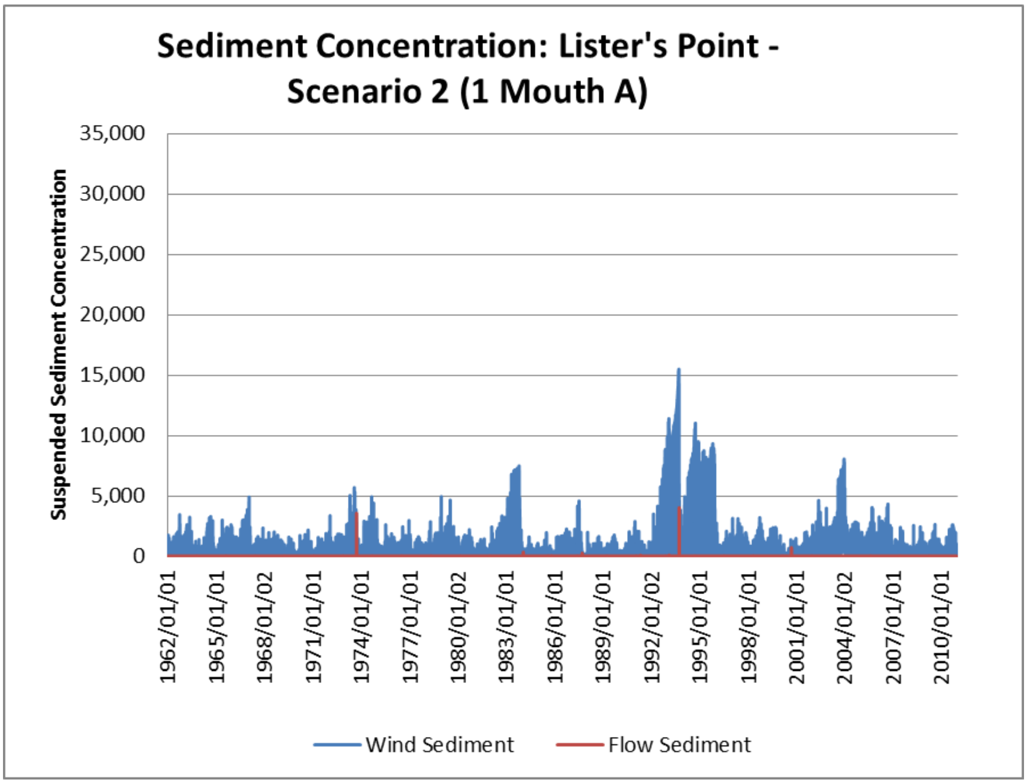

Figure G-3 Suspended sediment concentration time series (daily data) at Lister's Point: Scenario 1 A

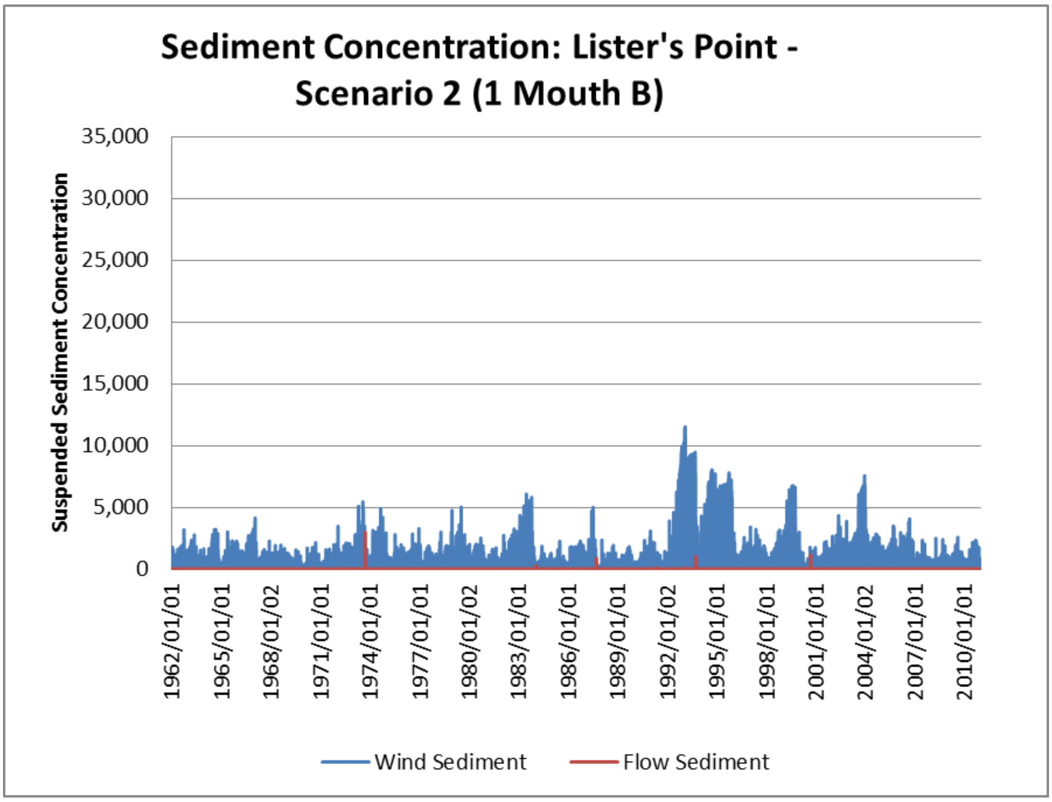

Figure G-4 **Suspended sediment concentration time series (daily data) at Lister's Point: Scenario 1 B**

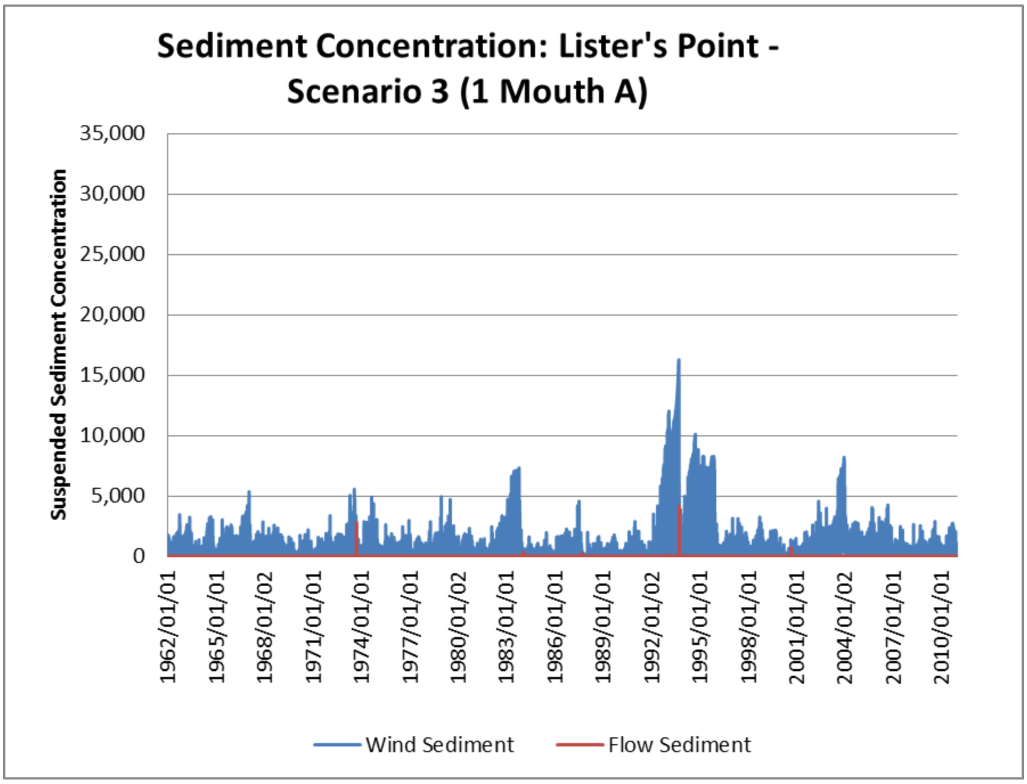

Figure G-5 **Suspended sediment concentration time series (daily data) at Lister's Point: Scenario 2 A**

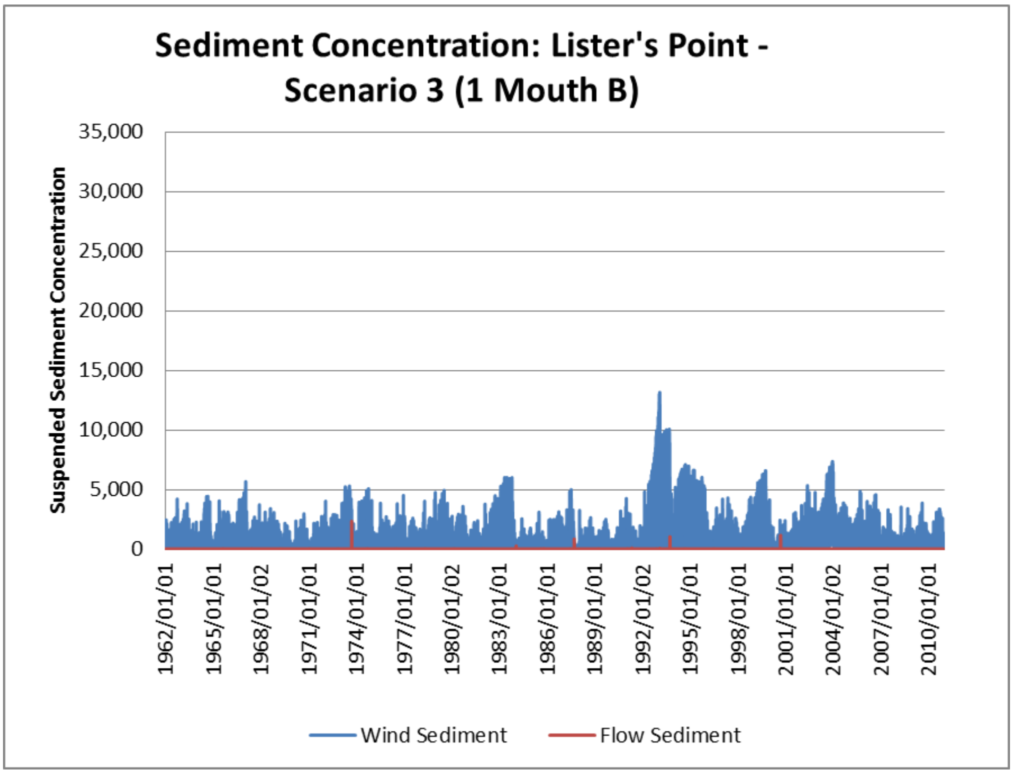

Figure G-6 Suspended sediment concentration time series (daily data) at Lister's Point: Scenario 2 B

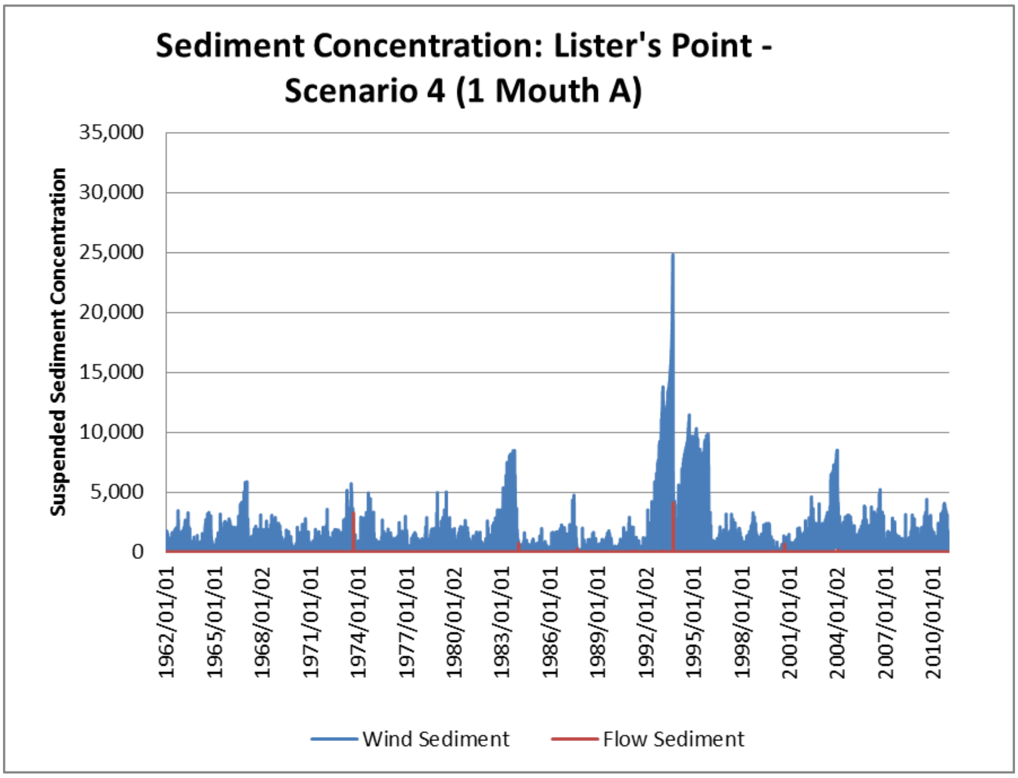

Figure G-7 Suspended sediment concentration time series (daily data) at Lister's Point: Scenario 3 A

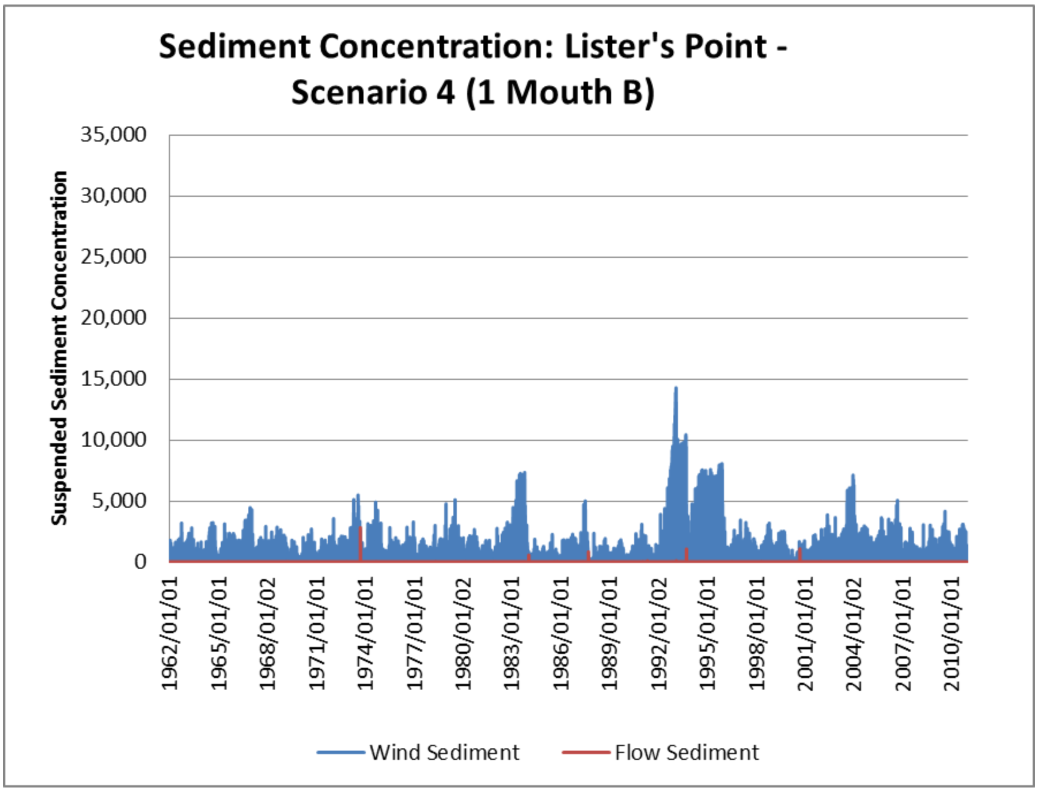

Figure G-8 **Suspended sediment concentration time series (daily data) at Lister's Point: Scenario 3 B**

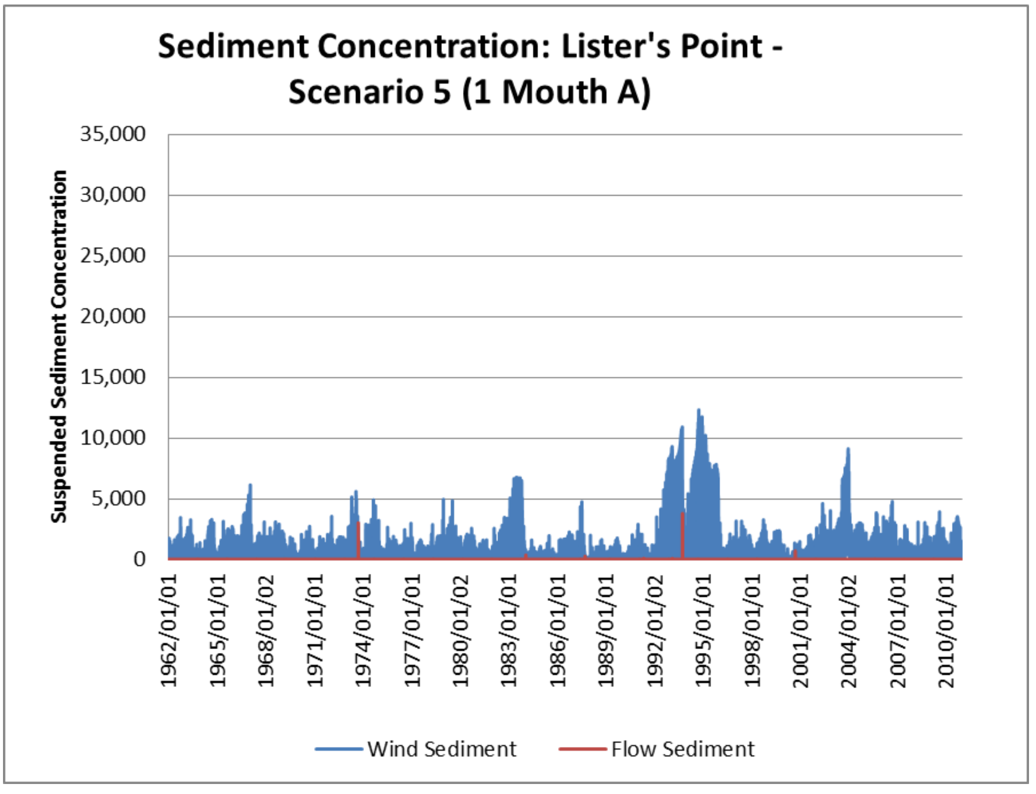

Figure G-9 **Suspended sediment concentration time series (daily data) at Lister's Point: Scenario 4 A**

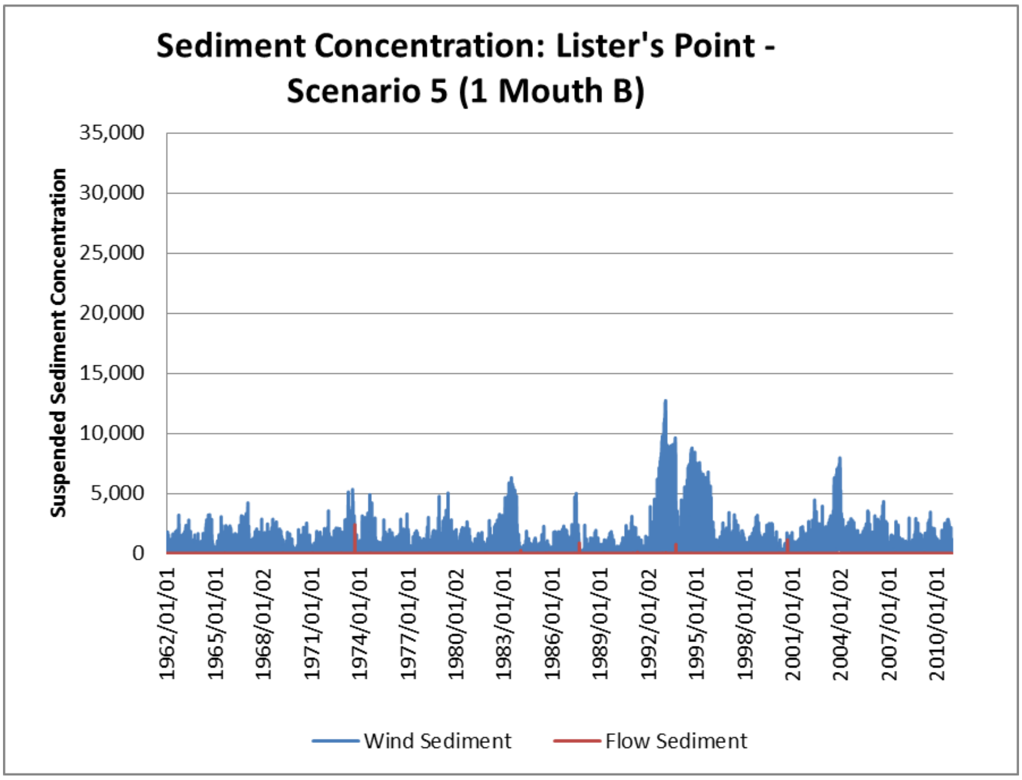

Figure G-10 Suspended sediment concentration time series (daily data) at Lister's Point: Scenario 4 B

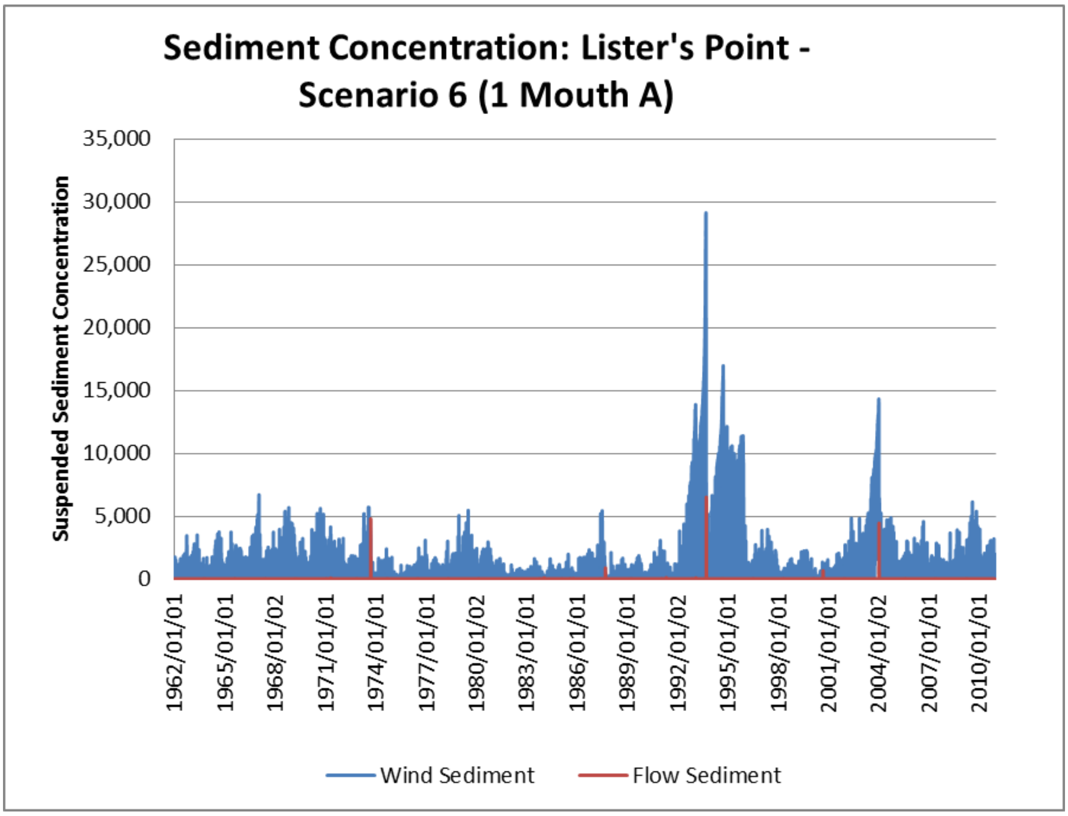

Figure G-11 Suspended sediment concentration time series (daily data) at Lister's Point: Scenario 5 A

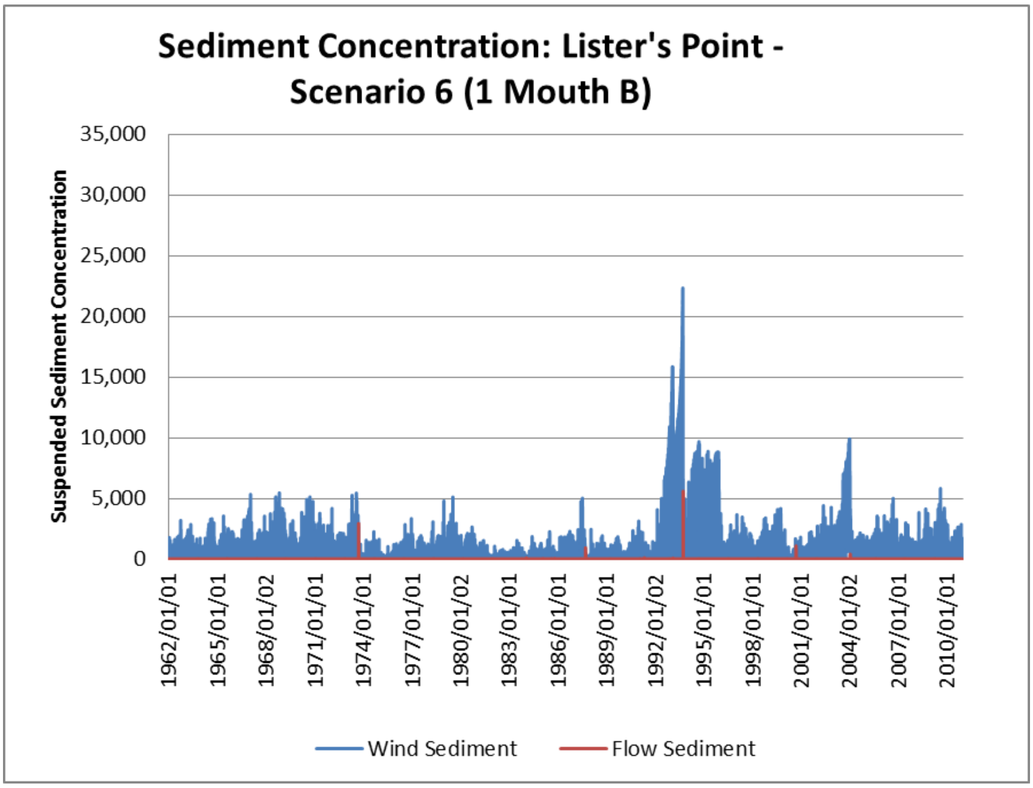

Figure G-12 Suspended sediment concentration time series (daily data) at Lister's Point: Scenario 5 B

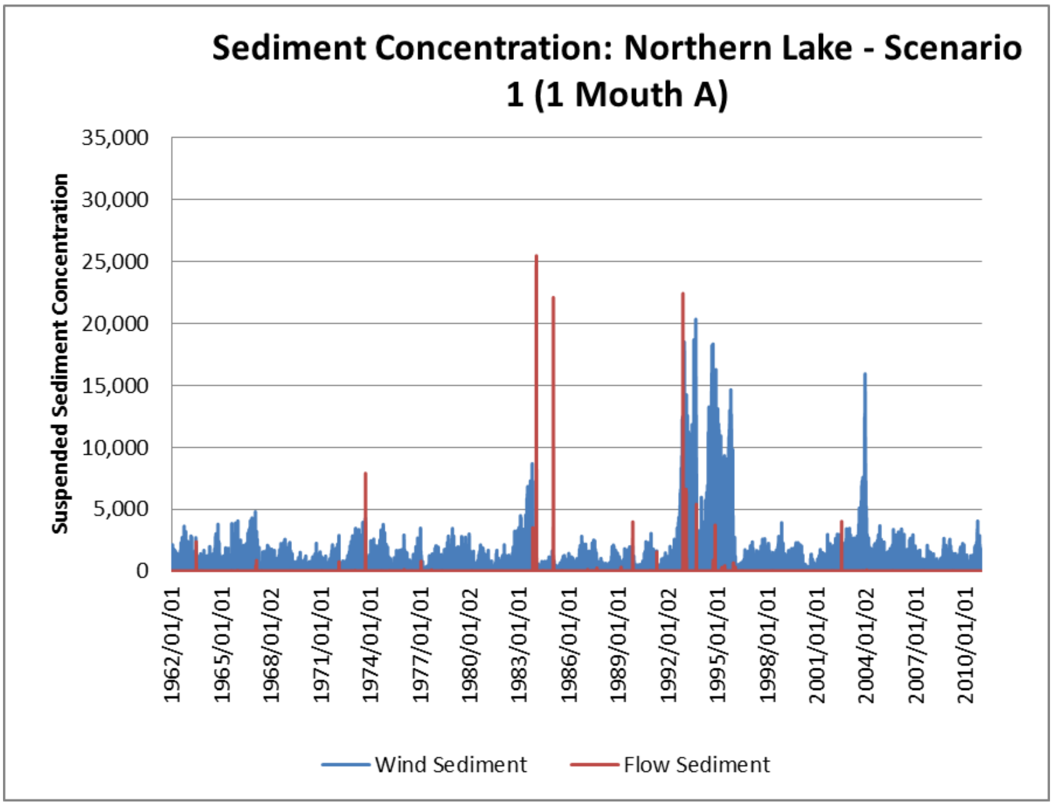

Figure G-13 Suspended sediment concentration time series (daily data) at Northern Lake: Baseline A

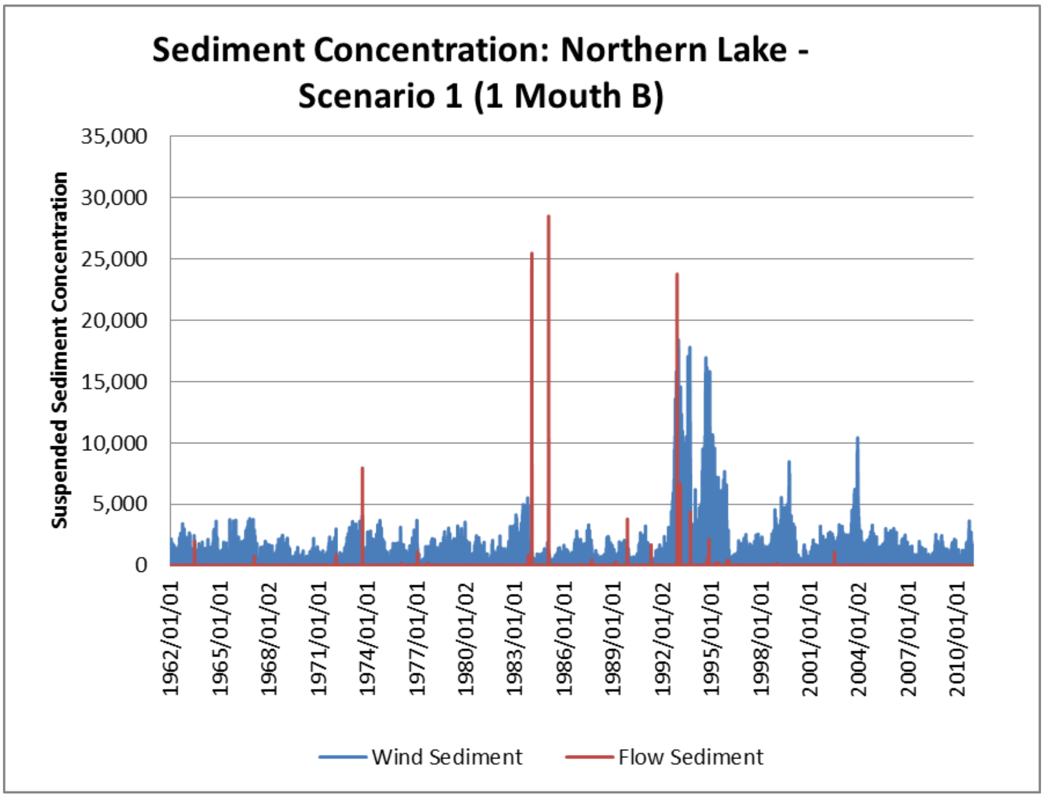

Figure G-14 **Suspended sediment concentration time series (daily data) at Northern Lake: Baseline B**

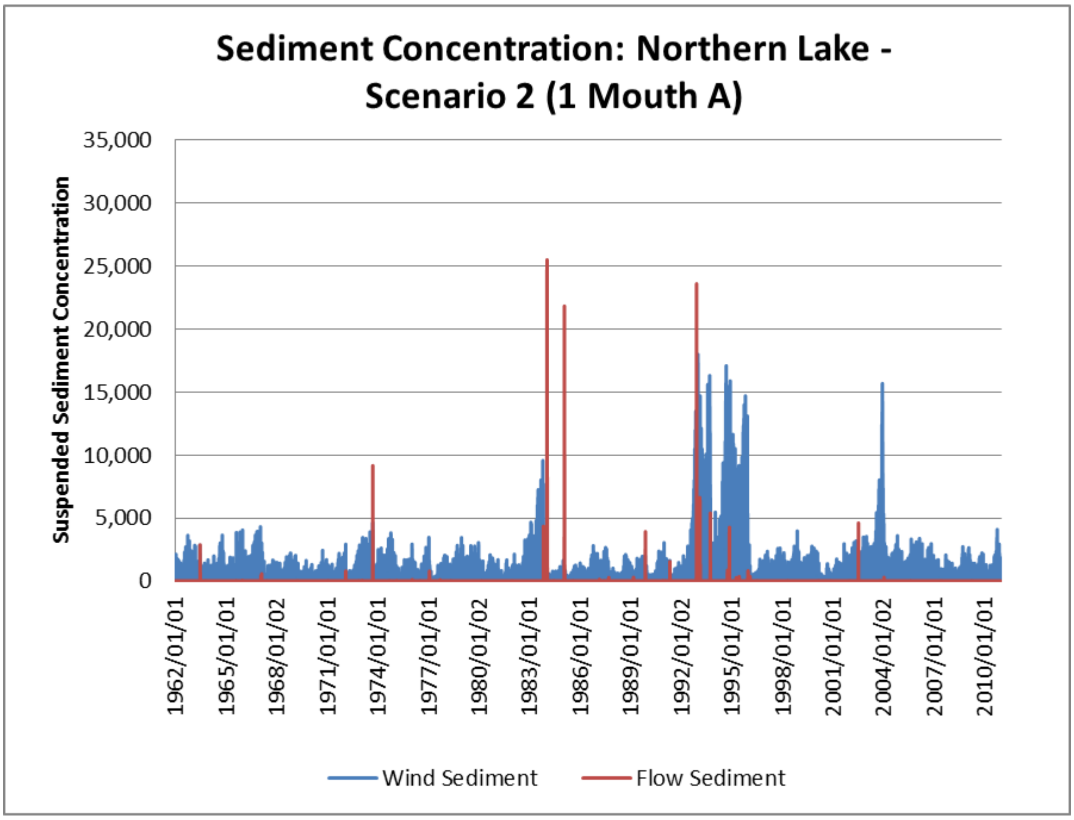

Figure G-15 **Suspended sediment concentration time series (daily data) at Northern Lake: Scenario 1 A**

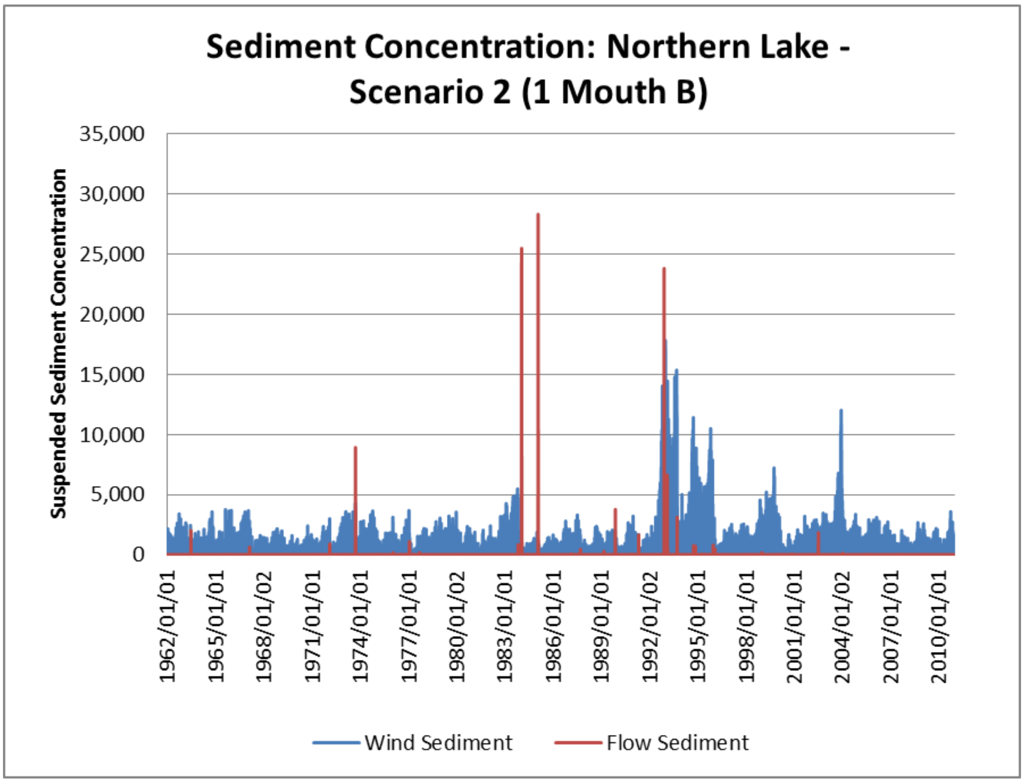

Figure G-16 Suspended sediment concentration time series (daily data) at Northern Lake: Scenario 1 B

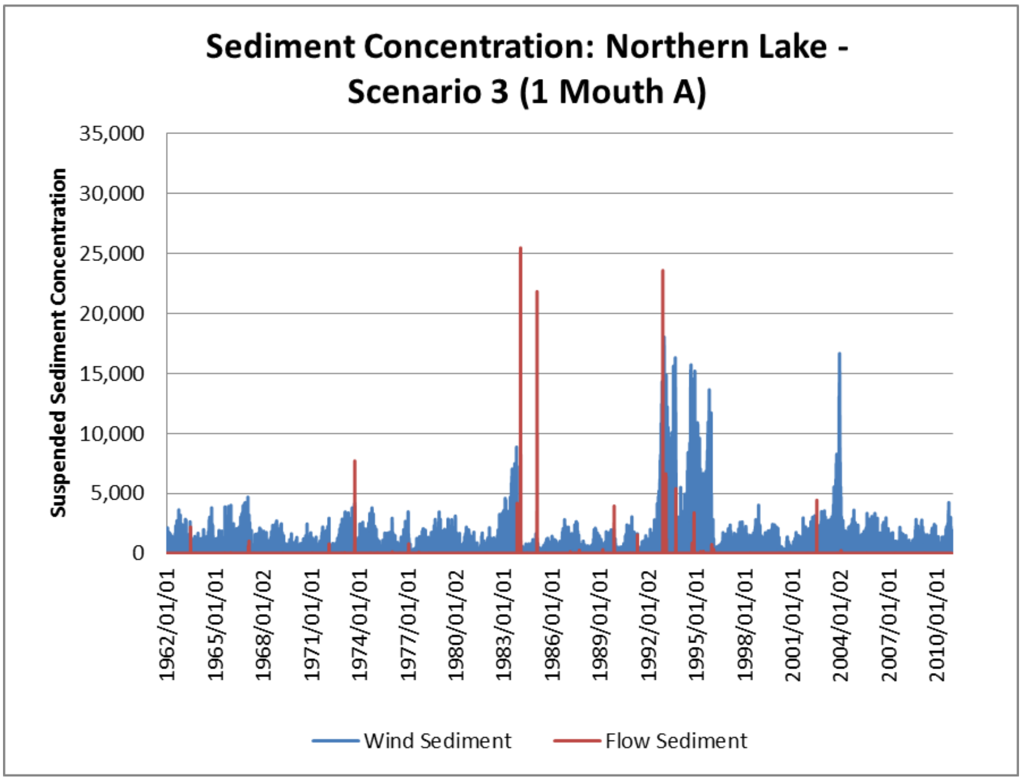

Figure G-17 Suspended sediment concentration time series (daily data) at Northern Lake: Scenario 2 A

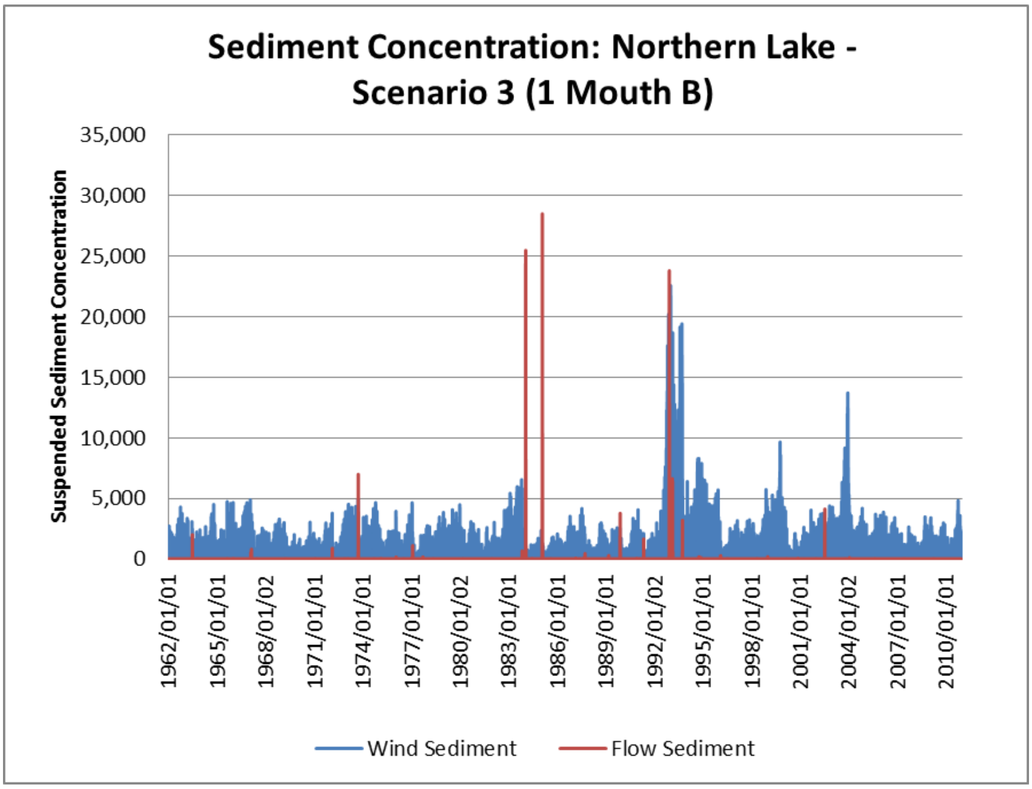

Figure G-18 Suspended sediment concentration time series (daily data) at Northern Lake: Scenario 2 B

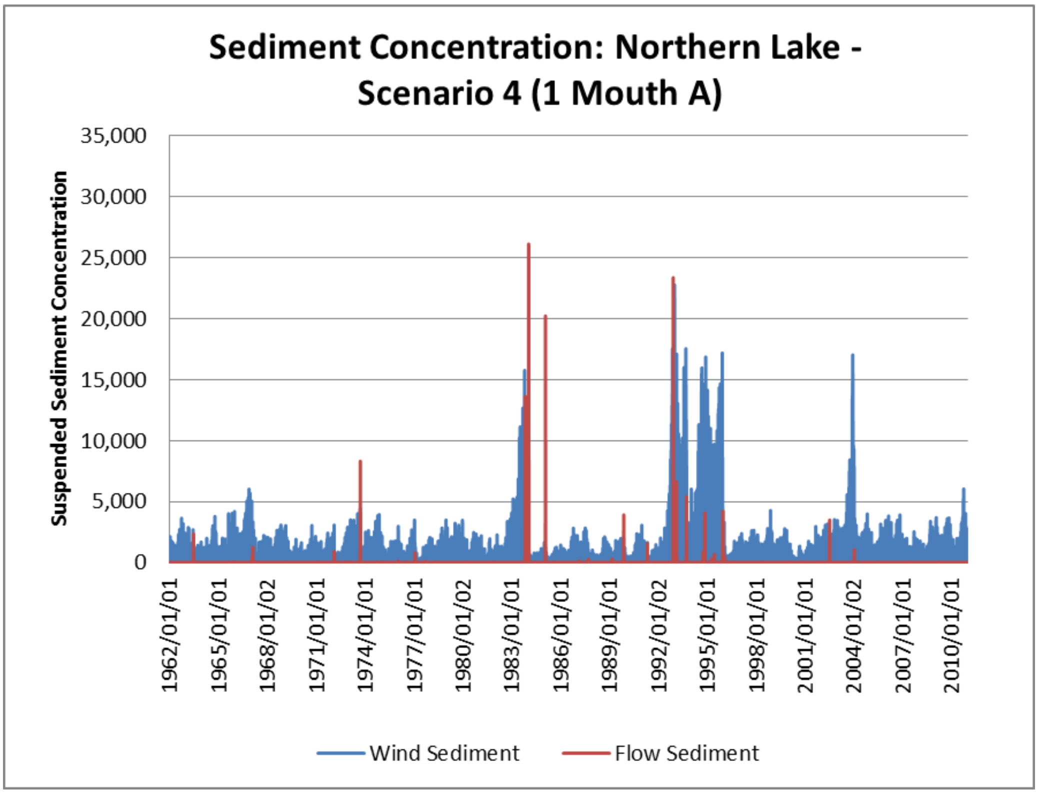

Figure G-19 Suspended sediment concentration time series (daily data) at Northern Lake: Scenario 3 A

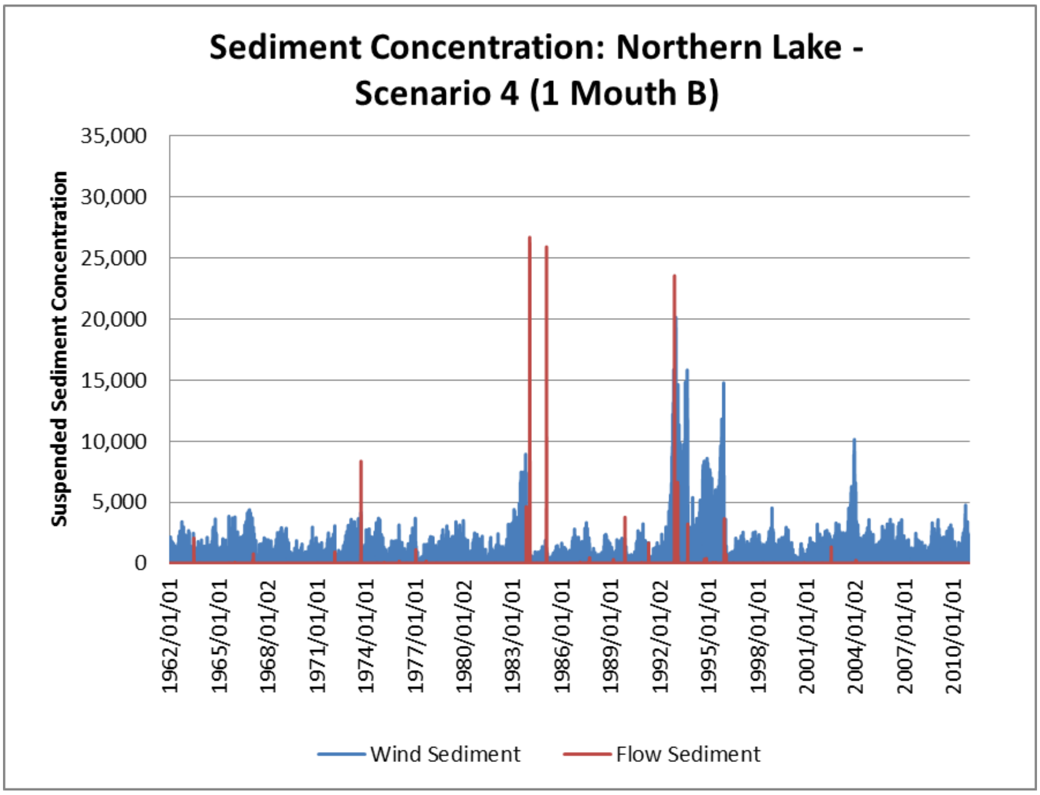

Figure G-20 Suspended sediment concentration time series (daily data) at Northern Lake: Scenario 3 B

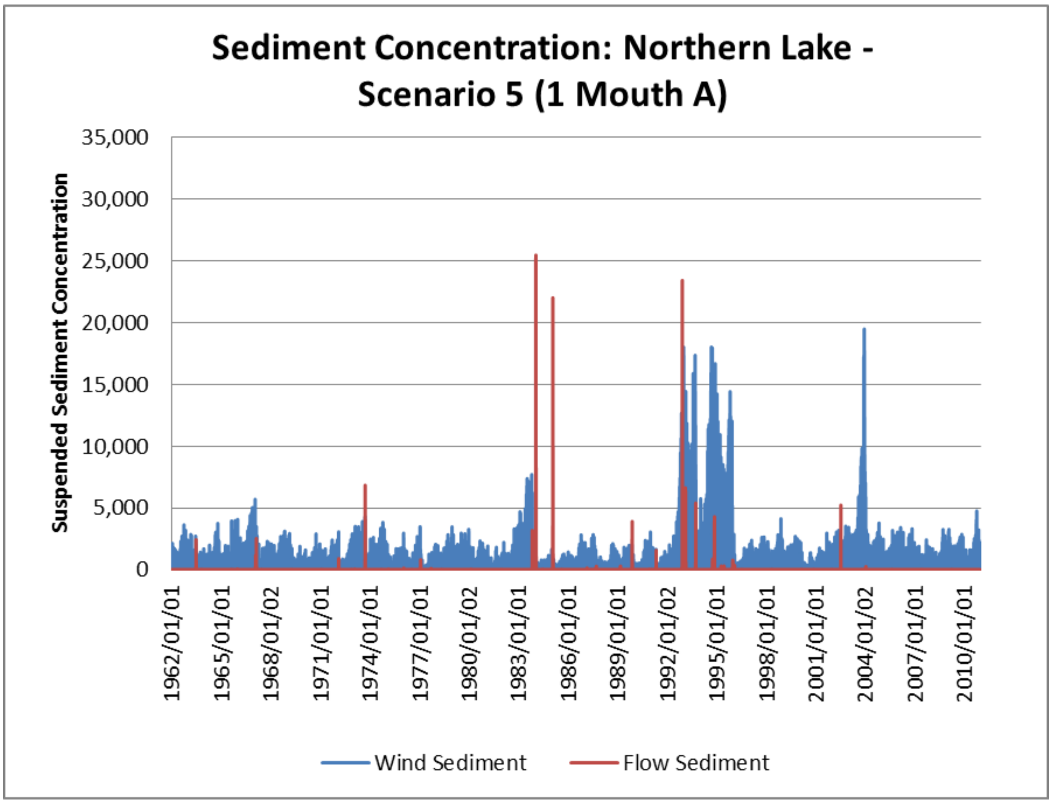

Figure G-21 Suspended sediment concentration time series (daily data) at Northern Lake: Scenario 4 A

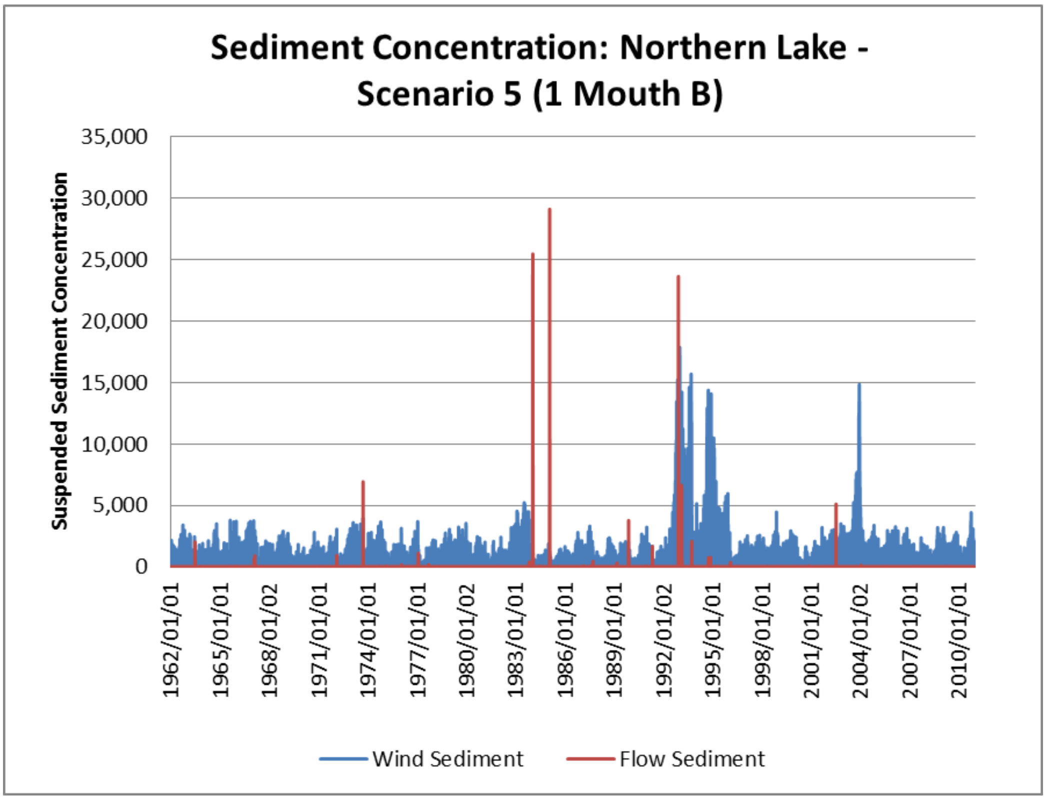

Figure G-22 Suspended sediment concentration time series (daily data) at Northern Lake: Scenario 4 B

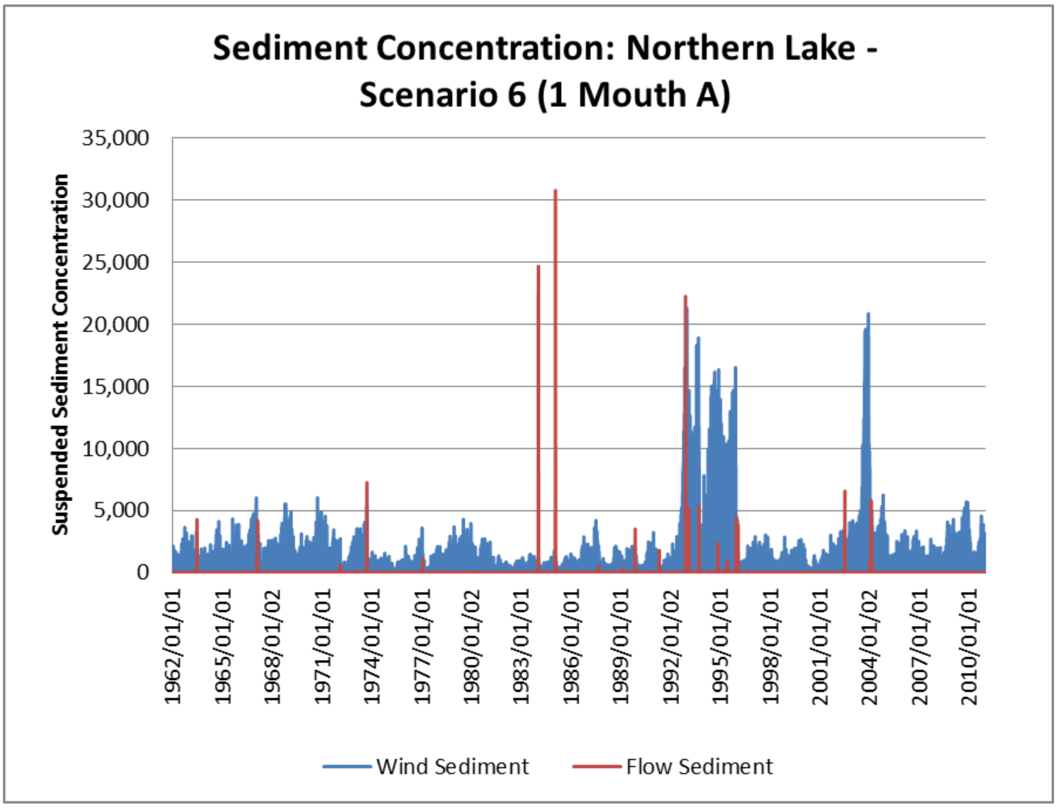

Figure G-23 Suspended sediment concentration time series (daily data) at Northern Lake: Scenario 5 A

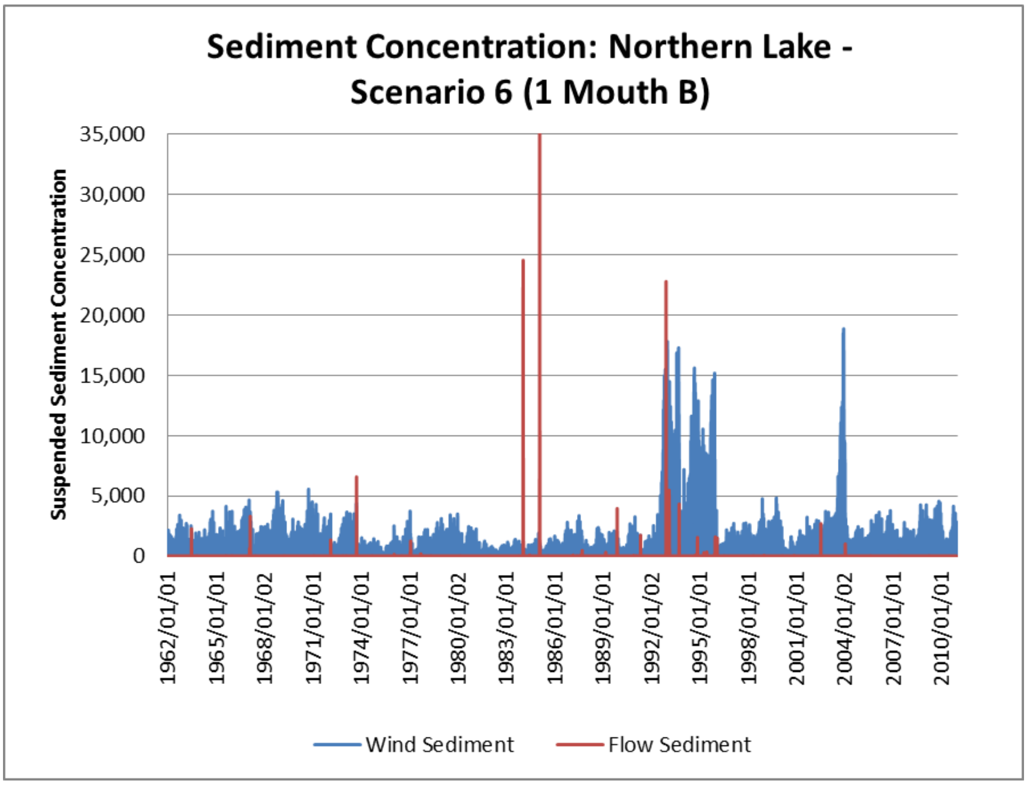

Figure G-24 Suspended sediment concentration time series (daily data) at Northern Lake: Scenario 5 B

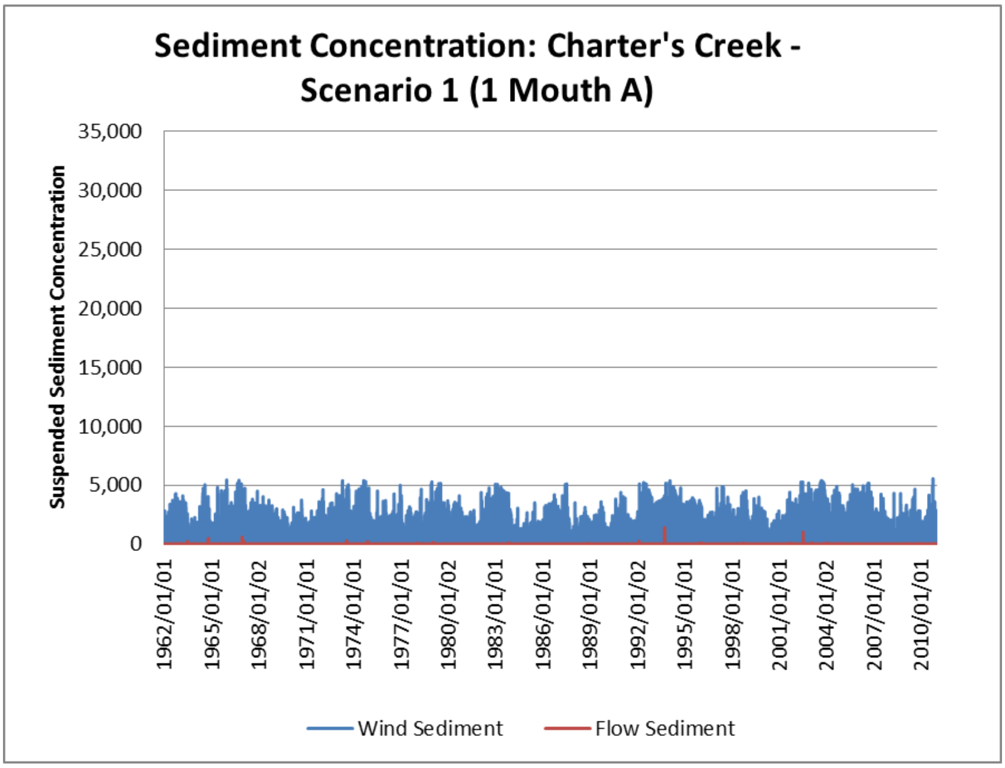

Figure G-25 Suspended sediment concentration time series (daily data) at Charters Creek: Baseline A

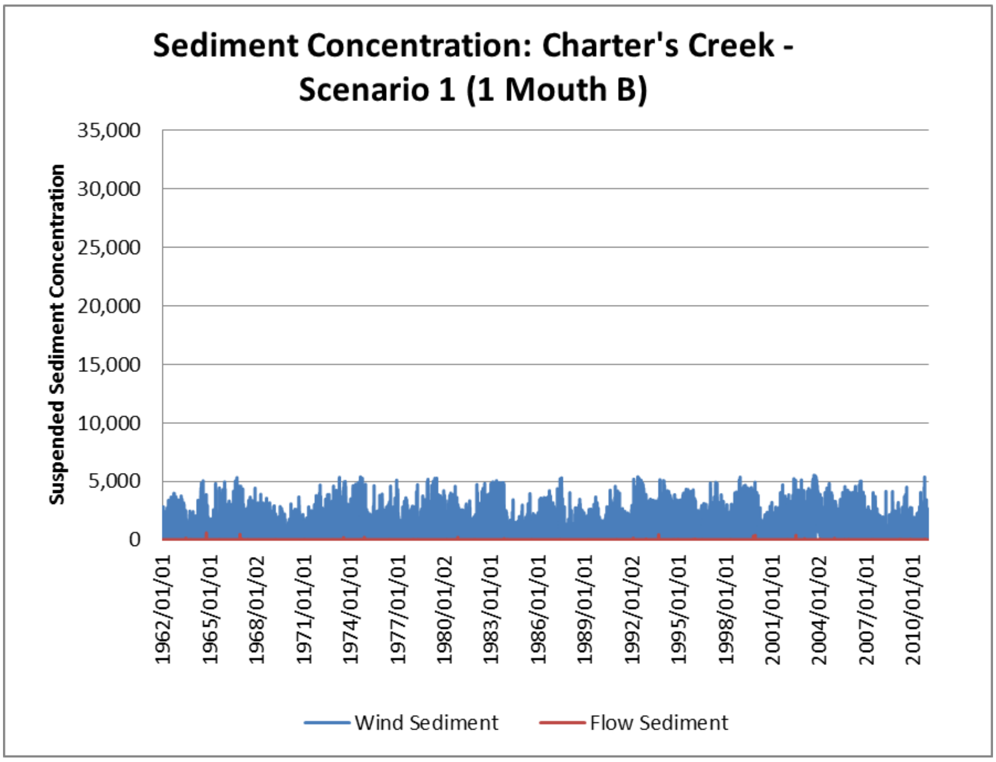

Figure G-26 **Suspended sediment concentration time series (daily data) at Charters Creek: Baseline B**

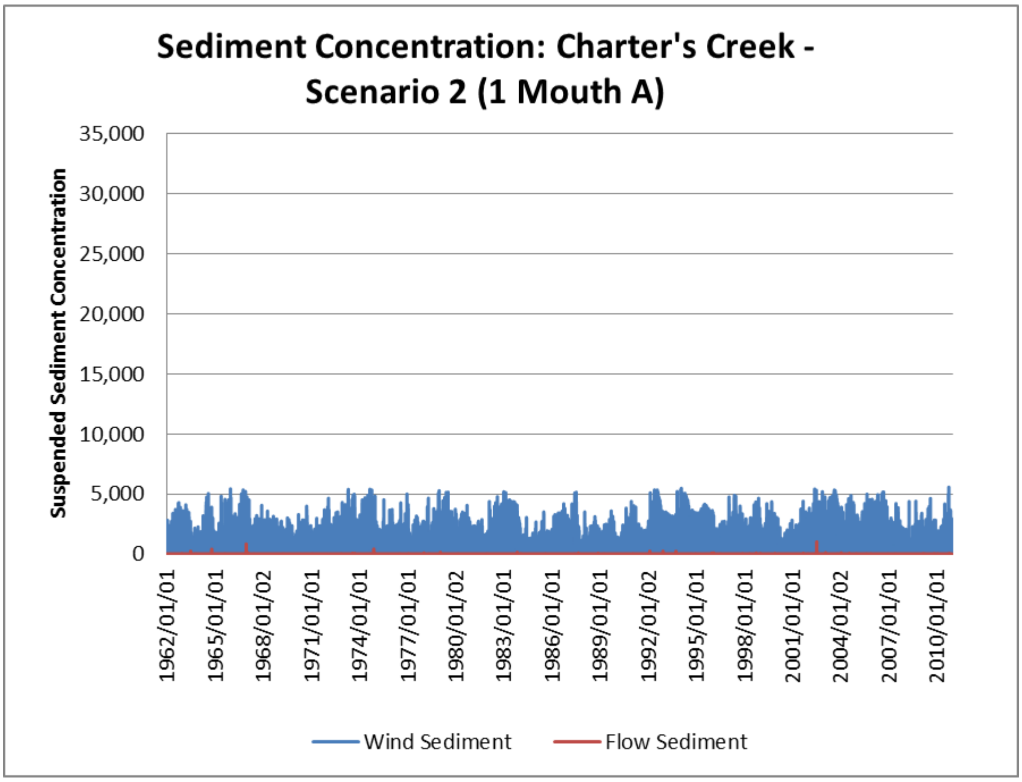

Figure G-27 **Suspended sediment concentration time series (daily data) at Charters Creek: Scenario 1 A**

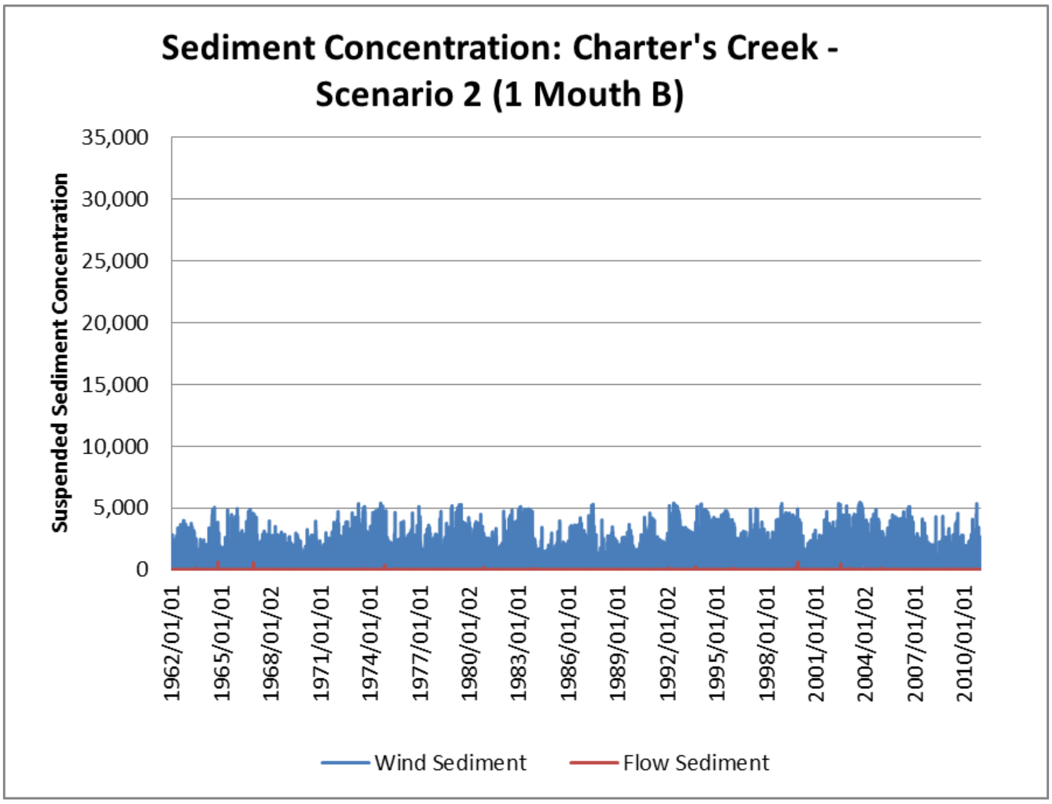

Figure G-28 **Suspended sediment concentration time series (daily data) at Charters Creek: Scenario 1 B**

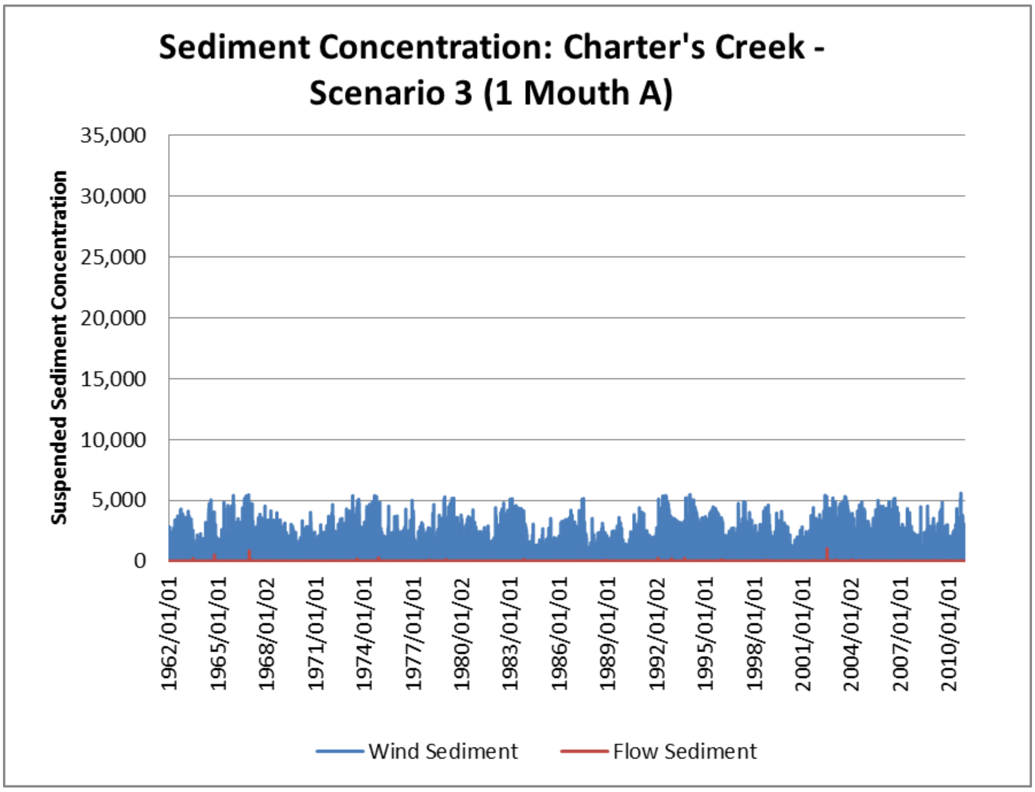

Figure G-29 **Suspended sediment concentration time series (daily data) at Charters Creek: Scenario 2 A**

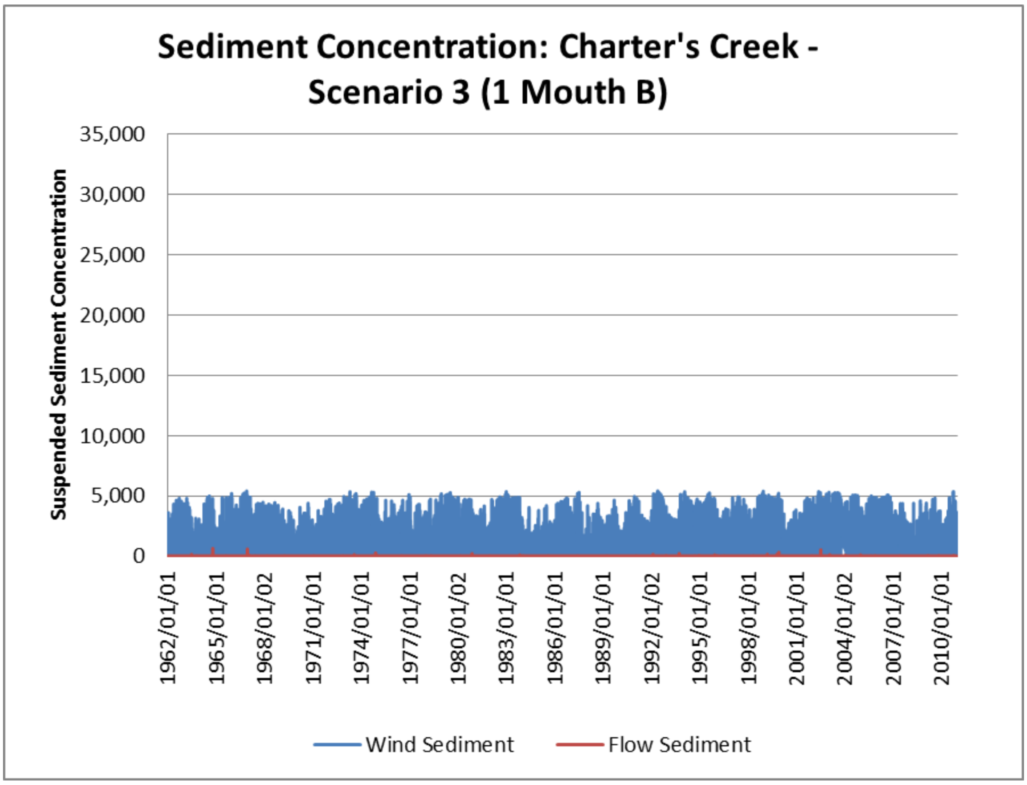

Figure G-30 Suspended sediment concentration time series (daily data) at Charters Creek: Scenario 2 B

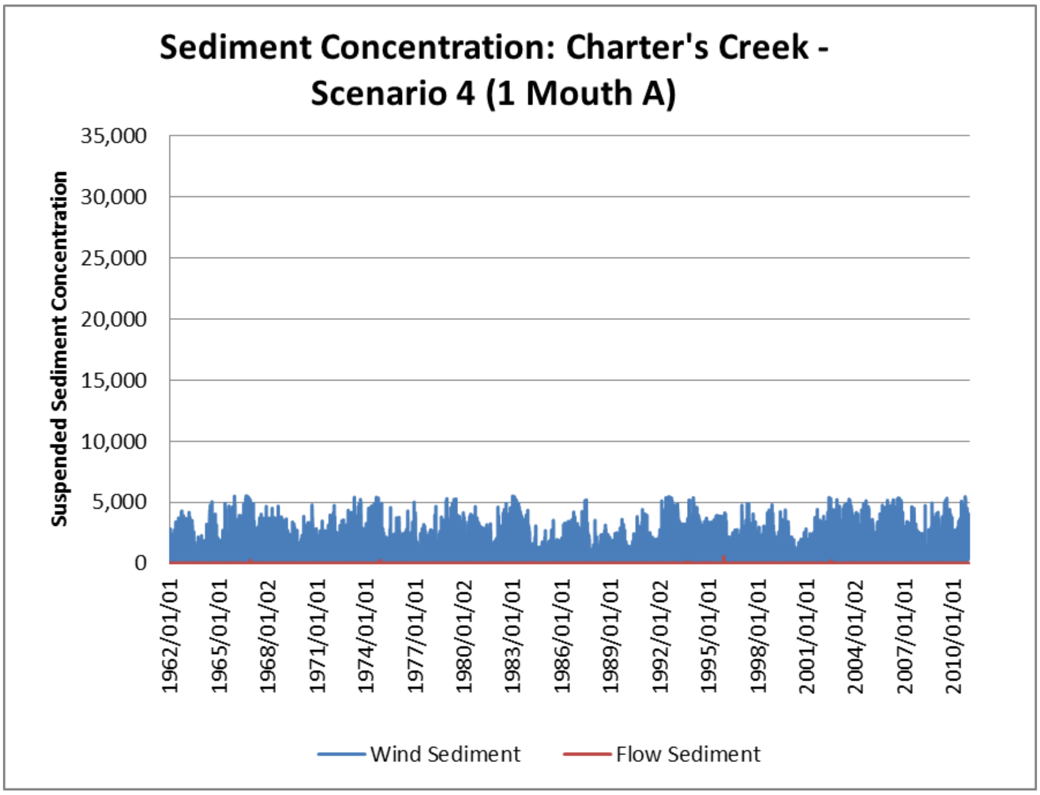

Figure G-31 Suspended sediment concentration time series (daily data) at Charters Creek: Scenario 3 A

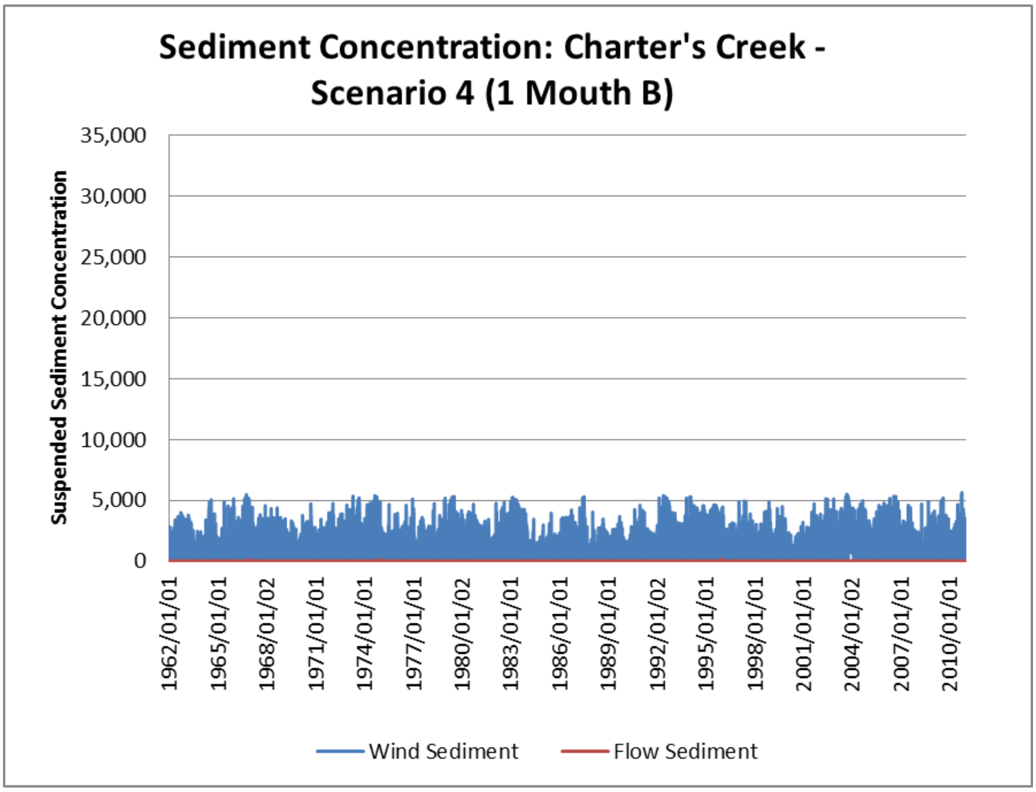

Figure G-32 **Suspended sediment concentration time series (daily data) at Charters Creek: Scenario 3 B**

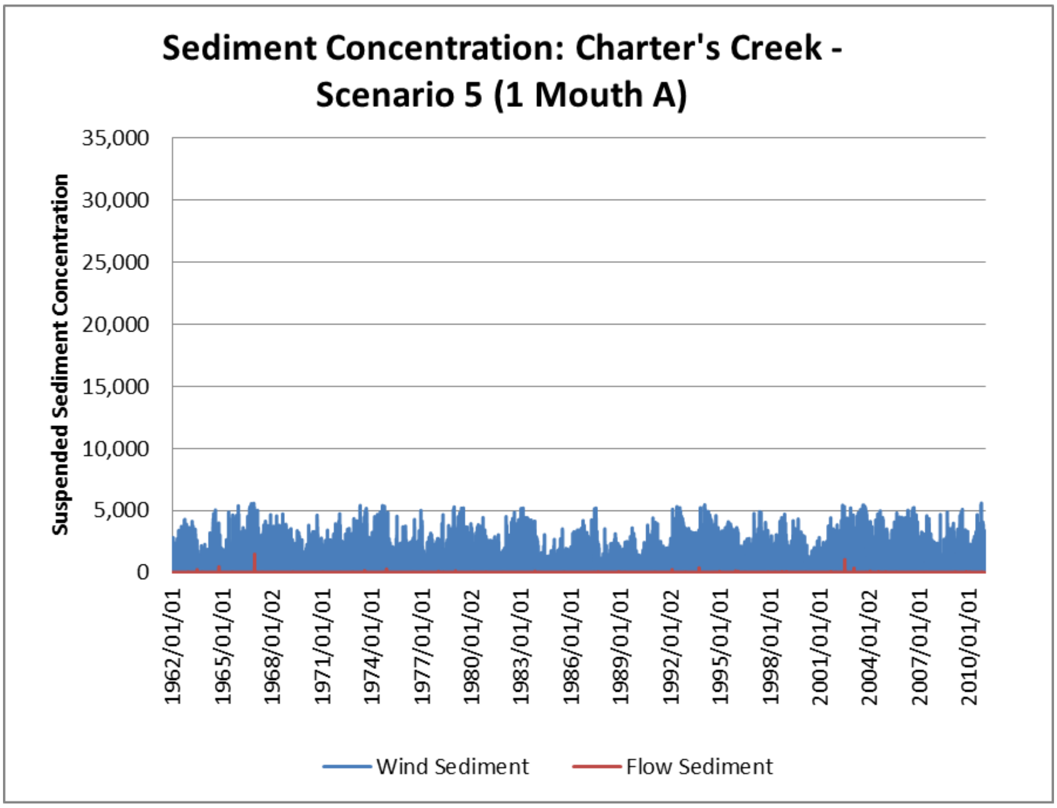

Figure G-33 **Suspended sediment concentration time series (daily data) at Charters Creek: Scenario 4 A**

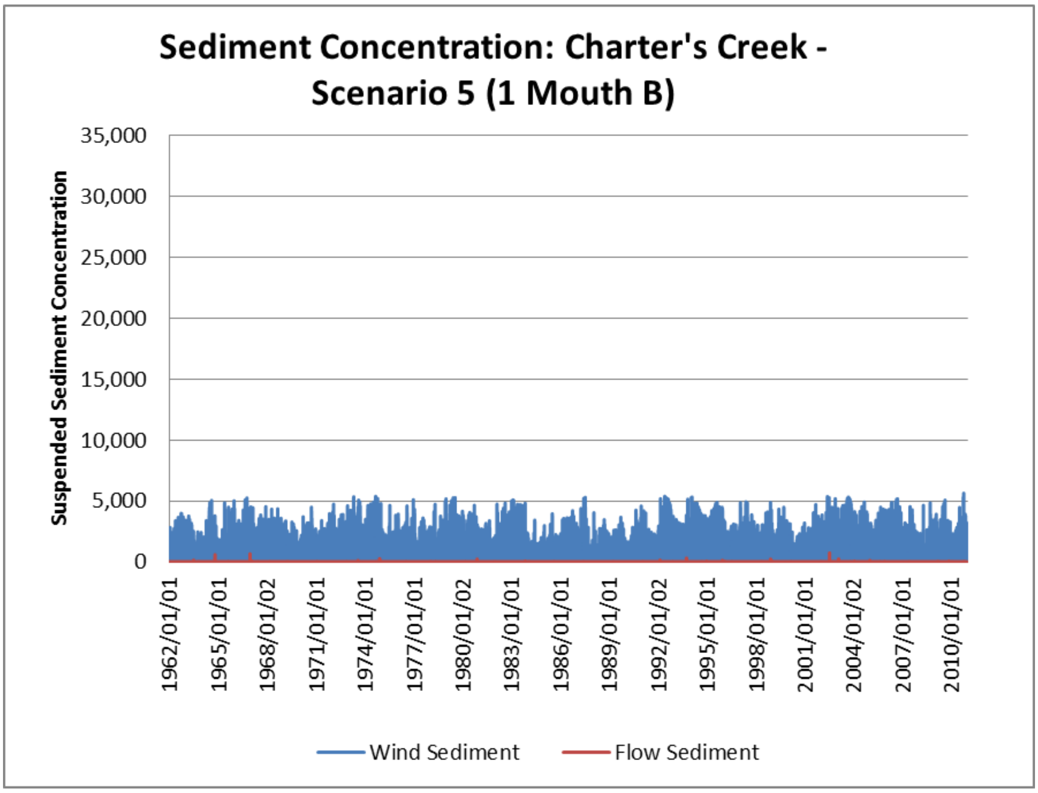

Figure G-34 **Suspended sediment concentration time series (daily data) at Charters Creek: Scenario 4 B**

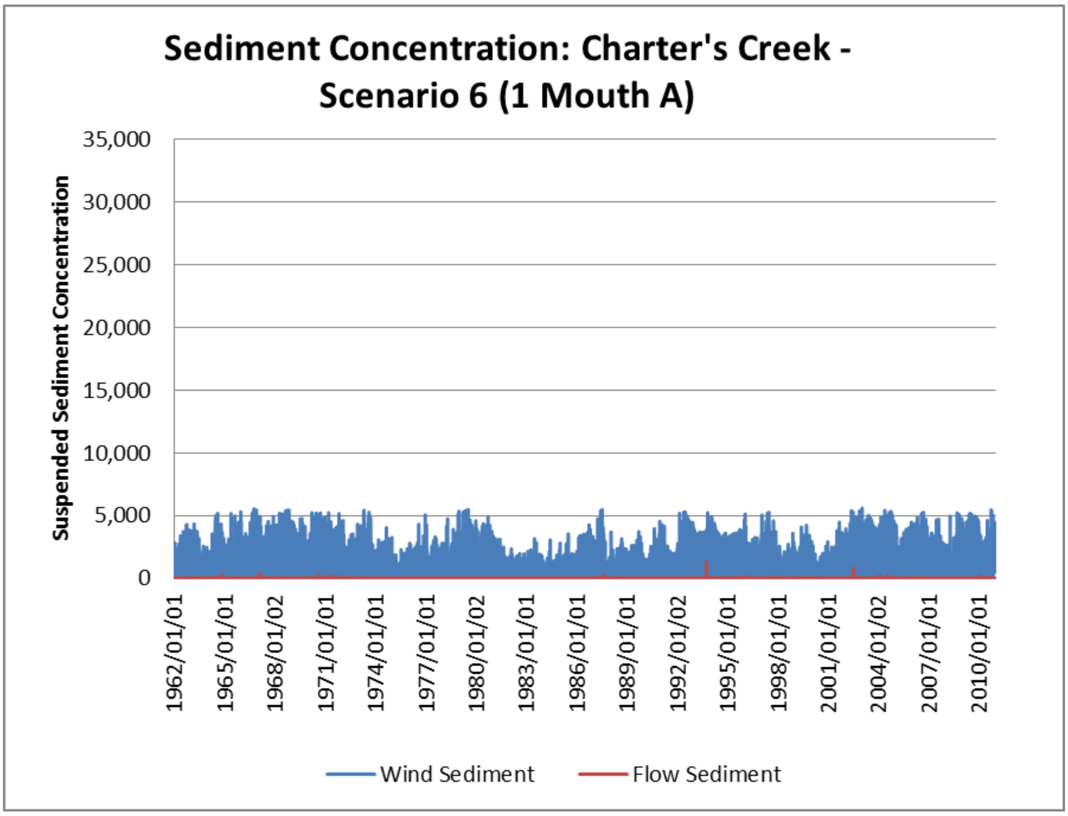

Figure G-35 **Suspended sediment concentration time series (daily data) at Charters Creek: Scenario 5 A**

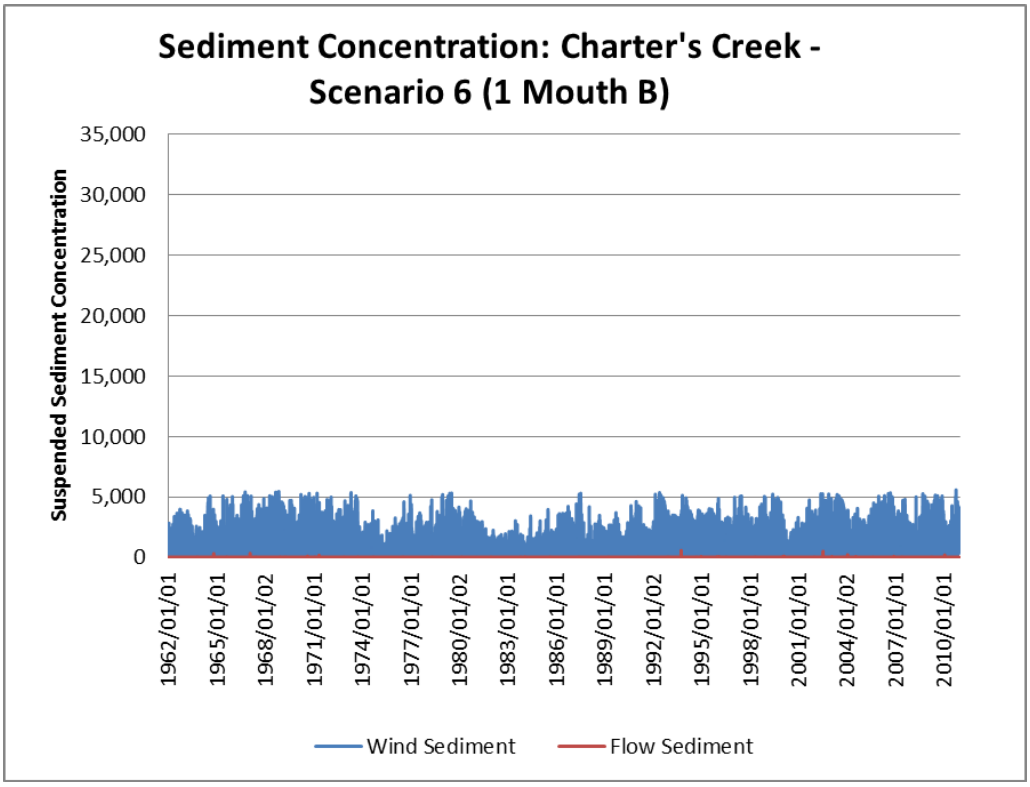

Figure G-36 Suspended sediment concentration time series (daily data) at Charters Creek: Scenario 5 B