# TECHNICAL REPORT

## DEVELOPMENT OF FLOW REGIMES TO MANAGE WATER QUALITY IN THE LOWER LAKES, SOUTH AUSTRALIA

## 2010/05



Government of South Australia
Department for Water

# DEVELOPMENT OF FLOW REGIMES TO MANAGE WATER QUALITY IN THE LOWER LAKES, SOUTH AUSTRALIA

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**September 2010**

**Technical Report DFW 2010/05**

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ISBN 978-1-921923-09-8

**Preferred way to cite this publication**
Heneker TM, 2010, *Development of Flow Regimes to Manage Water Quality in the Lower Lakes, South Australia*, DFW Technical Report 2010/05, Government of South Australia, through Department for Water, Adelaide

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# FOREWORD

South Australia's Department for Water leads the management of our most valuable resource—water.

Water is fundamental to our health, our way of life and our environment. It underpins growth in population and our economy—and these are critical to South Australia's future prosperity.

High quality science and monitoring of our State's natural water resources is central to the work that we do. This will ensure we have a better understanding of our surface and groundwater resources so that there is sustainable allocation of water between communities, industry and the environment.

Department for Water scientific and technical staff continue to expand their knowledge of our water resources through undertaking investigations, technical reviews and resource modelling.

**Scott Ashby**
**CHIEF EXECUTIVE**
**DEPARTMENT FOR WATER**

# ACKNOWLEDGEMENTS

This work formed an integral component of the Department of Environment and Natural Resources' Coorong, Lower Lakes and Murray Mouth program for determining the environmental water requirements to manage the Coorong, Lake Alexandrina and Lake Albert Ramsar Wetland of International Importance. The support received from contributors to this program has been very much appreciated.

This report has been peer reviewed by Dr Dugald Black, Hydrological Modelling Coordinator, CSIRO Land and Water and Kumar Savadamuthu, Principal Hydrologist, Department for Water. The suggestions provided by the peer reviewers were very helpful in identifying some assumptions that required further clarification for improved understanding and report readability.

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# EXECUTIVE SUMMARY


This report presents the results of an investigation into the development of inflow and outflow regimes required for the Lower Lakes in South Australia, for the purpose of maintaining a desired ecological character, which was described using threshold water quality (defined in terms of salinity) and water level targets. This work formed an integral component of the Department of Environment and Natural Resources' Coorong, Lower Lakes and Murray Mouth program for determining the environmental water requirements to manage the Coorong, Lake Alexandrina and Lake Albert Ramsar Wetland of International Importance. The environmental water requirements recommended through this program have been presented by the South Australian Government to the Murray–Darling Basin Authority (MDBA) for use during the development of their Basin Plan.

Salinity in Lake Alexandrina is primarily controlled by lake inflows and outflows through the barrages located at Goolwa, Tauwitcherie, Ewe Island, Mundoo and Boundary Creek. The nature of Lake Albert, as a terminal wetland with its narrow connection with Lake Alexandrina, means that flow into and out of this lake is controlled by water level, wind and evaporation. It is not practical to manage salinity levels within Lake Albert independently. As such, the salinity targets evaluated are defined in terms of thresholds solely for Lake Alexandrina and, based on ecological sensitivities, were examined for targets of 700, 1000 and 1500 EC.

Historically, the magnitude of lake inflows and barrage outflows have been highly variable, with a resulting substantial variation in salinity. An initial analysis of historical barrage outflows and the salinity variation in Lake Alexandrina was undertaken with the objective of understanding how the magnitude of outflows affect in-lake salinity. This analysis showed that there is a marked increase in salinity as annual barrage outflows fall below 2000 GL and three year cumulative outflows fall below 4000 GL.

Hydrological modelling provided the most appropriate and effective means of exploring a range of flow regimes to develop operational rules to achieve the various salinity threshold targets. The MDBA model *BIGMOD* (MDBC 2002) was used as the primary flow and salinity modelling tool in a number of recent studies and was used here. In order to objectively develop operational rules to deliver a flow regime to meet each of the three salinity threshold targets, input data was modified to remove the inter-annual influence from variables such as system losses, diversions and groundwater salt inflows as well as the intra-annual variability of lake inflows.

In the first instance, the required annual average inflow and hence annual average barrage outflows were determined to meet the salinity targets. For the 700, 1000 and 1500 EC targets respectively, average annual inflows ($I_{AVE}$) of 4850, 2850 and 1850 GL were required. These equated to annual average barrage outflows ($B_{AVE}$) of 4000, 2000 and 1000 GL respectively. For ecological and operational delivery purposes it is not appropriate to implement a flow regime based on a constant annual inflow and outflow target. However, this analysis provided an understanding of the magnitudes of flow volumes required to meet salinity targets in Lake Alexandrina and the corresponding impact of those inflow volumes on Lake Albert salinity.

The influence of high variability in inter-annual inflows and barrage outflows was considered. The development of a flow regime that can be managed annually to ensure that salinity threshold levels are maintained continuously needs to account for this variability. The assessment showed that high inflows, and consequently high barrage outflows, lowered salinity but the short memory of the system meant that salinity levels in Lake Alexandrina rose quickly in years with low or no outflows. An iterative approach was used to determine the influence of high lake inflows and barrage outflows in a given year

on the required lake inflows and barrage outflows in following years, in addition to the minimum lake inflow and barrage outflow in a given year needed to maintain salinity below each salinity target. This analysis concluded that one, two and three-year inflow sequences need to be considered to manage salinity in the Lower Lakes and that the system cannot be managed using a long-term average outflow target.

Barrage outflows are the key driver for managing salinity levels in Lake Alexandrina. However, barrage outflows are the result of lake inflows and losses and diversions across the lakes. To determine the barrage requirements to manage salinity levels, the inflow requirements were determined first assuming constant annual losses. In practice, inflows may need to be adjusted based on actual losses and diversions each year.

From the analysis of inter-annual inflows and outflows, a set of rules was developed to define the minimum lake inflow required in a given year, defined as $Q_X$. The rules require cumulative lake inflow parameters to be determined for one, two and three-year sequences for each salinity threshold, with:

- $I_1$ being the minimum lake inflow in any given year;
- $I_2$ being the minimum cumulative lake inflow over two years; and
- $I_3$ being the minimum cumulative lake inflow over three years.

The minimum lake inflow required in any year ($Q_X$) to maintain the salinity in Lake Alexandrina below a prescribed threshold, given the actual annual lake inflow for the previous two years ($Q_{X-1}$ and $Q_{X-2}$), is then the greater of:

1. $I_1$
2. $I_2 - Q_{X-1}$
3. $I_3 - Q_{X-1} - Q^*_{X-2}$ (where $Q^*_{X-2}$ is equal to the minimum of $Q_{X-2}$ or $I_{AVE}$)

A corresponding set of barrage outflow parameters can be calculated (noting the relationship between inflows and outflows is linked to assumed losses and diversions across the lakes) with the minimum barrage outflow required in a given year, $F_X$, is determined using similar rules for cumulative barrage outflow parameters for one, two and three-year sequences for each salinity threshold, with:

- $B_1$ being the minimum barrage outflow in any given year;
- $B_2$ being the minimum cumulative barrage outflow over two years; and
- $B_3$ being the minimum cumulative barrage outflow over three years.

The minimum barrage outflow required in any year ($F_X$) to maintain the salinity in Lake Alexandrina below a prescribed threshold, given the actual annual barrage outflows for the previous two years ($F_{X-1}$ and $F_{X-2}$), is then the greater of:

1. $B_1$
2. $B_2 - F_{X-1}$
3. $B_3 - F_{X-1} - F^*_{X-2}$ (where $F^*_{X-2}$ is equal to the minimum of $F_{X-2}$ or $B_{AVE}$)

Based on an analysis of the salinity tolerances for a number of indicator species (Lester *et al.* 2011a) and the analysis of historical salinity levels and variations undertaken through this investigation, it has been recommended to the Coorong, Lower Lakes and Murray Mouth program (Lester *et al.* 2011b), that a salinity threshold of 1000 EC should be maintained in Lake Alexandrina for the majority of the time, with maximum salinity no higher than 1500 EC.

The barrage outflow parameters to achieve the 1000 EC threshold were $B_1$ = 650 GL, $B_2$ = 4000 GL and $B_3$ = 6000 GL, with $B_{AVE}$ equal to 2000 GL.

As a result, the minimum barrage outflow required in a given year ($F_X$) to maintain Lake Alexandrina salinity below 1000 EC is equal to the greater of:

1. 650 GL
2. 4000 GL - $F_{X-1}$
3. 6000 GL - $F_{X-1}$ - $F^*_{X-2}$ (where $F^*_{X-2}$ is min($F_{X-2}$, 2000 GL))

The above criteria accommodate lower system water availability in a given year by factoring in a minimum inflow and outflow, which is less than the average annual inflow and outflow. In the following year however, Lake Alexandrina requires a higher inflow and outflow to meet the minimum requirements, thereby ensuring that salinities remain below the threshold.

The flow regimes developed for each salinity threshold were validated using an historical inflow sequence as well as two climate sequences with reduced water availability (climate change scenarios Cmid and Cdry from the Murray-Darling Basin Sustainable Yields project). Each adjusted flow regime using the above rules was found to appropriately manage salinity within the corresponding threshold.

Finally, water availability within the River Murray System to provide for the flow regimes to manage salinity in the Lower Lakes was examined. For the data available it was concluded that even during the historically lowest inflow sequence on record (Cdry) there would be sufficient water available.

# 1. INTRODUCTION

## 1.1. OVERVIEW AND OBJECTIVES

In July 2008, the Commonwealth Government instigated the Murray Futures Program for South Australia. As part of this program, the Department of Environment and Natural Resources (DENR) has the responsibility to develop a long-term plan for the Coorong, Lower Lakes and Murray Mouth (CLLMM) Ramsar site. A component of this long-term plan is the development of end-of-system flow targets that will support the desired ecological character for the region.

Over the last ten years, a number of attempts have been made to determine an end-of-system flow target for CLLMM Ramsar site. The ensuing targets have generally been centred around a single, long-term average annual barrage outflow, or a combination of annual barrage outflow volumes of varying magnitudes and associated return periods. There has been little, if any, consideration of the impact of multi-year sequences. In addition, the consequential ecological outcomes from the flow targets developed have often been inferred, rather than directly tested or modelled.

Despite the substantial quantities of knowledge collected by researchers and Government agencies on the ecology of the CLLMM region as a whole, the primary focus of the ecological benefits of end-of-system flow targets has been on the Coorong and Murray Mouth. Based on the information available, it appears that few studies have been undertaken to determine the flow regimes required to support the desired ecological character in the Lower Lakes themselves (refer Figure 1). The purpose of this report is to present the results of an investigation into the development of the inflow and outflow regimes required for the Lower Lakes for the purposes of maintaining a desired ecological character, which was described using threshold water quality (defined in terms of salinity) and water level targets.

Salinity in Lake Alexandrina is primarily controlled by lake inflows and outflows through the barrages located at Goolwa, Tauwitcherie, Ewe Island, Mundoo and Boundary Creek. The nature of Lake Albert as a terminal wetland, with its narrow connection with Lake Alexandrina, means that flow into and out of this lake is controlled by water level, wind and evaporation. It is not practical to manage salinity levels within this lake independently. Historically, salinities in Lake Albert have been higher than those in Lake Alexandrina, with different ecological function and species within each lake as a result. As such, the salinity targets evaluated in this investigation have been defined in terms of thresholds solely for Lake Alexandrina and, based on ecological sensitivities (Lester *et al*. 2011a), have initially been set at 700, 1000 and 1500 EC. The primary objectives and required outcomes from this investigation were to:

1. determine the flow regimes required to maintain salinity within Lake Alexandrina below 700, 1000 and 1500 EC thresholds, including consideration of multi-year flow sequences, in a form suitable for an operational model;
2. consider the required flow regimes in the context of historical inflows to Lake Alexandrina; and
3. consider the required flow regimes in the context of inflows to Lake Alexandrina under a number of potential climate change scenarios, assuming the current water sharing arrangements as defined under the Murray-Darling Basin Agreement.

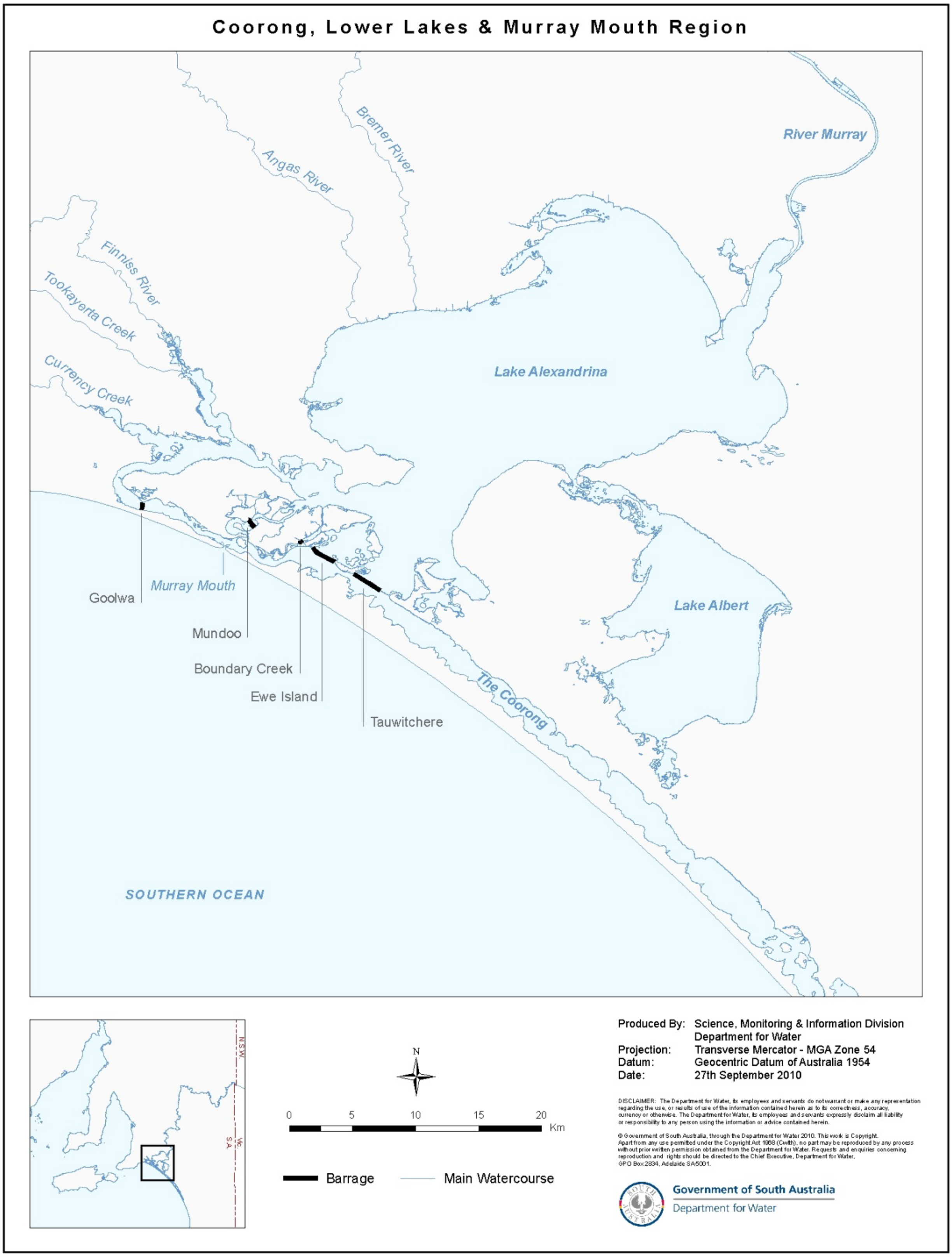



**Figure 1 Coorong, Lower Lakes and Murray Mouth Region**

## 1.2. METHODOLOGY

Hydrological modelling provides the most appropriate and effective means of exploring a range of flow regimes that may achieve the various salinity threshold targets in the Lower Lakes. The Murray-Darling Basin Authority (MDBA) model *BIGMOD* (MDBC 2002) has been used as the primary flow and salinity modelling tool in a number of recent programs including *The Living Murray* and *CSIRO Sustainable Yields*. The component of *BIGMOD* that extends from Lock 1 to the barrages was used to consider the delivery of various flow regimes to the Lower Lakes and to evaluate the outflows through the barrages and hence, determine the corresponding salinity response.

There are a number of different model setups available within the *BIGMOD* framework to produce a daily sequence of inflows, outflow and salinities. For this investigation, the "current conditions" model setup was used. Simply, this means that the assumptions relating to the current system parameters, such as infrastructure (dams, locks, barrages), operating rules, water sharing rules under the Murray-Darling Basin (MDB) Agreement and the level of diversions are applied across the full modelled period. The resultant flow sequences and salinities are then those that would have occurred given current system operations for specified climate sequences.

Three climate sequences were considered in this investigation, as follows:

1. Historical (or observed) climate.
2. Cmid – Murray–Darling Basin Sustainable Yields (MDBSY) "Median Dry" climate change scenario, which is a reduction of the historical climate (in terms of rainfall and Murray System inflows) to account for the 2030 median climate change projection from the MDBSY project.
3. Cdry – Murray–Darling Basin Sustainable Yields (MDBSY) "Extreme Dry" climate change scenario, which is a reduction of the historical climate (in terms of rainfall and Murray System inflows) to account for the 2030 dry climate change projection from the MDBSY project.

Each of these climate sequences were applied across the period from 1891 to 2008 with current system operations to produce "historical", "Cmid" and "Cdry" inflow, outflow and salinity sequences.

The process used to determine the flow regimes required to maintain the salinity in Lake Alexandrina below a given threshold was then, as follows:

1. Examine the observed and modelled historical record of lake levels and salinity within both Lake Alexandrina and Lake Albert to confirm model suitability for this analysis.
2. Modify the historical model to allow the objective examination of the requirements for various salinity thresholds in Lake Alexandrina based on inflows and outflows using the following approach:
    a. Analyse historical inter-annual variability in losses, salt inflows (via river inflows and groundwater discharge) and diversions to determine appropriate averaged values that remove the influence of these variables during individual years.
    b. Analyse intra-annual variability of lake inflows and barrage outflows to generate a modified intra-annual inflow sequence that preserves the total annual inflow volumes.
    c. Test the resultant lake inflows, barrage outflows and salinity response from the modified historical model.
3. Determine the annual lake inflows and barrage outflows required to maintain salinities below each of the threshold levels.
4. Evaluate the impact of inter-annual flow variation on salinity by considering annual inflow sequences of varying magnitude.

5. Using the annual lake inflow requirements and understanding of the salinity impacts from inter-annual flow variations, determine the one, two and three-year flow sequence requirements to meet the salinity thresholds in a form suitable for an operational model.
6. Compare the required flow regimes with the modelled historical inflows to Lake Alexandrina, and adjust the modelled historical sequence as required to evaluate the salinity responses.
7. Compare the required flow regimes with inflows to Lake Alexandrina under the MDBSY (CSIRO, 2008) climate change scenarios Cmid and Cdry, which assumes current water sharing arrangements as defined under the Murray-Darling Basin Agreement. Adjust the reduced inflow sequences as required and evaluate the salinity responses.
8. Confirm water availability within the River Murray System to provide for the flow regimes required to manage salinity in the Lower Lakes.

# 2. MODELLING APPROACH AND ASSUMPTIONS

## 2.1. MODEL DESCRIPTION

*BIGMOD* (MDBC 2002) is a computer model that conceptualises and simulates the River Murray system by dividing the river into a number of river reaches. In each river reach, the major processes modelled include the routing of flow and salinity, losses, inflows, extractions, the operation of storages and weirs based on specified rules and the diversion of water into branches. It has been calibrated to available data and is regularly re-calibrated as new data or information becomes available or operating rules are changed.

At the Lower Lakes, *BIGMOD* maintains a continuous water and salt balance and the key requirements from this component of the model was to provide a good representation of water levels and salinities as well as an ability to estimate the flow over the Barrages. The major components of the water balance are inflows (surface flows from the River Murray and Eastern Mount Lofty Ranges (EMLR) tributaries and groundwater inflows), barrage outflows, rainfall, evaporation, seepage, water supply and irrigation extractions.

## 2.2. MODEL SETUP

There are a number of standard model setups that can be used within *BIGMOD* to produce modelled datasets for the period 1891/92 to 2007/08 (the MDB water year is from June to May). For this investigation, the current conditions (or production) model setup was used. This assumes that the current parameters of the system, such as infrastructure (dams, locks, barrages), operating rules, water sharing rules under the MDB Agreement and the level of diversions, are applied across the full modelled period.

The nature of the current conditions model setup in assuming the current parameters of the system means that the model outputs will not necessarily be an exact replicate of what was actually observed. Most of the current infrastructure and operating rules have only been in place since 1975, from which point the majority of observed data was available. Observed data is only used when considering the representation of modelled data under historical climate conditions and in a statistical summary of observed salinity. Otherwise, the data and analysis presented in this report is modelled and will be referred to as historical, Cmid or Cdry inflows, outflows and salinities as appropriate.

*BIGMOD* was run using the current conditions model setup in two modes as follows:

1. The full model was run with the standard *BIGMOD* boundary conditions to provide modelled historical inflow and salinity datasets for Lake Alexandrina and barrage outflow datasets. These datasets were used to evaluate the model representation of observed data in Section 2.3, to examine the characteristics of historical inflows to the Lower Lakes, barrages outflows and salinity in Section 3.2, to analyse the relationship between historical barrage outflows and salinity in Section 3.3, and during an initial analysis of reduced water availability under the Cmid and Cdry scenarios in Section 5.1.
2. The model was run from Lock 1 to the barrages only. Using the datasets and analysis from (1), a modified historical model was developed (Section 2.4) in which the boundary conditions for flow were set at Lock 1 and for salinity at Wellington. This was used in the development of flow regimes for salinity threshold targets in Sections 3.4 to 3.6 and the validation of these regimes in Sections 4, 5.2 and 5.3.

## *2.3. REPRESENTATION OF OBSERVED DATA*

Historically there have been difficulties in calibrating models for the Lower Lakes due to a number of issues including upstream flow measurement inaccuracies, non measurement of barrage outflows, non-metered diversions such as those to the Lower Murray Swamps and irregular recording of other diversions, unknown groundwater seepage rates, limited periods of estimated inflow data from the EMLR tributaries and limited pan evaporation records. However, using available data on River Murray inflows, extractions, rainfall and evaporation, *BIGMOD* has been calibrated to ensure a good reproduction of the historical rise and fall of lake levels over the period for which data is available.

The main area of difference between observed and modelled data since 1975 was expected to be in the representation of salinity. This does not necessarily indicate inadequacies in the model. River Murray salinity has been significantly reduced through the implementation of the *1988 Salinity and Drainage Strategy* and the *Basin Salinity Management Strategy 2001-2015* (MDBC 2001). These strategies have included the construction of Salt Interception Schemes (SIS), which are designed to intercept salt before it reaches the river.

The estimates of salt inflows along each reach of the river is calibrated for each month based on observed data. The current conditions model setup then includes estimated (modelled) reductions in salt load entering the river due to the operation of the commissioned SISs at the time. As observed salinities are the product of the ongoing implementation of these schemes, it is expected that recorded salinities from the early part of the model period will be higher than the simulated values, with these values progressively converging. The replication of salinities in the later part of the modelled time-series will be of most interest, although the impact of salt reduction schemes are likely to be less evident in the salinities observed in Lake Alexandrina and Lake Albert than in the main river channel.

### 2.3.1. LAKE LEVELS

It is not possible to calibrate the model over the entire period of record, primarily because barrage releases are not recorded. In addition, while the management of water levels in the lakes and any required barrage releases may follow general rules to maximise water retention and minimise unwanted flooding, it is difficult to formulate actual operations into model rules that can replicate historical actions.

A selected period of historical data shown in Figure 2 highlights that water levels in any given year have been managed, either by design or necessity, to a range of maximum heights. For example, in 1977 water levels remained around 0.75m AHD and in 1994 around 0.8m AHD but in other years the maximum levels generally ranged from 0.8 to over 0.9m AHD. As a result of this, calibration has been undertaken for periods when the barrages were closed.

It is likely that the maximum water level attained during the high inflow season influences the minimum water level reached in the following low inflow season. This will need to be considered during any analysis to determine a preferred intra-annual water level operating range but was not required as part of this investigation.

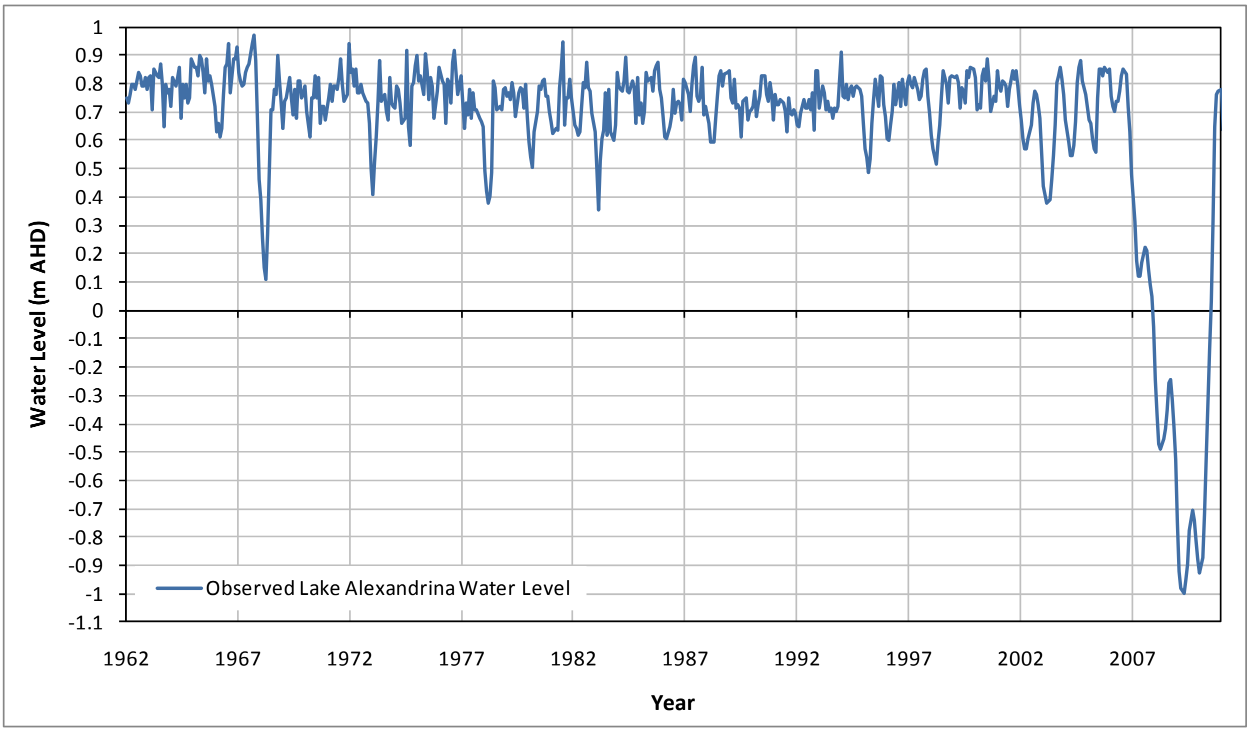



**Figure 2 Observed Lake Alexandrina Lake Levels (1962 to 2010)**

Figure 3 shows observed levels in Lake Alexandrina for period 2003 to mid-2007, together with the modelled levels using *BIGMOD*. As can be seen, the model provides a good representation of the rise and fall of lake levels over this period.

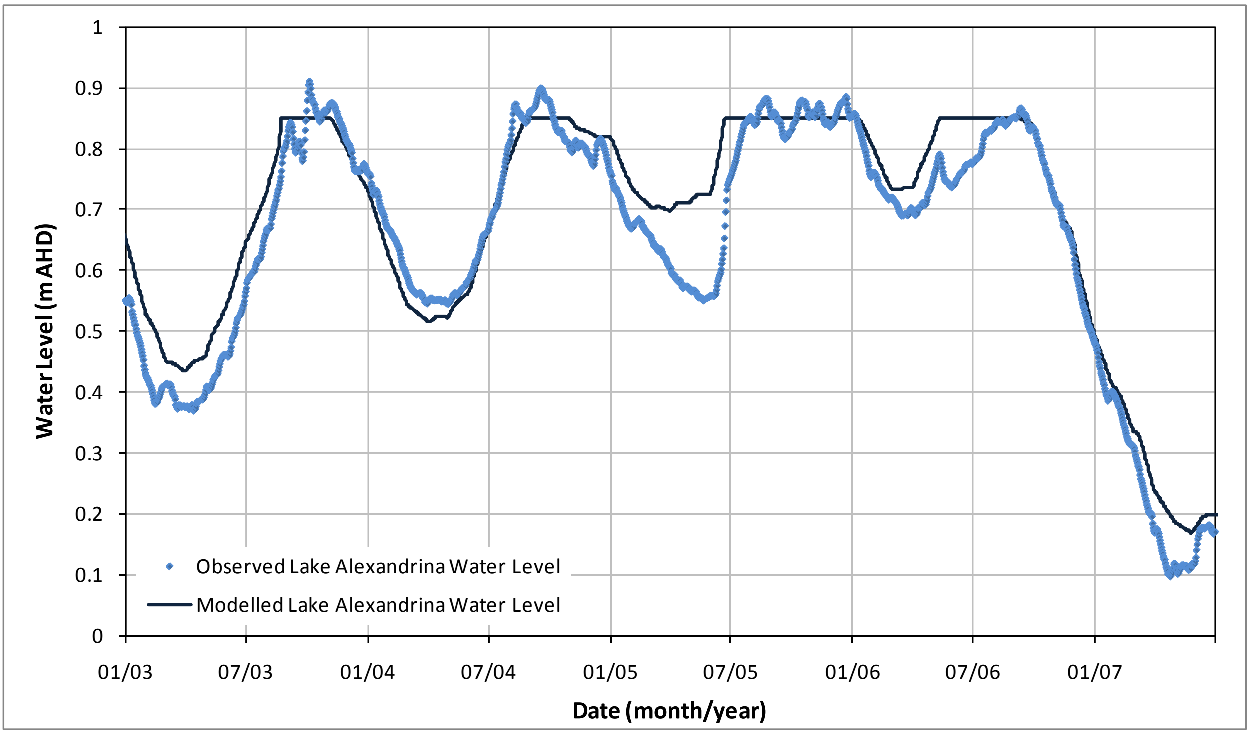



**Figure 3 Representation of Observed Lake Levels**

### 2.3.2. SALINITY

Figure 4 shows the observed and modelled historical salinity data for Lake Alexandrina from 1975 to 2007. *BIGMOD* only models salinity for the full River Murray System from 1975 due to lack of observed data to use as input for model boundary conditions.

The available observed data was primarily daily recorded data, although there was some weekly data in the 1980s and 1990s and no data was recorded from mid-1999 until mid-2002. Where possible, data from more than one station has been averaged to provide an estimate of average lake salinity. From the 2006/07 water year onwards, salinity has been significantly greater than any of the proposed threshold limits.

The magnitude of the modelled peaks in the first half of the record is lower than the observed data, as expected due in part to the implementation of the major SISs that were commissioned at Woolpunda and Waikerie in the early 1990s. In the second half of the record there is a good relationship between the observed and modelled data and the rise and fall in salinity over the full modelled period is well replicated. The latter indicates that the model performs well in modelling the changes in salinity in the lake due to inflows, barrage discharges, losses and inter-change with Lake Albert. The overall correlation between the modelled and observed data is 0.93.

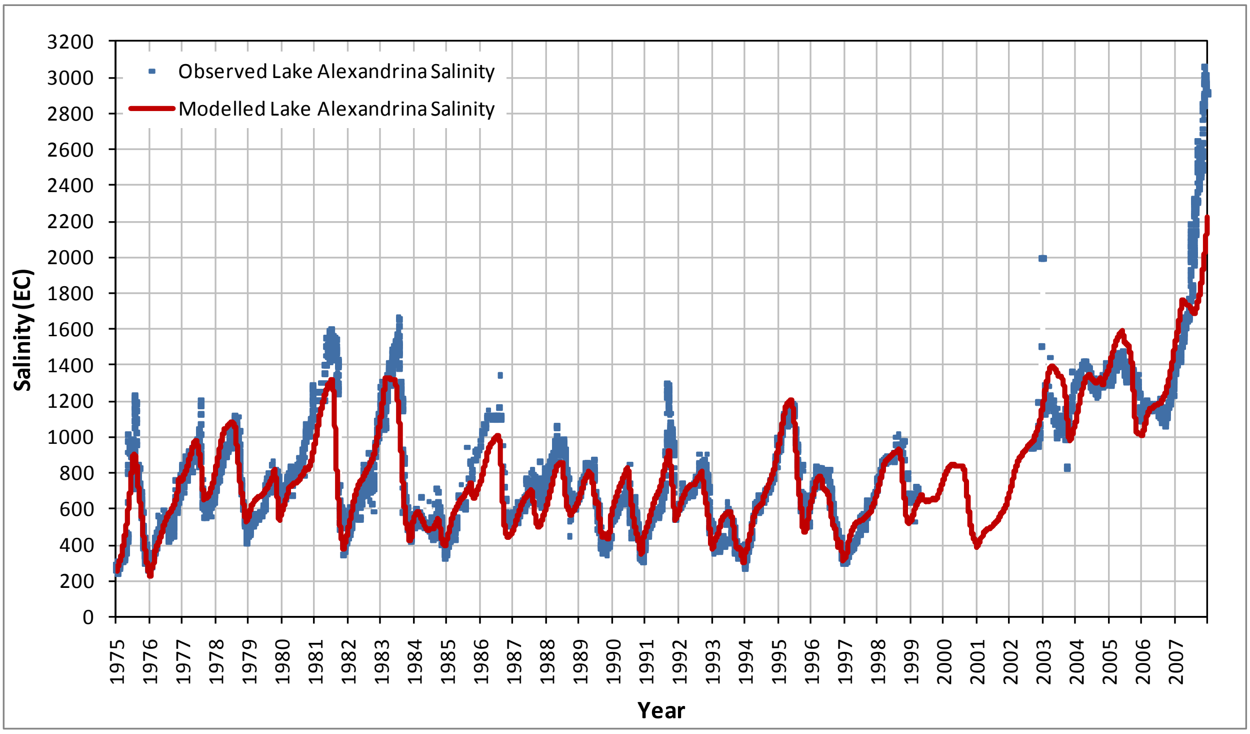



**Figure 4 Observed and Modelled Historical Lake Alexandrina Salinity**

Figure 5 shows observed and modelled historical salinity data for Lake Albert from 1975 to the end of 2007. Observed data has been recorded daily since 1987. Prior to mid-1985 only weekly data was available and no data was available from mid-1985 until beginning of 1987.

The overall correlation between the observed and modelled data is 0.80 and the good relationship from 1992 onwards is evident. The modelled estimates in the first half of the record are lower than the observed, which is again expected due to the commissioning of SISs in the early 1990s. Due to the terminal nature of Lake Albert, modelling of salinity in this lake will be more heavily influenced by the adequacy of the relationship for the exchange of flow between the two lakes. A calibrated constant exchange of 600 ML/day is assumed in the model and no intra- or inter-annual variation is considered. Recently developed hydrodynamic models for the Lower Lakes may provide more information on the nature and variation in magnitude of this exchange due to wind effects and sedimentation. These have not been applied in this investigation but could be used to inform future model development.

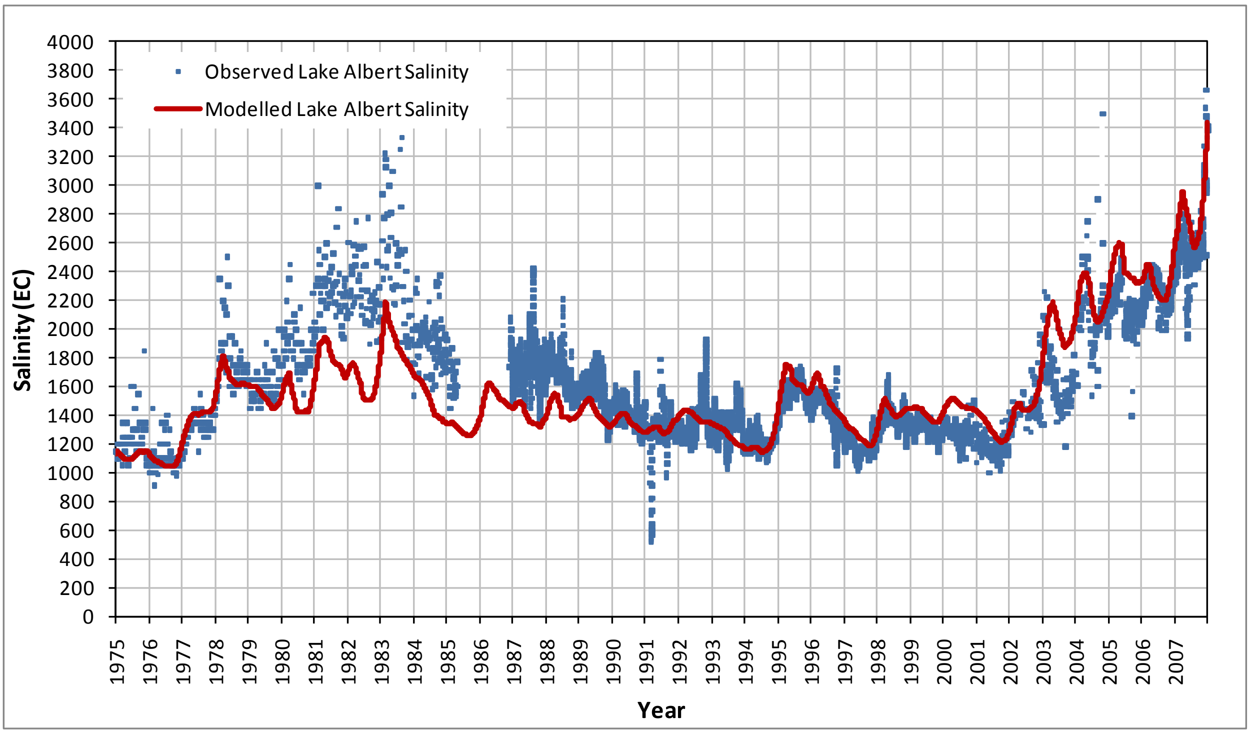



**Figure 5 Observed and Modelled Historical Lake Albert Salinity**

Figure 6 shows the relationship between the observed historical salinity data for Lake Alexandrina and Lake Albert from 1975 to 2009. There are three distinct periods identifiable within the data, with a significant shift in the relationship once water levels began falling below historical levels.

1. For the period to the end of March 2007 (shown in Figure 7), salinities in Lake Alexandrina up to around 1000 EC correspond to salinities in Lake Albert within a band from 1000 to 2000 EC. For salinities greater than 1000 EC in Lake Alexandrina, salinities in Lake Albert begin increasing. This data corresponds to water levels in both lakes between 0.25 and 0.85m AHD and hence what could be considered normal interchange between the lakes.
2. Between April and November 2007 water levels fell from 0.25 to 0.0m AHD and the connection between the lakes became shallower and reduced interchange between the lakes likely occurred. Despite salinities in Lake Alexandrina increasing from 1500 to 3000 EC, salinities in Lake Albert remained generally constant around 2500 EC.
3. Between December 2007 and March 2008 the connection between the lakes decreased further until they became effectively disconnected, except under specific wind conditions. The construction of a blocking bank at Narrung removed any natural connection. Pumping from Lake Alexandrina to Lake Albert began in May 2008. From this point until November 2009, salinities have steadily increased due to salt transport via pumping and evapo-concentration. While there appears to be a good relationship between the salinity in both lakes, it would not be applicable if the lakes were connected and natural interchange was occurring.

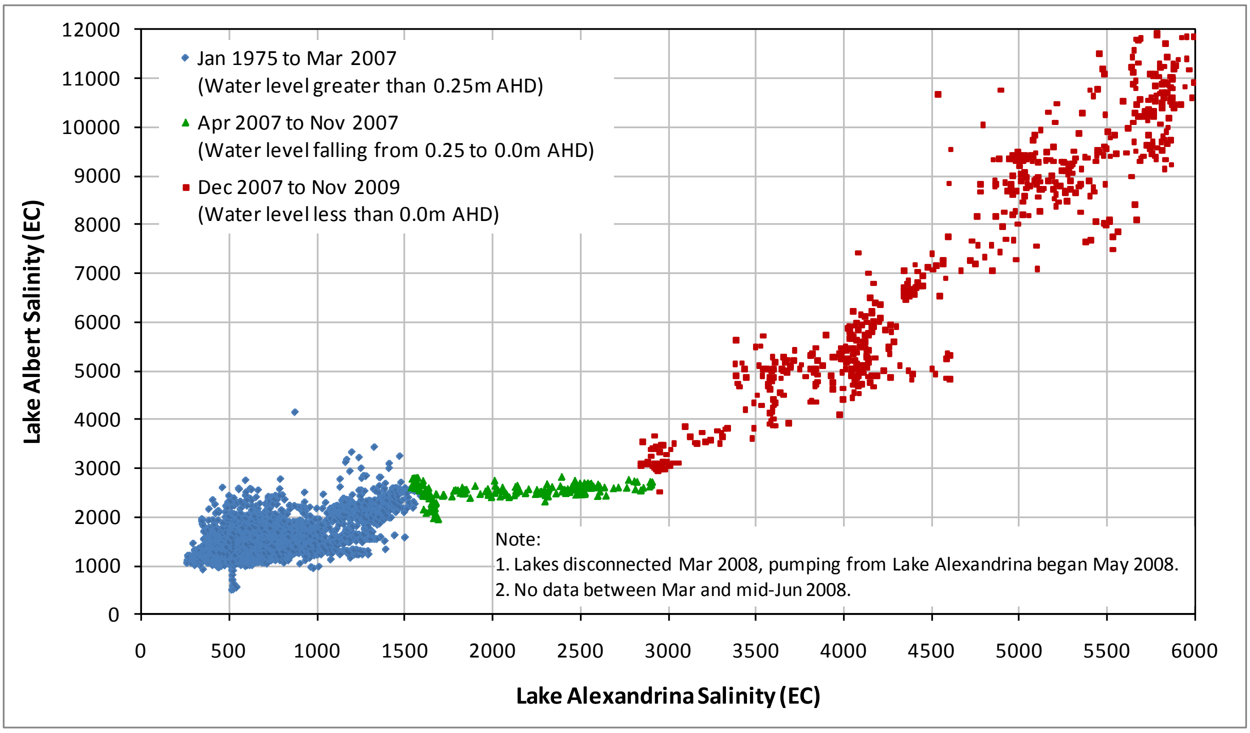



**Figure 6 Observed Salinity in Lake Alexandrina and Lake Albert (1975 to 2009)**

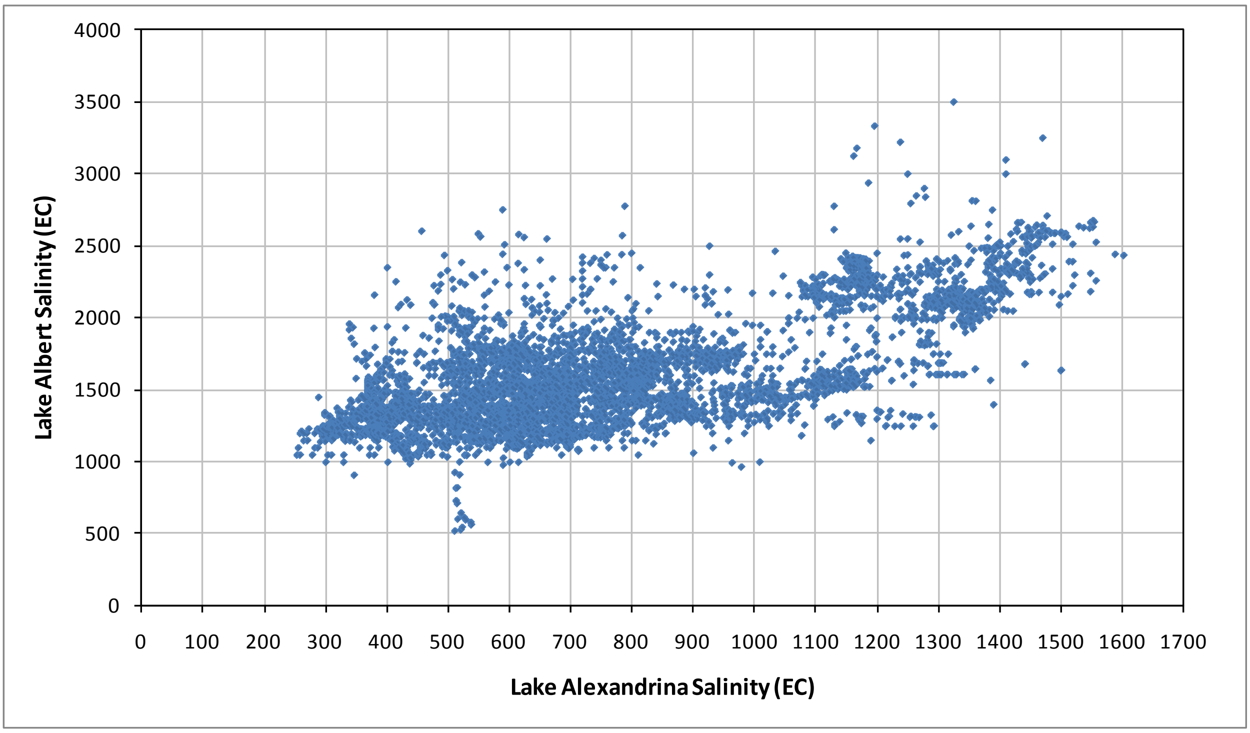



**Figure 7 Observed Salinity in Lake Alexandrina and Lake Albert (Pre-April 2007)**

Figure 8 shows the observed and modelled relationship between Lake Alexandrina and Lake Albert for the period of normal connection and interchange (January 1975 to March 2007). The modelled data lies within the envelope created by the majority of the observed data, indicating a good relationship between salinity in the two lakes.

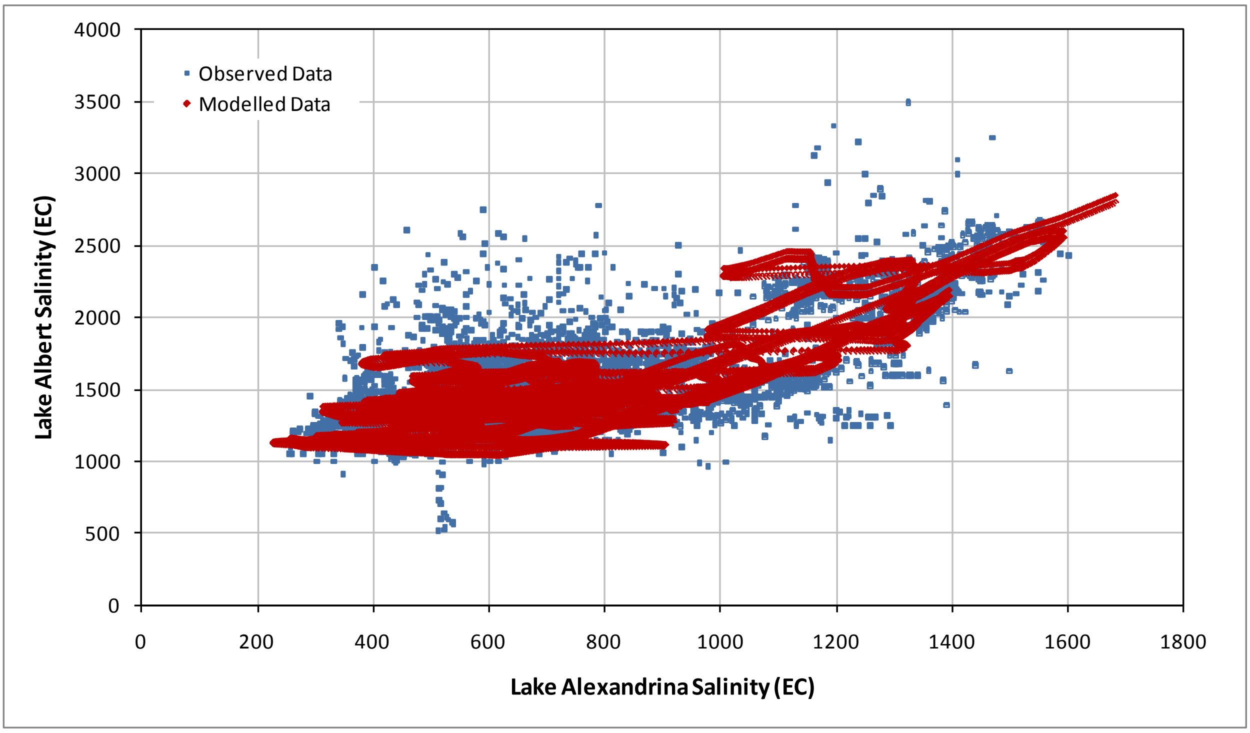



**Figure 8 Observed and Modelled Salinity in Lake Alexandrina and Lake Albert (Pre-April 2007)**

## *2.4. MODIFIED HISTORICAL MODEL*

Modifying the historical model was necessary for the objective consideration of the requirements for various salinity thresholds in Lake Alexandrina based on inflows and outflows. This involved:

- an analysis of the inter-annual variability in losses, diversions and groundwater salt inflows to produce averaged values that can be used in preference to historical data to remove the influence of these variables during individual years.
- an analysis of the salinity of inflows to Lake Alexandrina to develop a inflow-salinity relationship that can be applied to all inflows at Wellington, thereby preserving the historical characteristics of salt inflows and removing the influence of any extractions between Lock 1 and Wellington.
- an analysis of the intra-annual variability of lake inflows and barrage outflow to develop an averaged intra-annual inflow sequence to be used to redistribute the total annual inflows.

### 2.4.1. NET LOSS

In Section 2.3 it was discussed that there have often been difficulties in calibrating models for the Lower Lakes due to a number of data-related issues including unknown groundwater seepage rates, limited periods of estimated inflow data from the EMLR tributaries and limited pan evaporation records. In comparison to other inputs, the inflow contribution from the EMLR tributaries and groundwater seepage rates are relatively small, with evaporation being the major loss of water from the system.

As a result, *BIGMOD* uses a calibrated evaporation multiplier (0.85) in the calculation of net loss, as follows:

$$\text{Net Loss} = \text{Evaporation} * 0.85 - \text{Rainfall} \quad (1)$$

The calculated net loss that is applied in *BIGMOD* is therefore inclusive of evaporation, rainfall, seepage and inflows from the EMLR tributaries. Net losses in *BIGMOD* have been calibrated using the best available rainfall and evaporation datasets shown in Table 1.

**Table 1 Data Sources for Net Loss Calculations**

| | Evaporation Data | Rainfall Data |
|---|---|---|
| **Lock 1 to Mannum** | Lock 1 | Tailem Bend |
| **Mannum to Wellington** | Wellington[1] | Tailem Bend |
| **Lake Alexandrina** | 30% Wellington[1] + 30% Tauwitcherie + 40% Milang | Tailem Bend |
| **Lake Albert** | 50% Tauwitcherie + 50% Milang | Tailem Bend |

[1] Data at Wellington is now substituted for data from Tailem Bend

Since the completion of the barrages in the early 1940s until the end of 2006/07 the river between Lock 1 and the barrages has generally operated at a level between 0.25 and 0.85m AHD. Over this period, the annual net loss in Lake Alexandrina and Lake Albert has ranged from 600 to 950 GL with an average of 800 GL. Losses from the main river channel and connected wetlands between Lock 1 and Wellington ranged from 45 to 105 GL with an average around 80 GL.

The modified historical model uses the mean climate data from the sources shown in Table 1. Between Lock 1 and Wellington the profile of the river means that the water surface area remains constant irrespective of the water level (for water levels between 0.2 and 0.75m AHD). Hence, the monthly net loss can be determined regardless of the river level. The magnitude of these losses is shown in Figure 9.

Mean climate data can also be used to calculate net losses in Lake Alexandrina and Lake Albert. However, the calculation of net loss in the lakes is dependent on the surface area of each lake on each day. Therefore, while the average net loss will be around 800 GL, there will be some variation from year to year, depending on the inflow. The intra-annual distribution of losses for the lakes is similar to that in Figure 9, although over summer losses have been calculated to be as high as 3700 ML/day in Lake Alexandrina and 970 ML/day in Lake Albert.

In each modified historical model run the flow is set at Lock 1. Therefore, to ensure that the desired inflow to Lake Alexandrina is preserved, the flow at Lock 1 in a given month (m) is defined as:

$$QL1_m = QLL_m + Loss_m \qquad m=1 \text{ to } 12 \quad (2)$$

where:

QL1 = the flow at Lock 1

QLL = the required flow into Lake Alexandrina

Loss = the net loss between Lock 1 and Lake Alexandrina

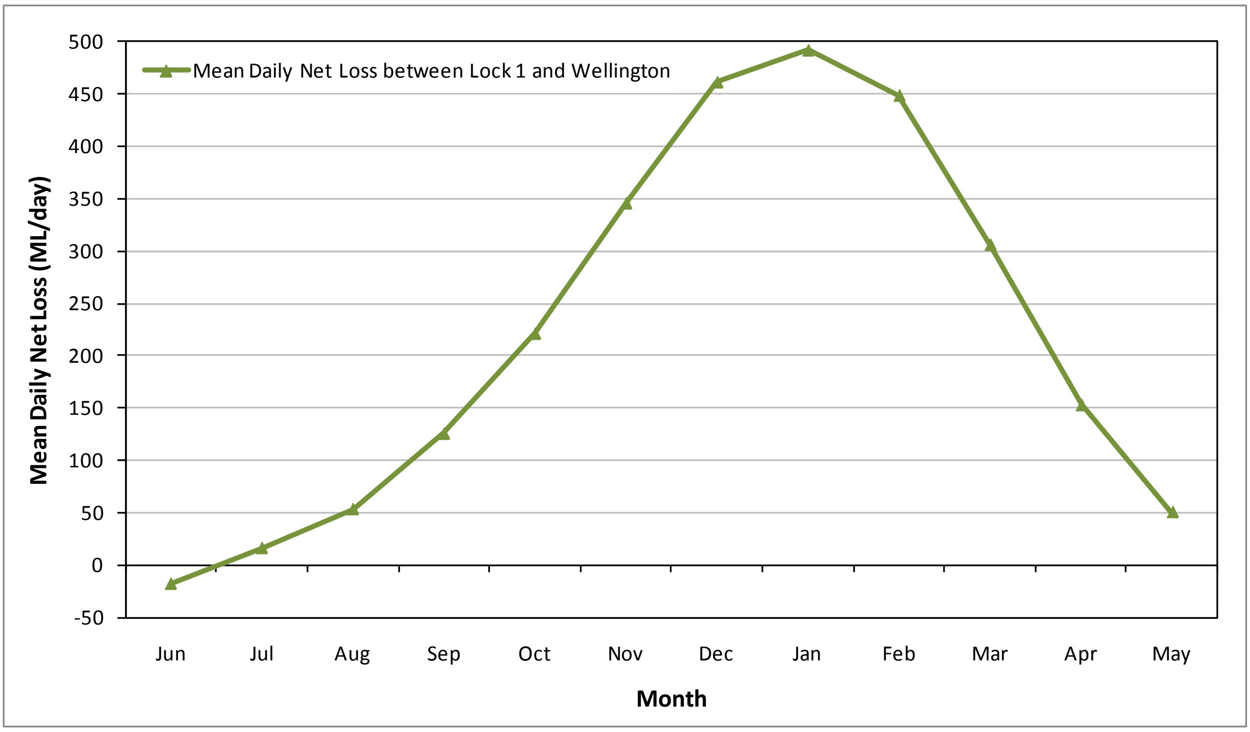



**Figure 9 Mean Daily Net Loss per Month Between Lock 1 and Wellington**

## 2.4.2. RIVER AND LAKE DIVERSIONS

Total annual diversions from Lake Alexandrina and Lake Albert for irrigation, stock and domestic purposes have remained consistent over the period 1975 to 2006, averaging 20 GL (18 to 22 GL range) and 33 GL (30 to 36 GL range) respectively. Figure 10 shows the monthly distribution of these annual values used in the modified historical model.

It is recognised that in recent years, diversions from both lakes have reduced or essentially ceased. With the construction of major stock, domestic and irrigation pipelines that pump water from upstream at Tailem Bend, it is uncertain if the level of diversions that will occur from the lakes once levels increase. However, given that diversions have or will soon recommence via the new pipelines, the net impact on lake levels and salinity from diversions upstream, or from the lakes themselves, are likely to be negligible.

The main river channel between Lock 1 and Wellington includes four major water supply pumping stations in addition to irrigation and other stock and domestic diversions. As the flow in each month at Lock 1 was calculated to preserve the required inflow to Lake Alexandrina (given the net loss between Lock 1 and Wellington), assumptions for these diversions were not required. If these diversions had been included, the flow at Lock 1 would have been adjusted to again ensure the preservation of the required inflow to Lake Alexandrina.

Extractions between Lock 1 and Wellington will affect the quantity of salt entering Lake Alexandrina. However, because the Lake Alexandrina inflow salinity was reset at Wellington using the relationship defined in Section 2.4.4, assumptions for these diversions were again not required.

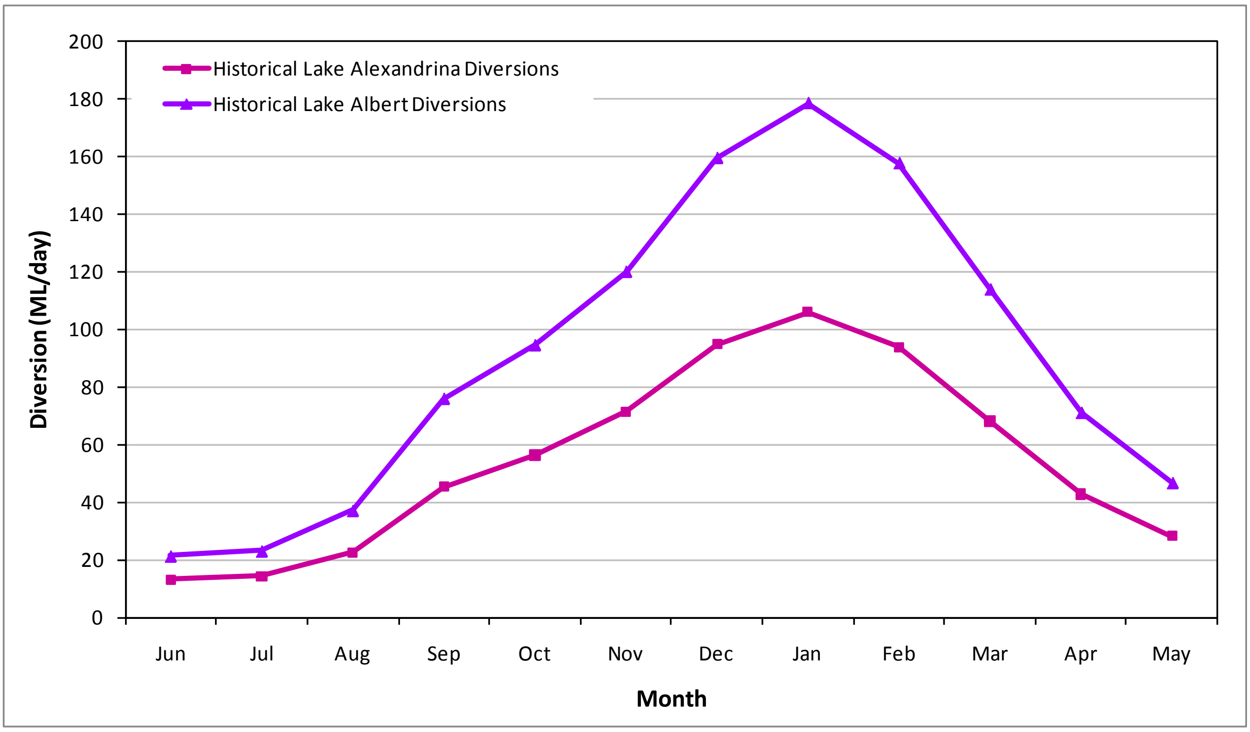



**Figure 10 Historical Lower Lakes Mean Daily Irrigation Extractions**

## 2.4.3. LAKE ALEXANDRINA GROUNDWATER SALT INFLOWS

Salt load inflows from groundwater are calibrated for each reach to match observed salinity data at various monitoring locations along the river. Figure 11 shows the estimated daily salt inflow to Lake Alexandrina for each month from 1975 to 1998, which includes salt inflows from both groundwater and the EMLR tributaries. From this data, mean monthly salt inflow rates were calculated and used in the model as shown in Figure 12.

It is recognised that salt load inflows in recent years have been lower than those shown in Figure 11, however, since 1998 there has been limited calibration by the MDBA to match observed salinity data for benchmark model runs. The salt loads shown here are considered representative of those likely during the flow regimes required to maintain threshold salinity levels in the lakes. As such, calibration of salt load inflows from 1999 until 2007 was not considered necessary for this investigation.

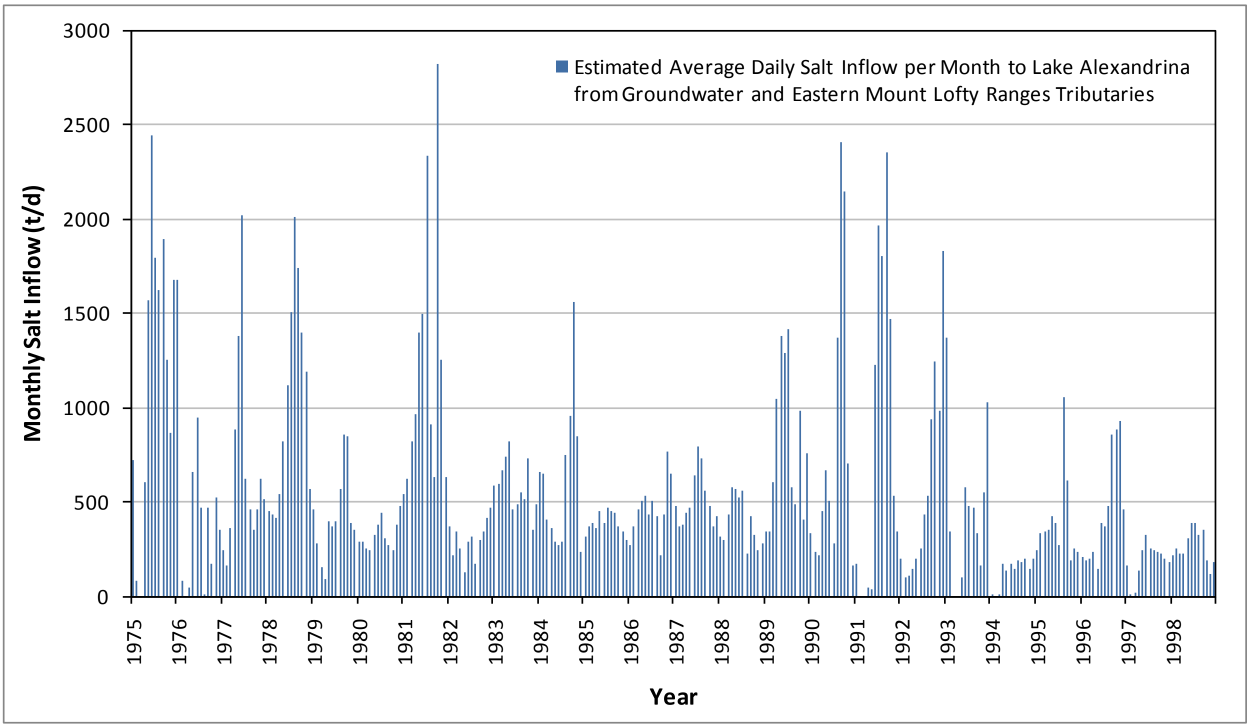



**Figure 11 Average Daily Salt Inflows per Month to Lake Alexandrina (1975 to 1998) from Groundwater and Eastern Mount Lofty Ranges Tributaries**

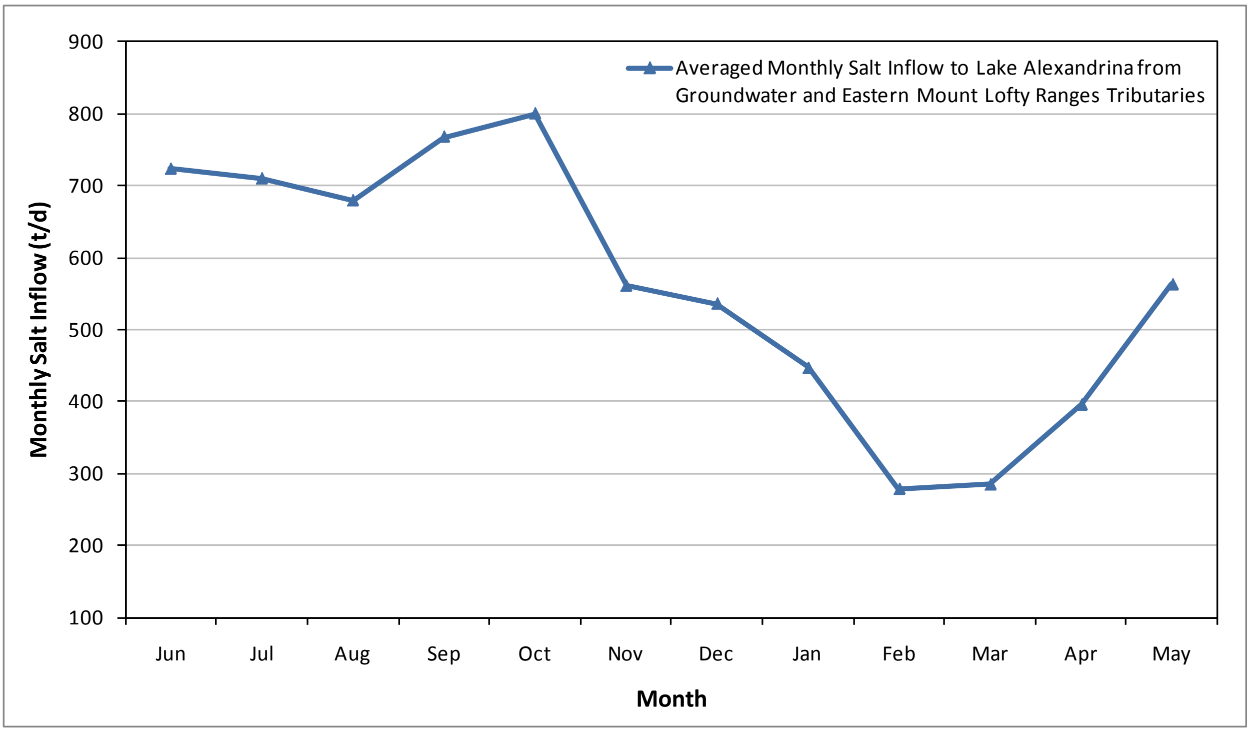



**Figure 12 Averaged Monthly Salt Inflow to Lake Alexandrina from Groundwater and Eastern Mount Lofty Ranges Tributaries**

### 2.4.4. LAKE ALEXANDRINA INFLOW SALINITY

The boundary condition for salinity during each historical model run was reset at Wellington to remove the influence of any diversions between Lock 1 and Wellington. This also removed the requirement to consider assumptions for these diversions. An analysis of the magnitude and salinity of inflow to Lake Alexandrina from the current conditions model run was undertaken to determine an appropriate inflow-salinity relationship that could be applied to all inflows at Wellington.

Figure 13 shows the salinity of historical inflows to Lake Alexandrina. Large variations for a given flow rate are evident, particularly for flows less than 40,000 ML/day. The flow regime required to manage salinity in the Lower Lakes will be sensitive to the inflow-salinity relationship developed for this data and as such, it was important to consider the factors that affect this relationship.

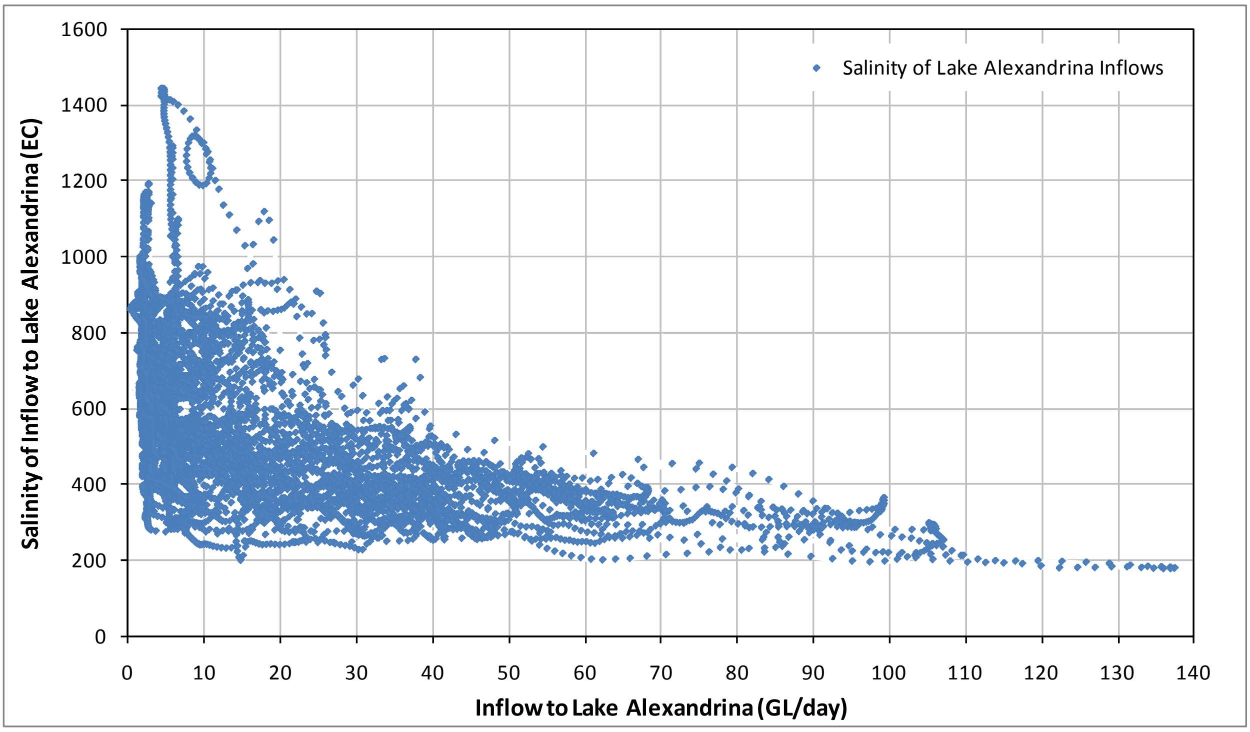



**Figure 13 Salinity of Historical Inflows to Lake Alexandrina**

The salinity of inflow to Lake Alexandrina is principally dependent on two factors:

1. The source of the flow to South Australia
2. The rate of flow through South Australia

There is often significant variation in the salinity of water held in the different major storages across the Murray-Darling Basin system. Water sourced from Dartmouth or Hume Dams generally has lower a salinity than water from Menindee Lakes. The salinity of the resulting flow to South Australia is further influenced by the use of Lake Victoria, both as a balancing storage but also as an option for reducing high salinity water before it enters South Australia.

Inflow rates in the lower flow range of less than 20,000 ML/day and particularly less than 10,000 ML/day were found to be critical for meeting the requirements for salinity management in the Lower Lakes, which is the flow range with the highest variation in salinity as shown in Figure 13. During extended low flow periods, inflows are more likely to be sourced from Hume Dam whereas during shorter low flow periods, or those following a high flow event, inflows may originate from a variety of locations including Menindee Lakes.

Significant salt loads enter the River Murray in South Australia each day. As a result, the salinity of inflow into Lake Alexandrina also reflects the flow rate and hence the amount of salt accumulated as the water flows through South Australia. As an example, during the recent low flow period from 2007 to 2010, the travel time from the South Australian border to Lake Alexandrina was often in the order of six months and the salinity increased markedly. For a low flow period following a high flow event, the salt load accumulated may also increase due to floodplain salt returns.

Due to the above, it was important to analyse the sequencing of historical inflow and salinity data with the overall variation shown in Figure 13. To do this, sequences of salinity data from both low and high flow periods across the full dataset were evaluated to determine if the overall variation in inflow salinity was due to separate events, that is, if some events have consistently higher inflow salinities while others have consistently lower salinity. If this was the case, the relationship could be developed to avoid any bias, such as an overstatement of adverse salinity impacts during extended low flow periods or an understatement of the benefits of higher flows.

This analysis found that there was no observable pattern between individual high and low flow periods and the associated inflow salinity data for those periods (i.e. individual low flow periods resulted in both high and low inflow salinity entering Lake Alexandrina). Therefore, it was determined that a regression relationship would provide a suitable representation of data. The broken-line equation determined to best describe the inflow-salinity relationship is shown in Figure 14. Additional break-points did not significantly improve this relationship. For inflows up to 100,000 ML/day, the salinity data from individual events were scattered around these regression lines. This relationship was then used to model Lake Alexandrina inflow salinity for the full modelled period.

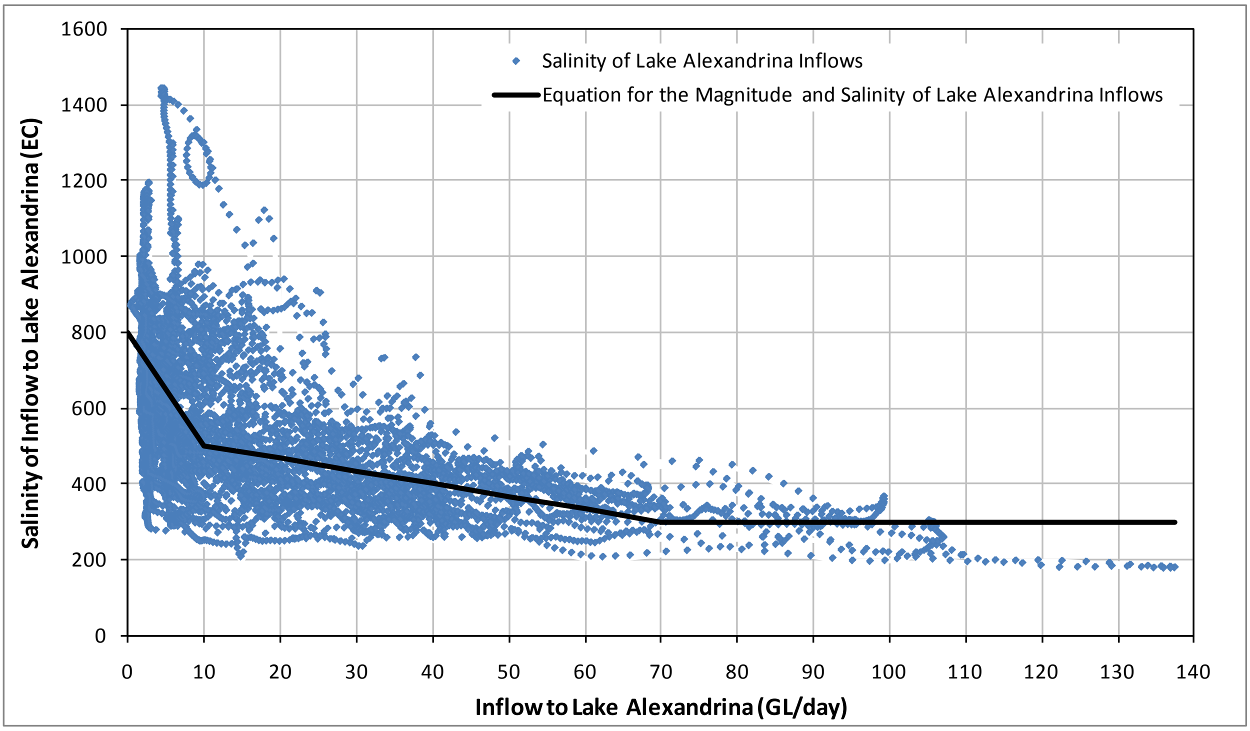



**Figure 14 Relationship between the Magnitude and Salinity of Lake Alexandrina Inflows**

The adopted relationship overestimates the salinity of very high inflows however there are only a smaller number of points and the resulting flow regimes were not found to be sensitive to flows in this range.

### 2.4.5. INTRA-ANNUAL DISTRIBUTION OF LAKE INFLOWS

Total annual inflows have been distributed as per the intra-annual distribution from the historical record. Figure 15 shows the averaged intra-annual distribution of inflows to Lake Alexandrina and as expected, this compares well with the averaged distribution of historical flows at the South Australian Border and those under natural conditions (pre-regulation). The distribution of entitlement flow as prescribed in the MDB Agreement is also shown in Figure 15, which differs significantly to the other three since it is targeted primarily for irrigated agriculture, rather than a reflection of the occurrence of unregulated flow events. This highlights that the delivery of any targeted environmental water should not follow a pattern of entitlement flows but a delivery pattern representative of natural conditions.

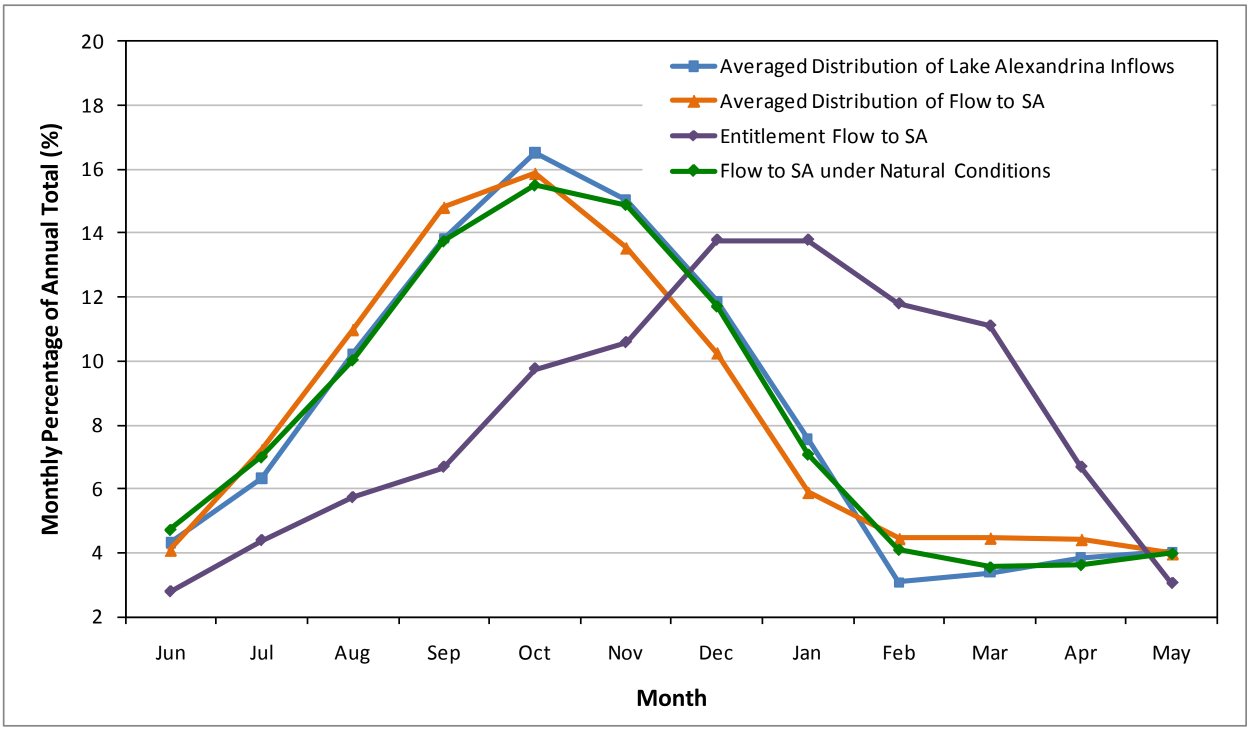



**Figure 15 Averaged Intra-Annual Distribution of Lake Alexandrina Inflow**

### 2.4.6. COMPARISON OF RESULTS FROM MODIFIED MODEL WITH HISTORICAL CONDITIONS MODEL

Lake inflows, barrage outflows and salinities from both the historical conditions and modified models were compared.

Figure 16 shows the Lake Alexandrina inflows and Figure 17 the barrage outflows from both models. As the total volume within each water year is the same, the differences are due solely to the use of the modified intra-annual inflow distribution. In the historical data, peak inflows generally occur for one or two months between June and December. It is difficult to reproduce the intra-annual timing and magnitude of peak inflows and hence outflows, because these peaks occur in different months each year. The difference in intra-annual timing of inflows makes little difference to the annual outflow volume.

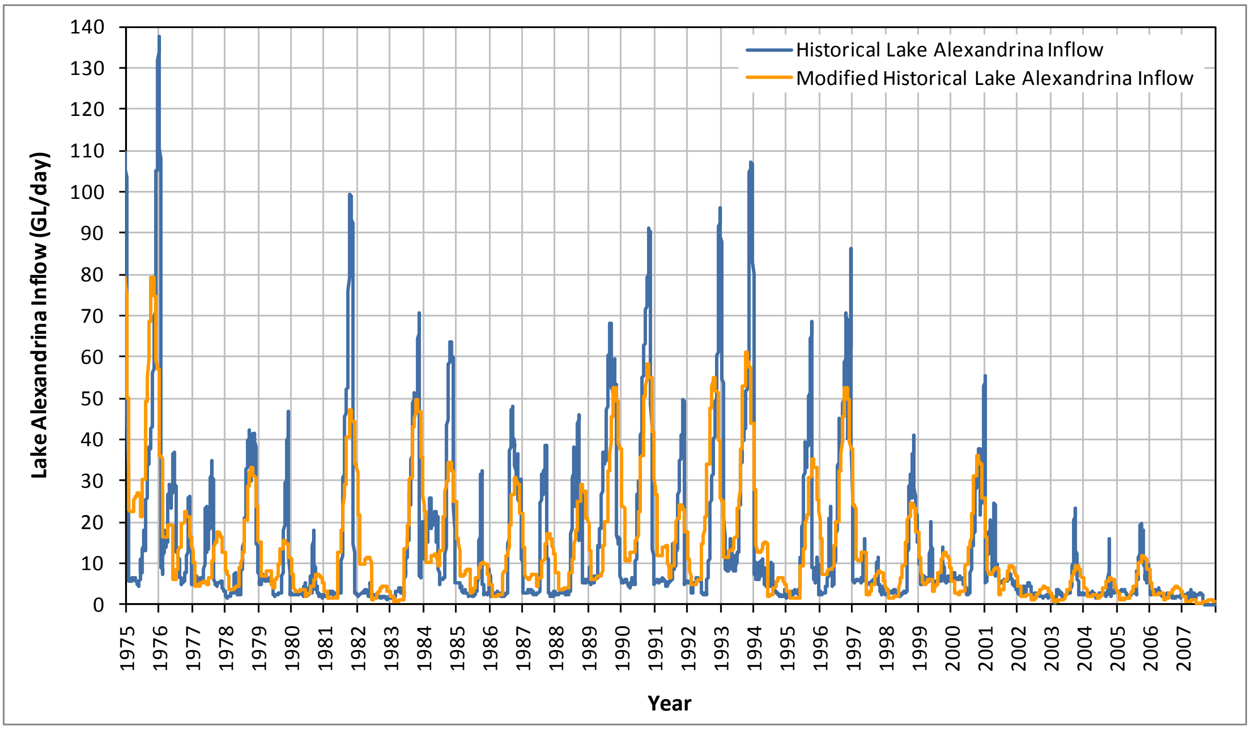



**Figure 16 Modelled Lake Alexandrina Inflow using Modified Intra-Annual Distribution**

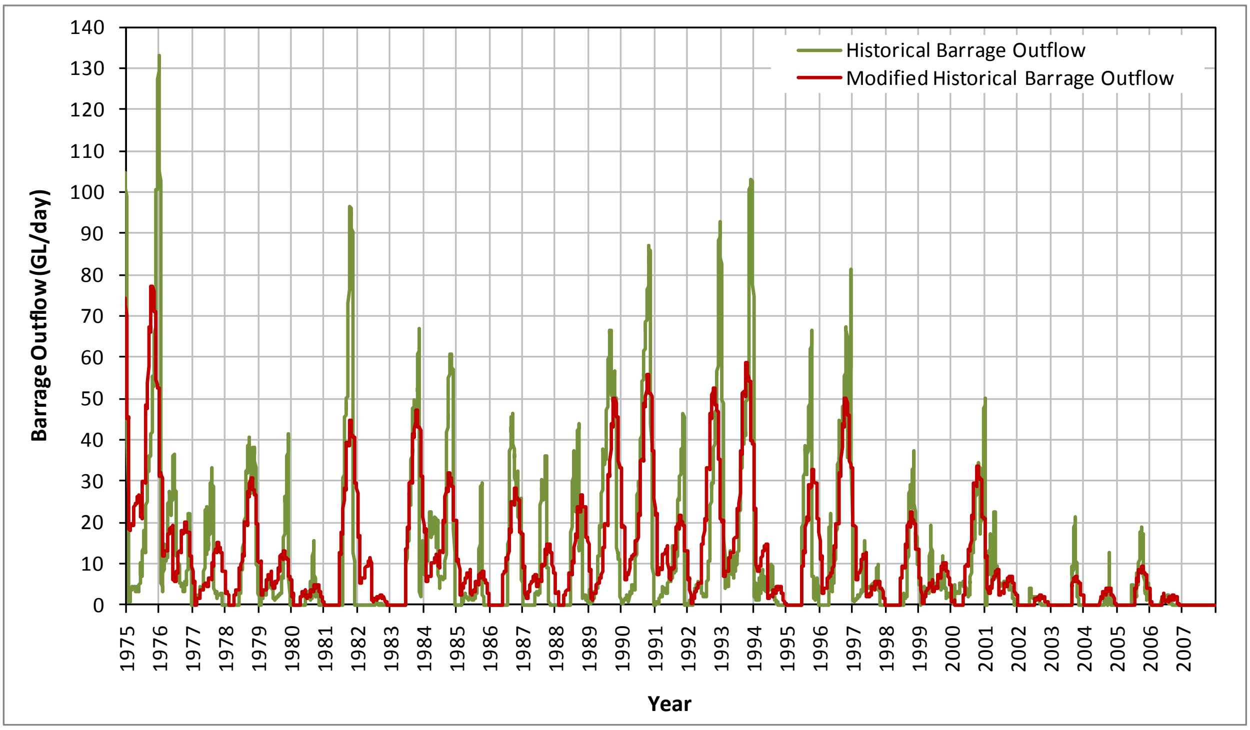



**Figure 17 Modelled Barrage Outflow using Modified Intra-Annual Lake Alexandrina Inflow Distribution**

Figure 18 compares modelled historical Lake Alexandrina salinity with that from the modified model. Given the differences in losses, salt load inflows and intra-annual distribution of inflows and hence barrage outflows, the relationship is considered reasonable. This result further justifies the applicability of the adopted flow-salinity relationship for determining water requirements. Figure 19 compares the modelled historical Lake Albert salinity with that from the modified model.

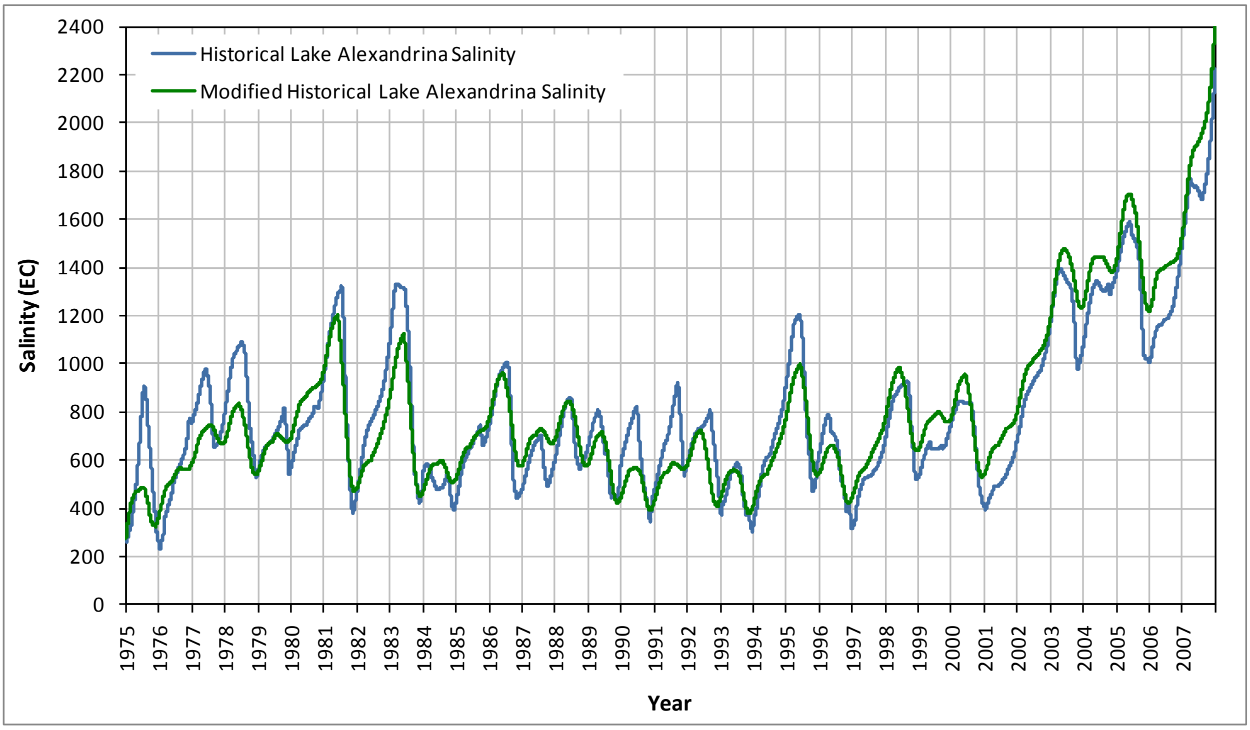



**Figure 18 Modelled Lake Alexandrina Salinity using Modified Model Inputs**

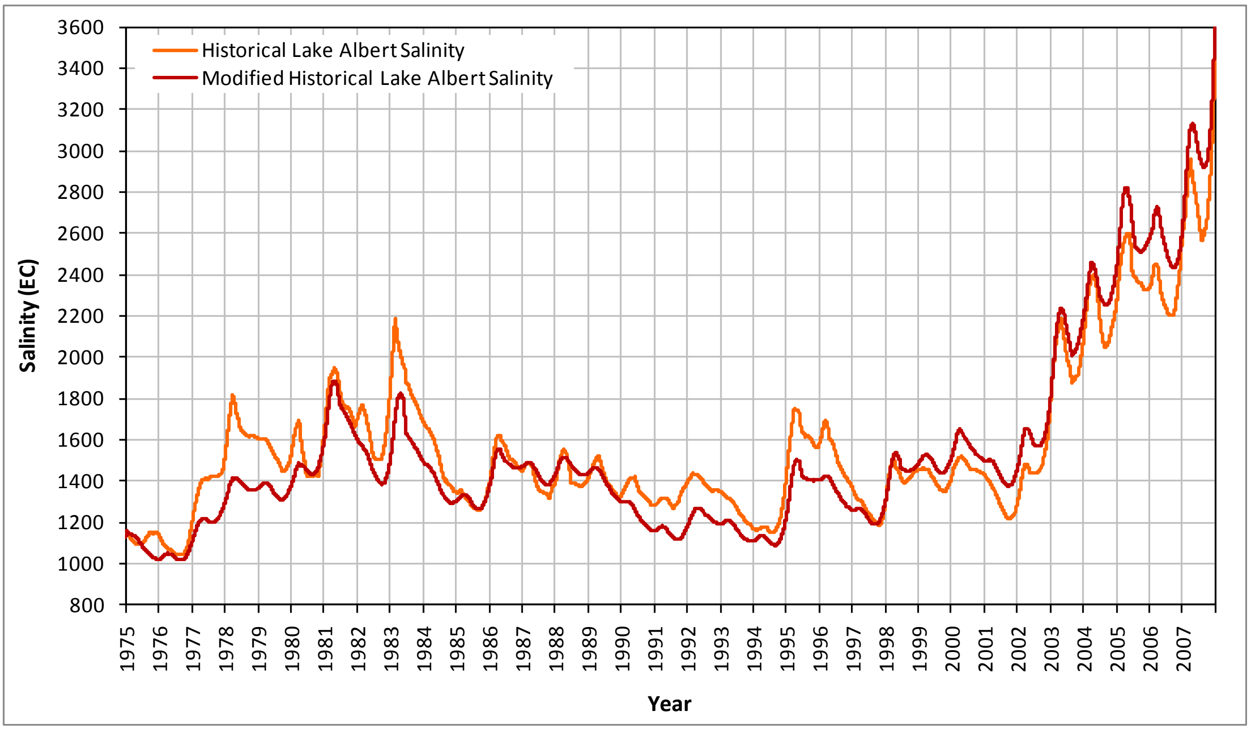



**Figure 19 Modelled Lake Albert Salinity using Modified Model Inputs**

While the reduced magnitude of the outflow peaks does not affect the salinity response within the lakes, it may impact on the salinity, water level and other ecological response within the Coorong and potentially the Murray Mouth. An alternative distribution that attempted to better represent the higher proportion of annual inflows over two to three months was trialled as shown in Figure 20. This was based on an analysis of the proportion of total flow occurring during peak flow months.

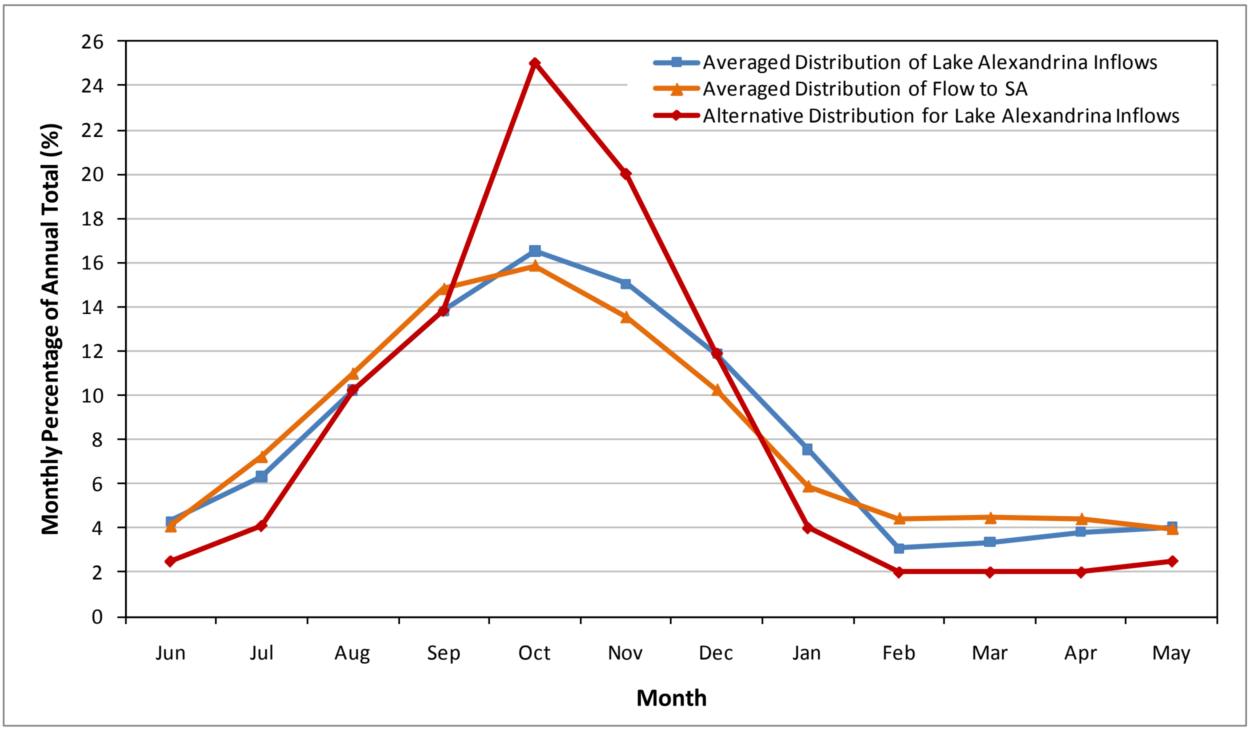



**Figure 20 Alternative Distribution for Lake Alexandrina Inflow**

Figures 21 and 22 show that the alternative distribution achieved a better representation of peak inflows and outflows. However, Figure 23 shows that there is essentially no impact on the salinity response in Lake Alexandrina from using the alternative distribution in preference to the averaged distribution for Lake Alexandrina inflows. As such, the averaged distribution was adopted for use in the modified historical model.

This result was expected given that the both the annual inflow and outflow volumes are consistent between both models and it is concluded that using the average inflow distribution is sufficient for this investigation. As high outflows have historically resulted from unregulated flow events, it is expected that the magnitude of peak outflows in any given year would be similar to those in Figure 22.

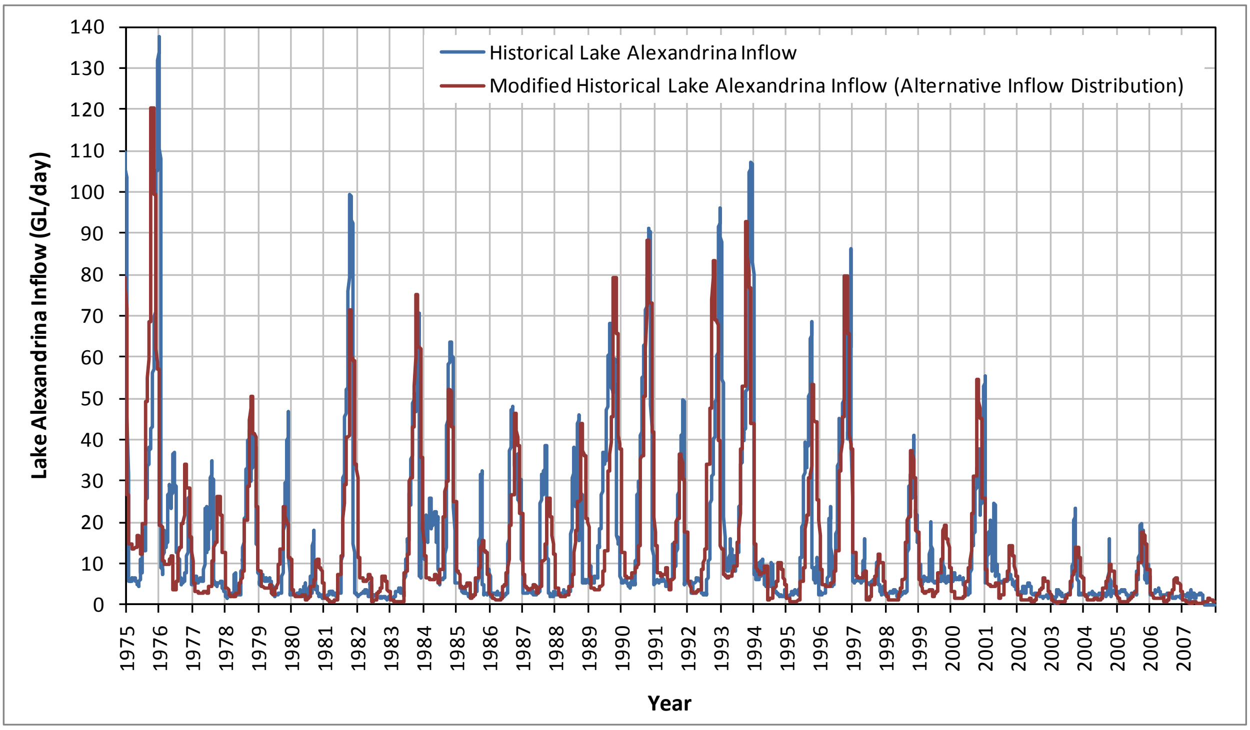



**Figure 21 Modelled Lake Alexandrina Inflow using Alternative Intra-Annual Distribution**

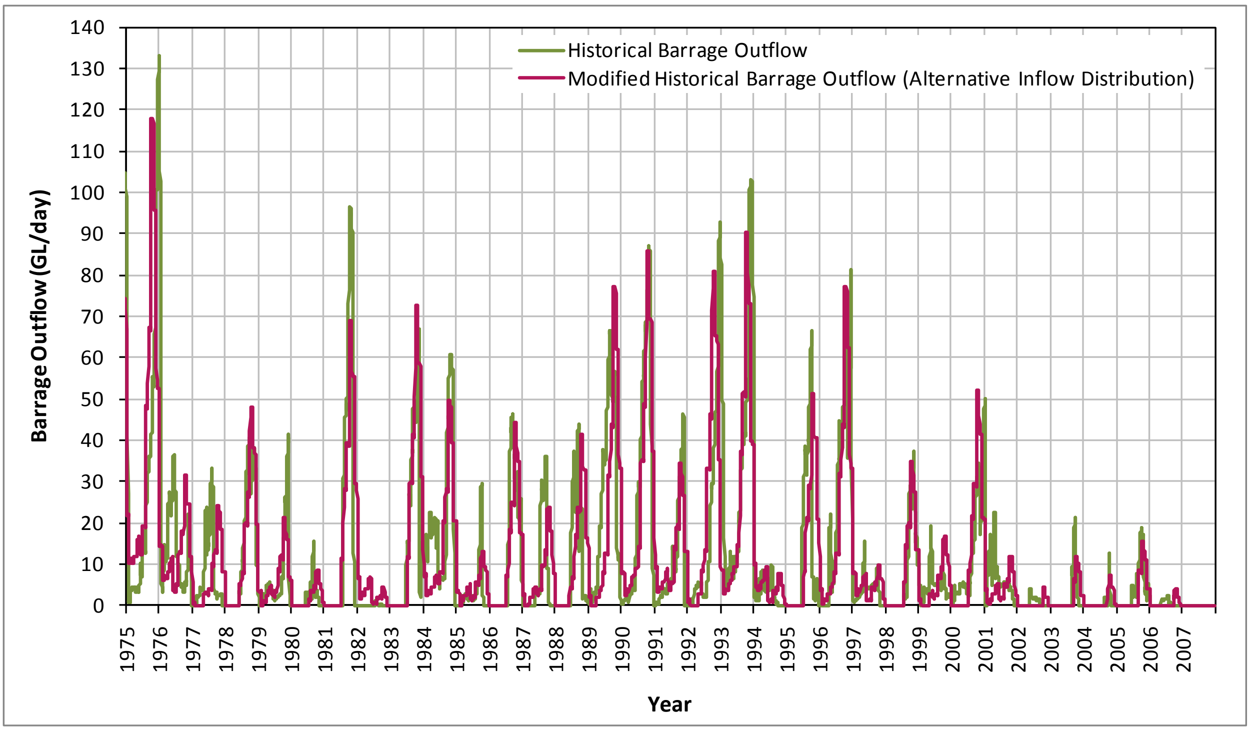



**Figure 22 Modelled Barrage Outflow from Alternative Intra-Annual Inflow Distribution**

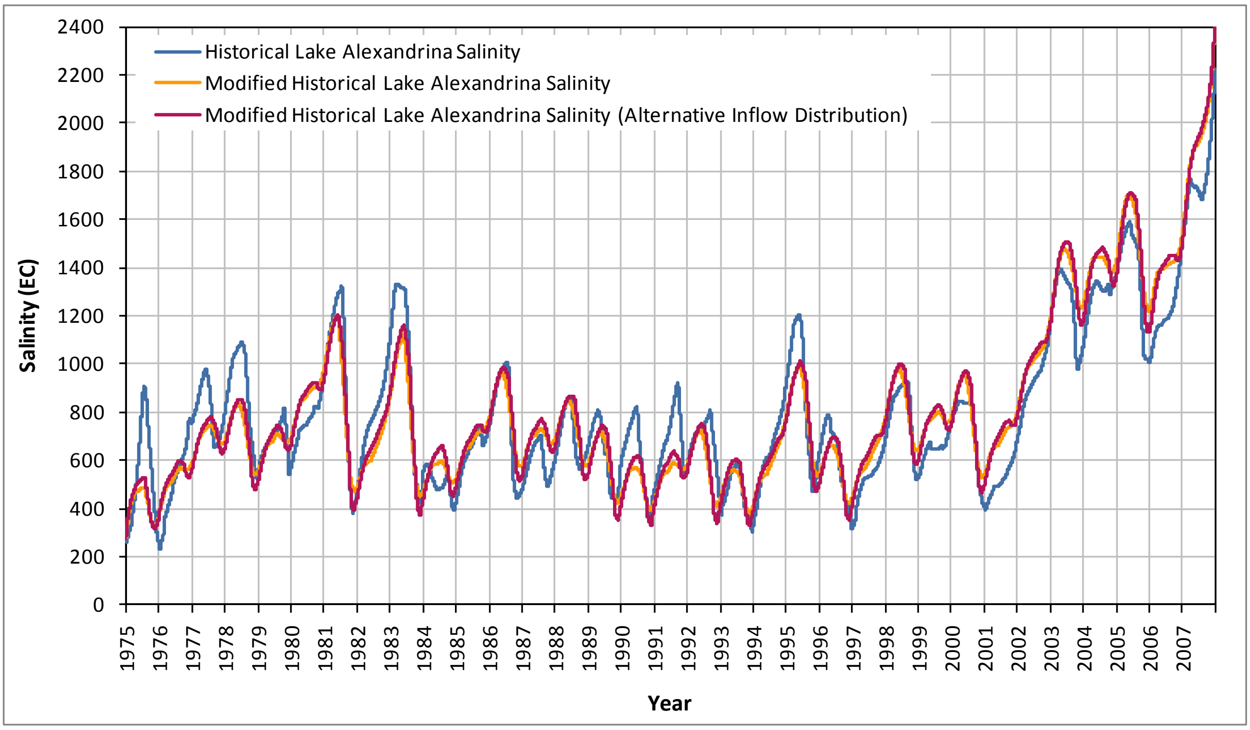



**Figure 23 Comparison of Modelled Lake Alexandrina Salinities using Averaged and Alternative Inflow Distributions**

# 3. DEVELOPMENT OF FLOW REGIMES FOR SALINITY THRESHOLD TARGETS

## 3.1. OVERVIEW

This section describes the development of the flow regimes required to deliver a number of potential salinity threshold targets for Lake Alexandrina. As lake inflows and barrage outflows are not directly measured, this analysis was undertaken using the modelled data under historical climate conditions and the current system operating and water sharing rules under the MDB Agreement. The analysis of lake inflows and barrage outflows is analysed over the entire modelled period from 1891/92 to 2007/08.

Given the limited input data available, the river and lake salinities that are modelled within the standard *BIGMOD* setup are only available from 1975. Therefore, the initial analysis of salinity and its relationship with other variables in Sections 3.2 to 3.4 is reported from 1975/76 to 2006/07. The shortened end date is due to the changed relationship that resulted from the disconnection of Lakes Alexandrina and Albert in late 2006/07 (refer Section 2.3).

## 3.2. CHARACTERISTICS OF HISTORICAL LAKE ALEXANDRINA INFLOWS, BARRAGE OUTFLOWS AND SALINITY

The high variability of inflows to the Lake Alexandrina and barrage outflows is highlighted by the statistics shown in Table 2 and the annual outflow totals in Figure 24.

**Table 2 Historical Lake Alexandrina Inflow and Barrage Outflow Statistics**

| Statistics | Annual Lake Inflow (GL) | | Annual Barrage Outflow (GL) | |
|---|---|---|---|---|
| | 1891/92 - 2007/08 | 1975/76 - 2007/08 | 1891/92 - 2007/08 | 1975/76 - 2007/08 |
| Mean | 5780 | 4960 | 4925 | 4110 |
| Median | 3920 | 4230 | 3020 | 3315 |
| Minimum | 195 | 195 | 0 | 0 |
| Maximum | 45790 | 14900 | 44850 | 14000 |
| 10th Percentile | 1110 | 920 | 260 | 185 |
| 90th Percentile | 12075 | 10245 | 11215 | 9435 |

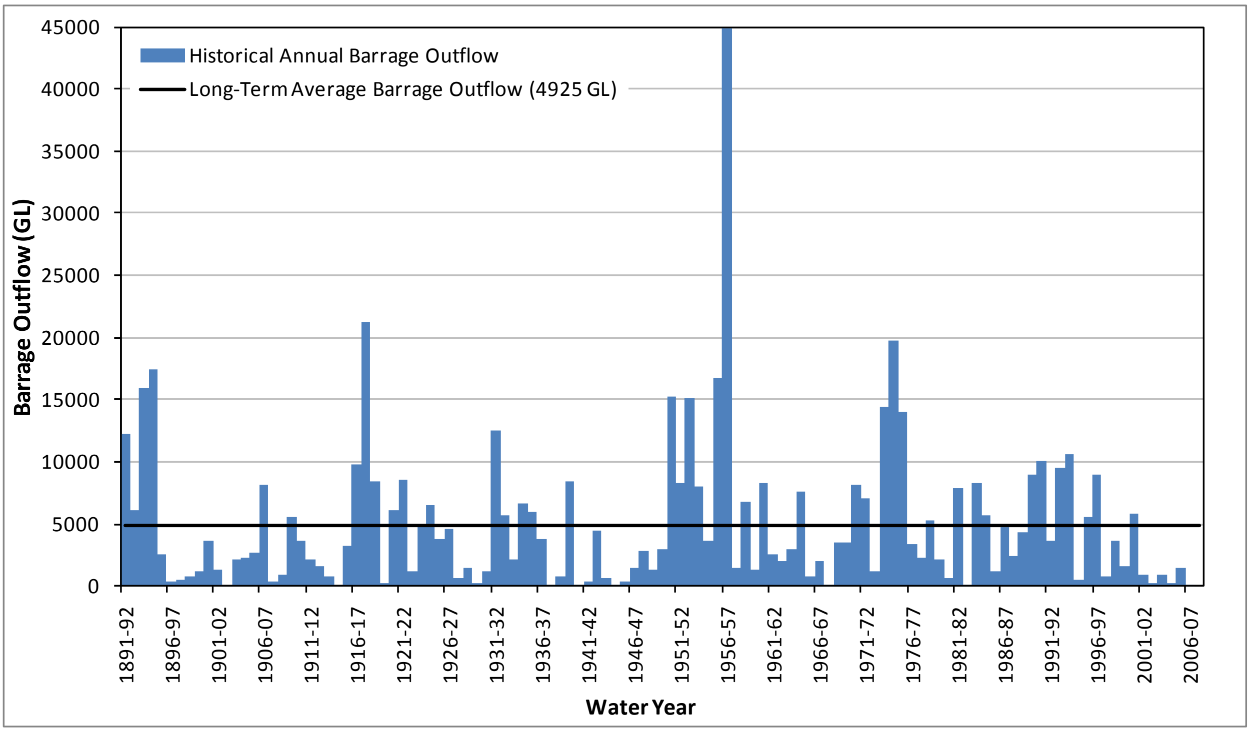



**Figure 24 Historical Annual Barrage Outflows**

Figure 25 shows the decadal variability in barrage outflows, highlighting extended periods of above and below average outflows. Note that the "Average Outflow for Decade" is the average outflow over non-overlapping ten year periods while the "10 Year Moving Average" is the average over successive ten year periods, each displaced by one year.

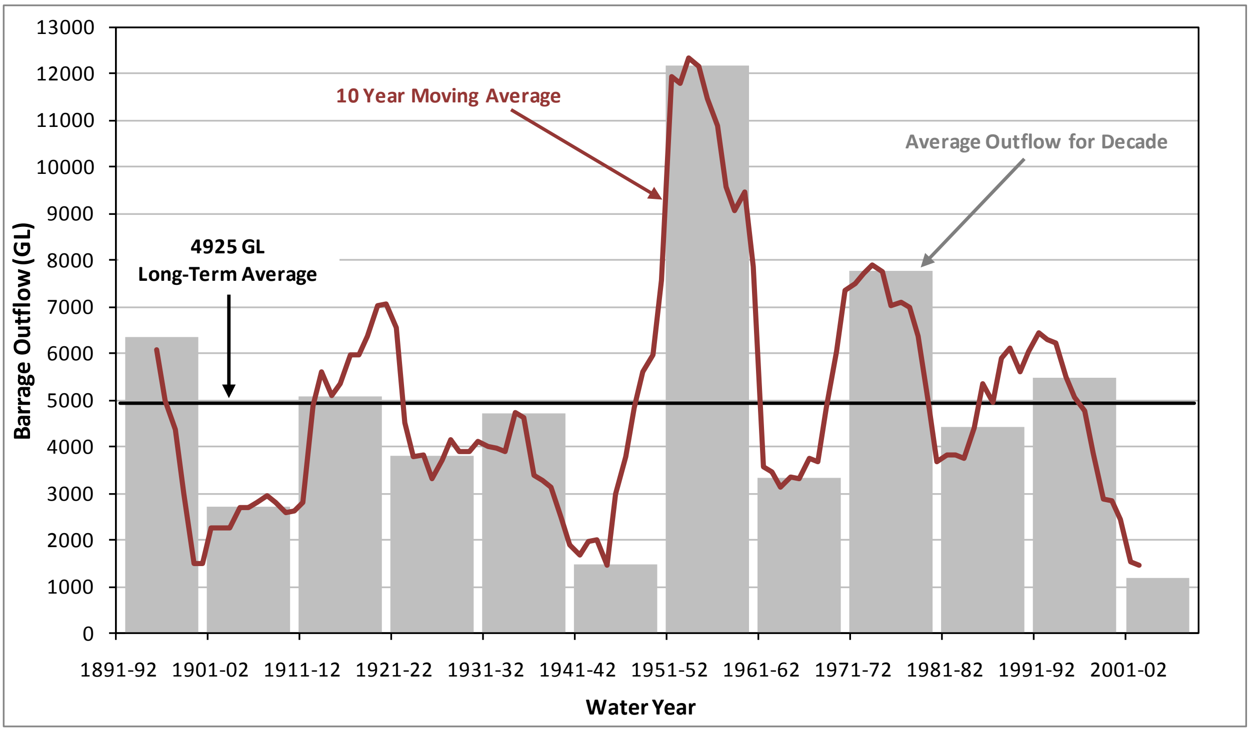



**Figure 25 Decadal Variability in Barrage Outflows**

Figure 26 shows the annual flow frequency curve. The frequency curves are similar for outflows below 10,000 GL per year (at around the 12% exceedance probability).

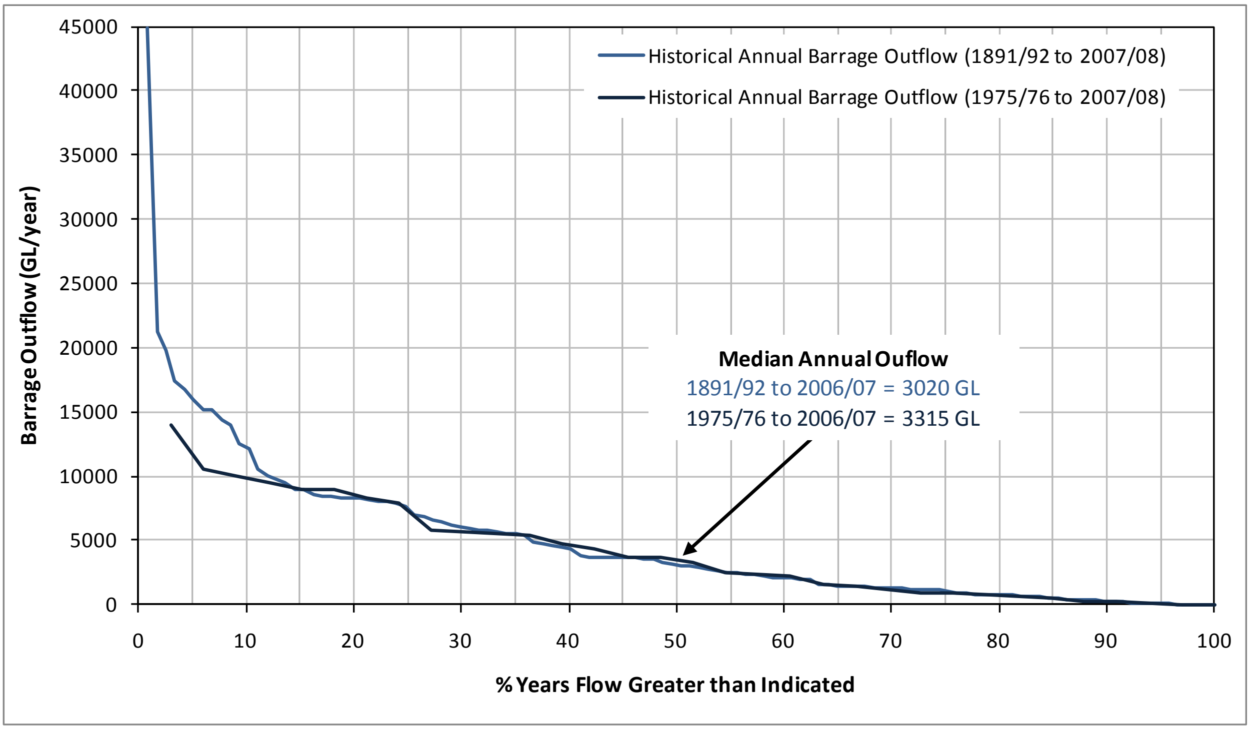



**Figure 26 Annual Barrage Outflow Frequency Curve**

Prior to 1975/76 there were nine years above 14,000 GL (the maximum outflow since 1975/76). Of these, four occurred during the wetter decade of the 1950s, two in the late 1890s and two in the years immediate prior to 1975/76 itself. With the exception of the years with the highest 10% of barrage outflows, this suggests that the variability across the shorter 1975/76 to 2007/08 period is similar to that across the longer 1891/92 to 2007/08 period.

Table 3 shows the statistics for modelled historical and observed Lake Alexandrina salinity and Figure 27 the frequency distribution of daily values. While the frequency distributions for both modelled historical and observed data are generally similar, there is some deviation with the frequency of salinities in the 900 to 1300 EC range.

**Table 3 Historical Lake Alexandrina Salinity Statistics (1975/76 to 2006/07)**

| Statistics | Lake Alexandrina Salinity (EC) | |
|---|---|---|
| | Observed | Modelled |
| Mean | 800 | 785 |
| Median | 725 | 715 |
| Minimum | 255 | 230 |
| Maximum | 1685 | 1765 |
| 10th Percentile | 420 | 460 |
| 90th Percentile | 1305 | 1280 |

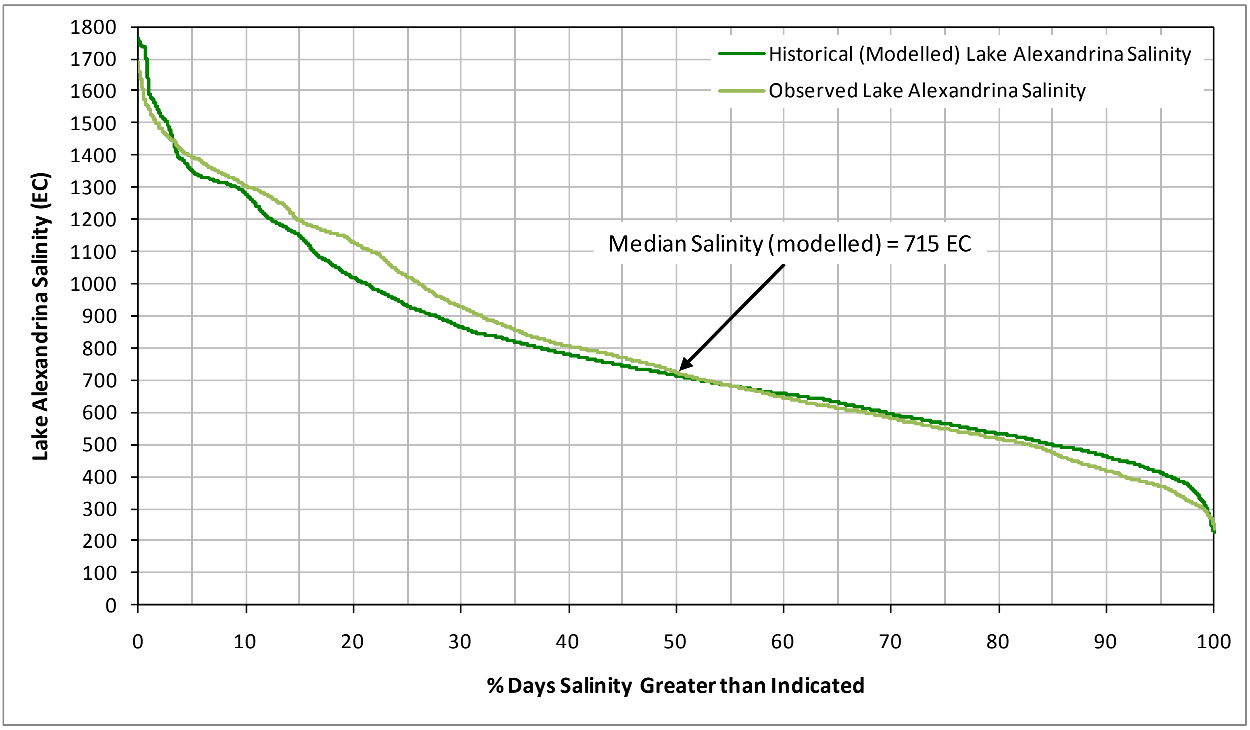



**Figure 27 Daily Salinity Frequency Curve for Lake Alexandrina (1975/76 to 2006/07)**

Salinity greater than 900 EC for 30% of days and greater than 1300 EC for 10% of days is represented well in both cases. However, between these the frequency of the observed salinities is underestimated. For example, the observed data shows salinities greater than 1000 EC for 25% of days but the modelled historical data only represents salinities greater than 1000 EC for 20% of days. While this range contains the target threshold value of 1000 EC, the small magnitude of the underestimated frequencies (up to 5%) is not likely to significantly affect the outcomes from this investigation.

Figure 27 showed the frequency of increasing salinities but not the duration that the salinity remains at these levels. Table 4 shows that for the modelled historical data from 1975/76 to 2006/07 there have been an equal number of periods, of almost the same average duration, above and below 700 EC (approximately the median value of 715 EC). However, it also shows that while salinity has only increased above 1000 EC seven times, it remained at this level for a significant length of time (average of 350 days).

**Table 4 Duration of Salinity in Lake Alexandrina above Threshold Values (1975/76 to 2006/07)**

| Salinity Threshold (EC) | Lake Alexandrina Salinity (EC) | |
|---|---|---|
| | No. Periods | Average Duration (days) |
| < 700 | 19 | 300 |
| > 700 | 19 | 320 |
| > 800 | 16 | 275 |
| > 1000 | 7 | 350 |
| > 1200 | 5 | 285 |
| > 1500 | 2 | 160 |

Table 5 shows the statistics for historical and observed Lake Albert salinity. Figure 28 shows the frequency distributions of daily values, which are generally consistent.

**Table 5 Historical Lake Albert Salinity Statistics (1975/76 to 2006/07)**

| Statistics | Lake Albert Salinity (EC) | |
|---|---|---|
| | Observed | Modelled |
| Mean | 1475 | 1560 |
| Median | 1440 | 1450 |
| Minimum | 965 | 1045 |
| Maximum | 2800 | 2960 |
| 10th Percentile | 1200 | 1220 |
| 90th Percentile | 2155 | 2150 |

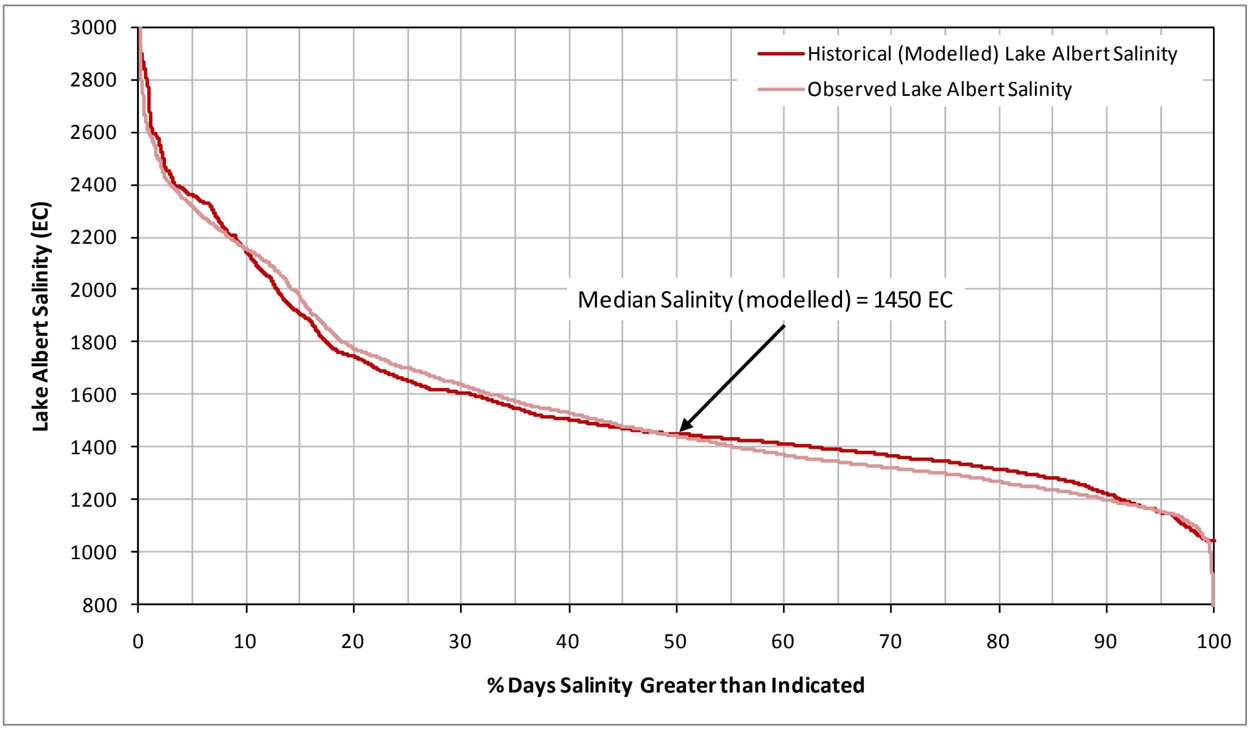



**Figure 28 Daily Salinity Frequency Curve for Lake Albert (1975/76 to 2006/07)**

Table 6 shows that for the modelled historical data from 1975/76 to 2006/07 there have been an equal number of periods, of almost the same average duration, above and below the 1450 EC median salinity. It also shows that while salinity has only increased above 2000 EC three times, once it has increased above this level it has generally remained there for a significant length of time (average of 500 days). Salinities above 2000 EC occur when salinities in Lake Alexandrina are also high (greater than 1000 EC). Given the statistics in Table 4, this indicates that it takes longer for salinities to decrease in Lake Albert than Lake Alexandrina, which is as expected given the narrow connection between the two lakes.

**Table 6 Duration of Lake Albert Salinity above Threshold Values (1975/76 to 2006/07)**

| Salinity Threshold (EC) | Lake Albert Salinity (EC) | |
|---|---|---|
| | No. Periods | Average Duration (days) |
| < 1450 | 12 | 495 |
| > 1450 | 13 | 455 |
| > 1700 | 6 | 430 |
| > 2000 | 3 | 500 |
| > 2300 | 3 | 270 |

## *3.3. RELATIONSHIP BETWEEN HISTORICAL BARRAGE OUTFLOW AND LAKE ALEXANDRINA SALINITY DATA*

The large inter-annual variation in historical barrage outflows has been shown earlier (Figure 24), with outflows ranging from 200 GL in 2006/07 to 45,000 GL in 1956/57. The analysis of historical barrage outflow and the resultant salinity variation is shown below for the period between 1975/76 and 2006/07. With an objective of understanding how the magnitude of outflows affect in-lake salinity, this analysis was undertaken over both single and multi-year sequences.

For Lake Alexandrina, the variation in average annual salinity with barrage outflow is shown in Figure 29. For outflows greater than 1000 GL per year, the annual average salinity is generally between 500 and 800 EC. This is likely to be a result of a combination of inflow salinities in the current year and the volume and salinity of inflows in the preceding year(s). It also shows that salinities generally rise above 800 EC once the annual barrage outflow falls below 1000 GL. The relationship for Lake Albert shown in Figure 30 is similar, which is expected given the close relationship between salinities in the two lakes.

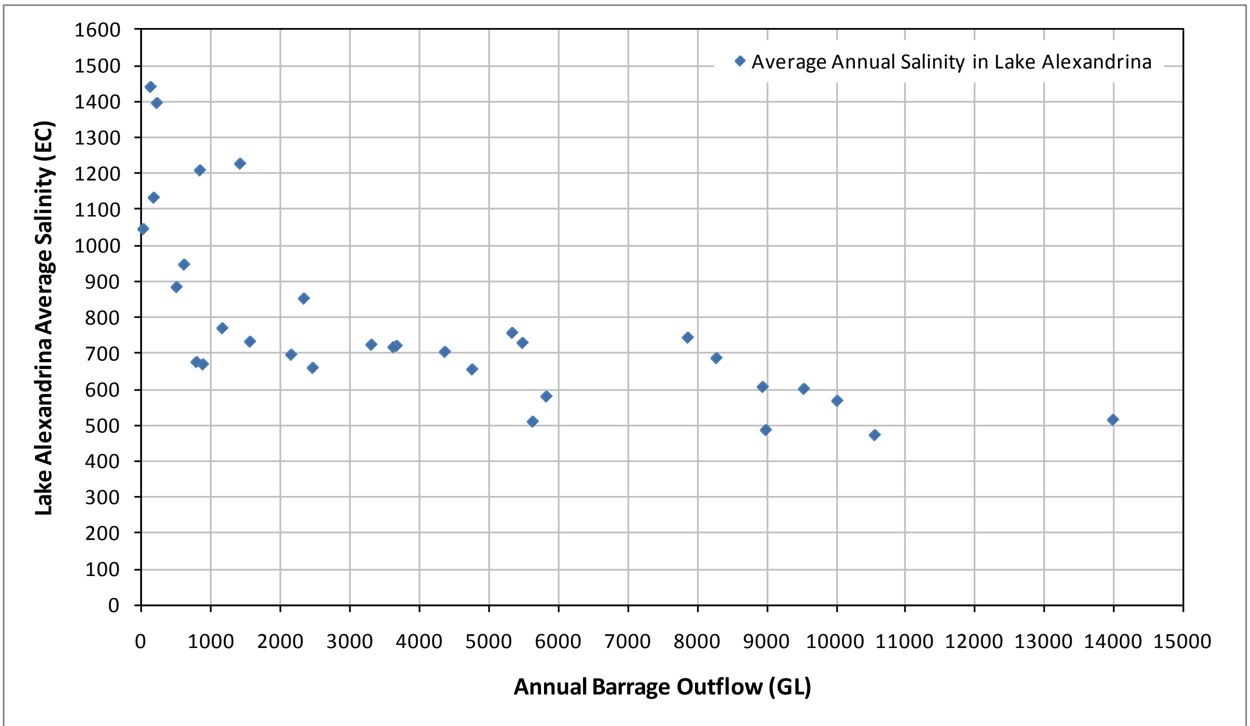



**Figure 29 Total Annual Barrage Outflow and Average Salinity in Lake Alexandrina**

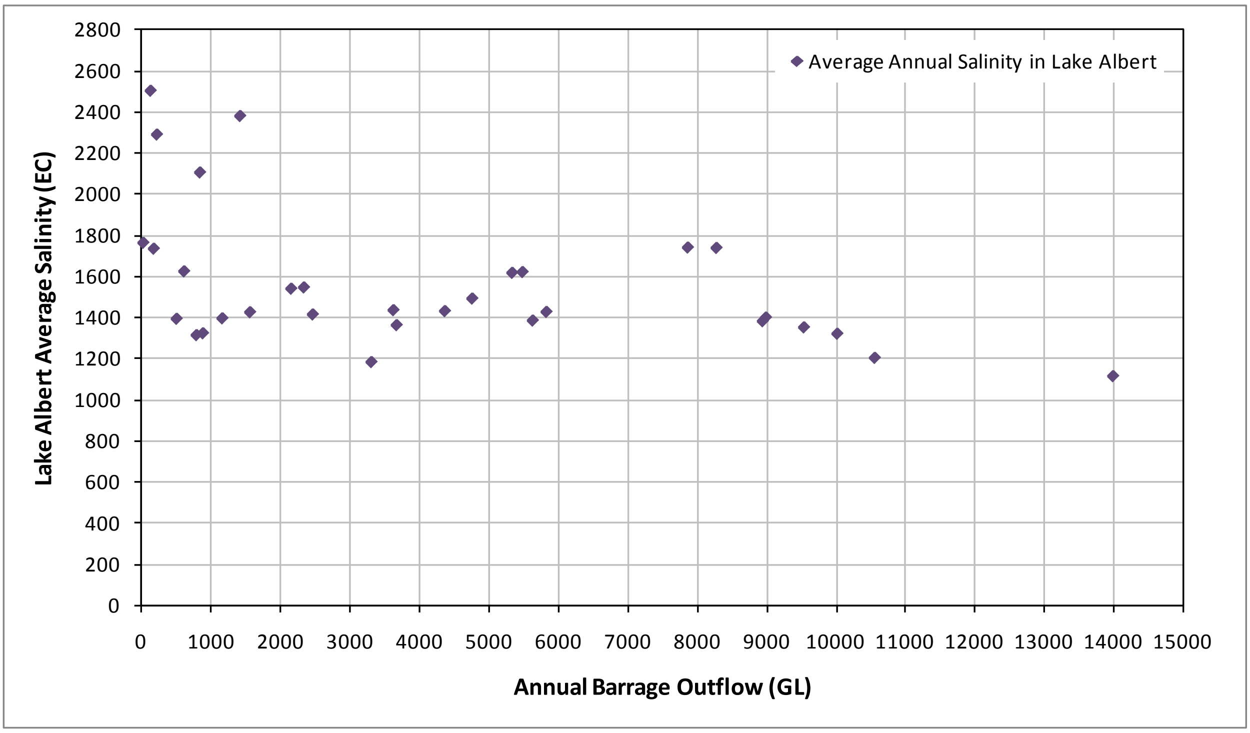



**Figure 30 Total Annual Barrage Outflow and Average Salinity in Lake Albert**

The significance of Lake Alexandrina inflow and salinity in preceding years on average salinity in Lake Alexandrina in a given year has been examined in this investigation using multi-cumulative barrage outflow totals. Sequences of up to ten years were considered but two- and three-year cumulative barrage outflow totals were found to be the most critical.

For a two-year cumulative barrage outflow, Figure 31 shows that salinity within Lake Alexandrina is generally maintained within the 500 to 800 EC range whilst the two-year cumulative barrage outflow over the current and previous year remains above 4000 GL. Salinities increase above 900 EC once outflows fall below this level.

For a three-year cumulative barrage outflow, Figure 32 shows that while most salinity levels in Lake Alexandrina are between 500 and 800 EC for total outflows greater than 6000 GL, there are a number of points outside of this salinity band with values as high as 1100 EC. This indicates that while a three-year cumulative barrage outflow greater than 6000 GL is generally sufficient to maintain salinities less than 800 EC, the inter-annual distribution of outflows within the three-year period is likely to be important. Once outflows fall below 6000 GL, salinities rise above 1100 EC. In contrast, Figure 33 shows that average salinities in Lake Albert remain within a similar range to Figure 30 for barrage outflows greater than 6000 GL.

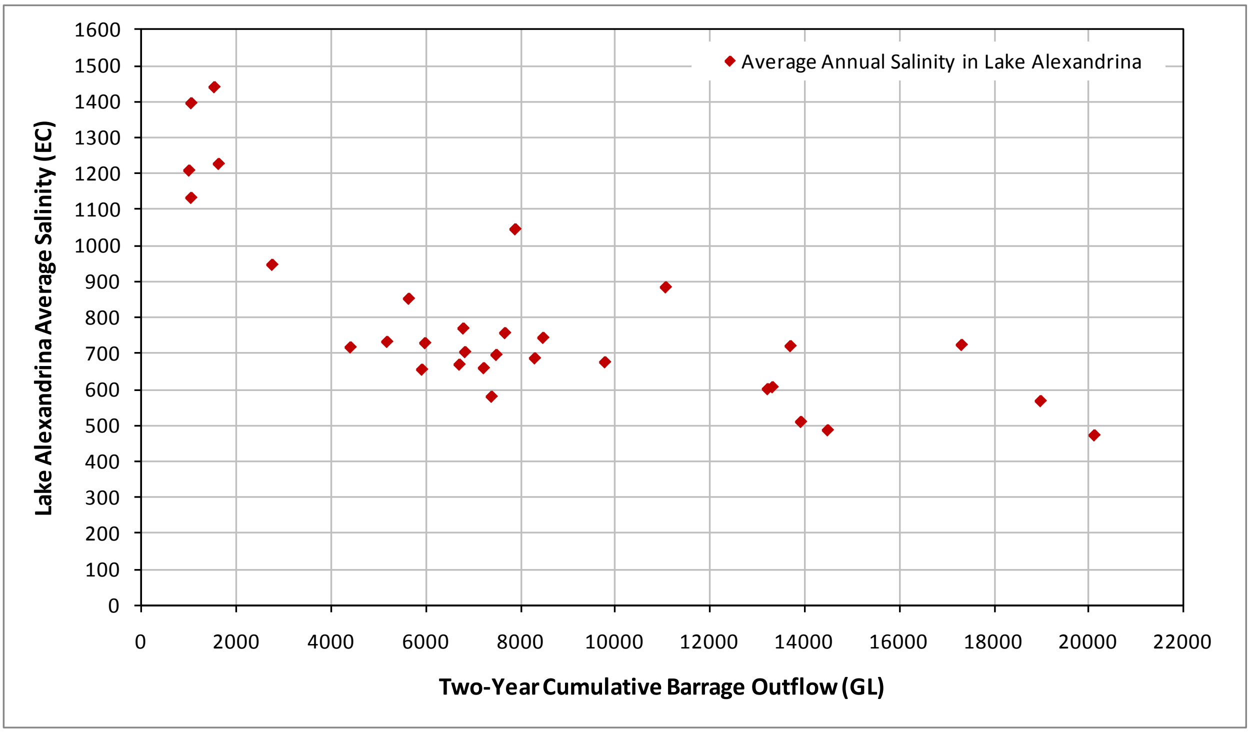



**Figure 31 Two-Year Cumulative Barrage Outflow and Average Annual Salinity in Lake Alexandrina**

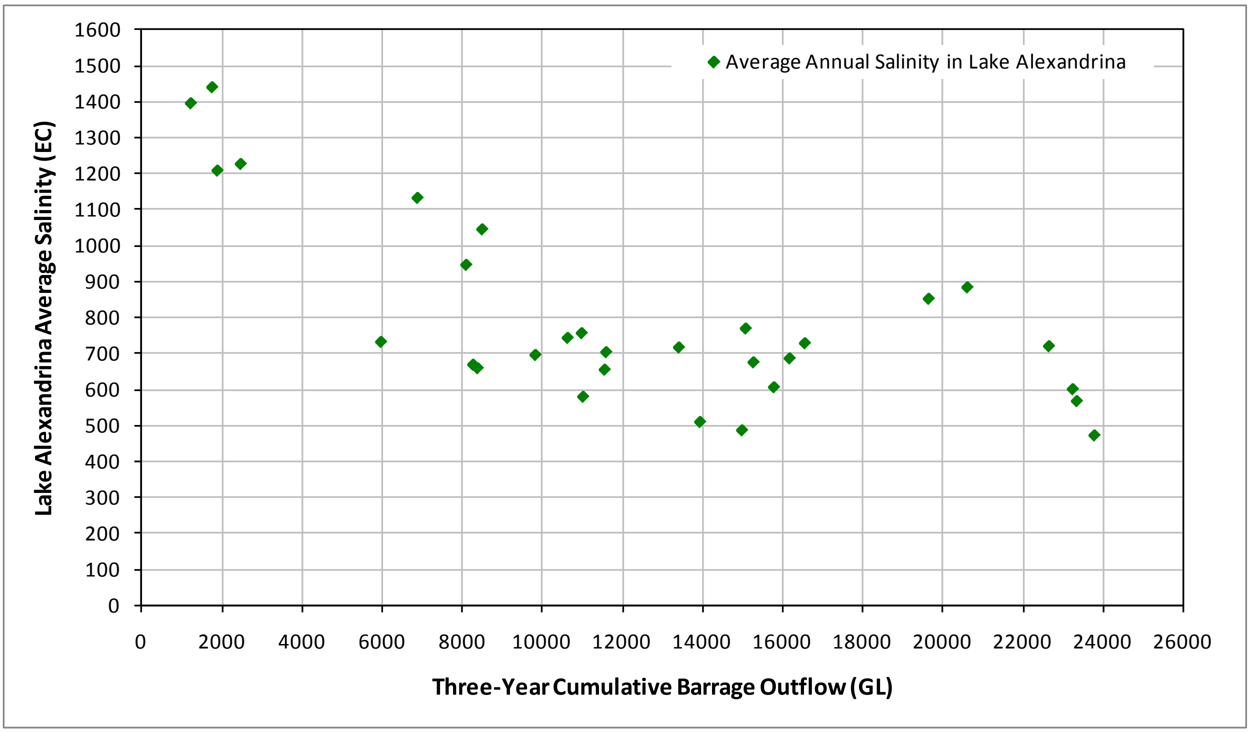



**Figure 32 Three-Year Cumulative Barrage Outflow and Average Annual Salinity in Lake Alexandrina**

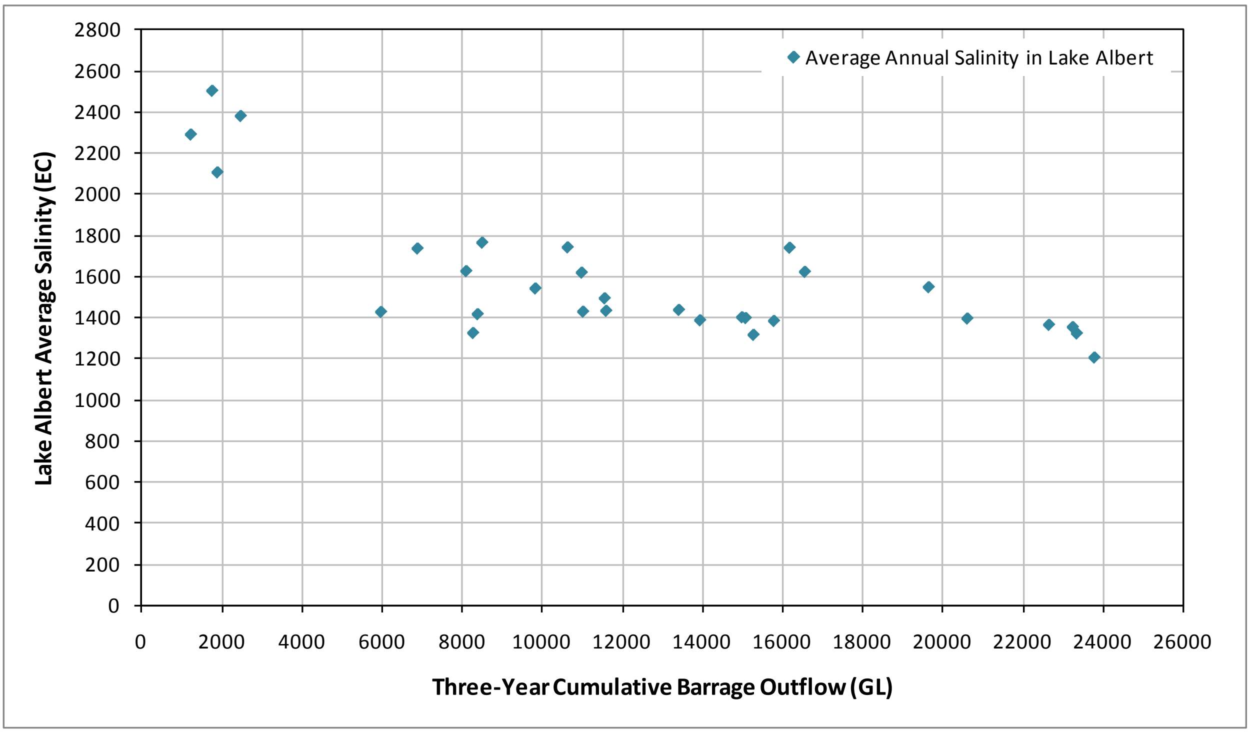



**Figure 33 Three-Year Cumulative Barrage Outflow and Average Annual Salinity in Lake Albert**

The effect of the sequence of actual outflow on salinity was then considered. Figure 34 highlights that once the cumulative three-year barrage discharge fell below 6000 GL, the salinity began to increase. During the period between 1987/88 and 2001/02 the three-year cumulative outflows were significantly greater than 6000 GL but once this cumulative total dropped, the salinity began rising quickly.

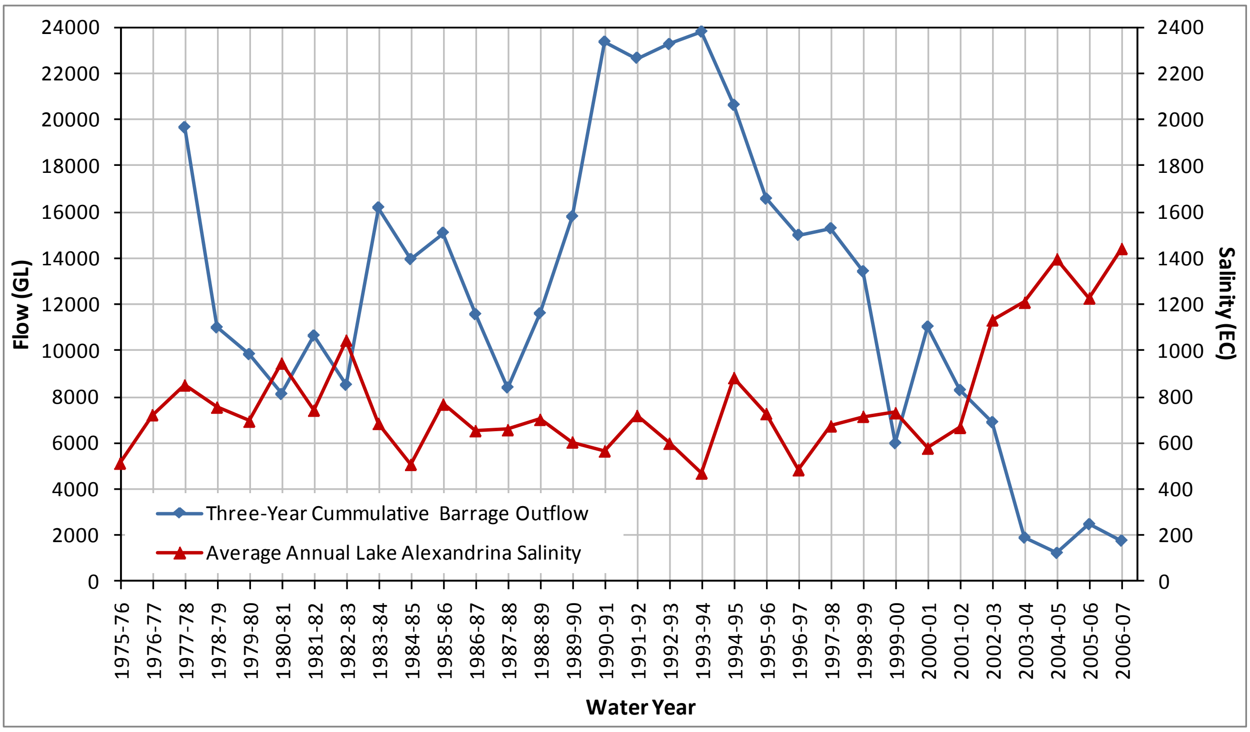



**Figure 34 Three-Year Cumulative Barrage Outflow and Average Annual Salinity in Lake Alexandrina**

Using a three-year rolling average salinity, Figure 35 again highlights the salinity increase with decreasing barrage outflows. Figure 36 shows a similar response to average annual Lake Albert salinity.

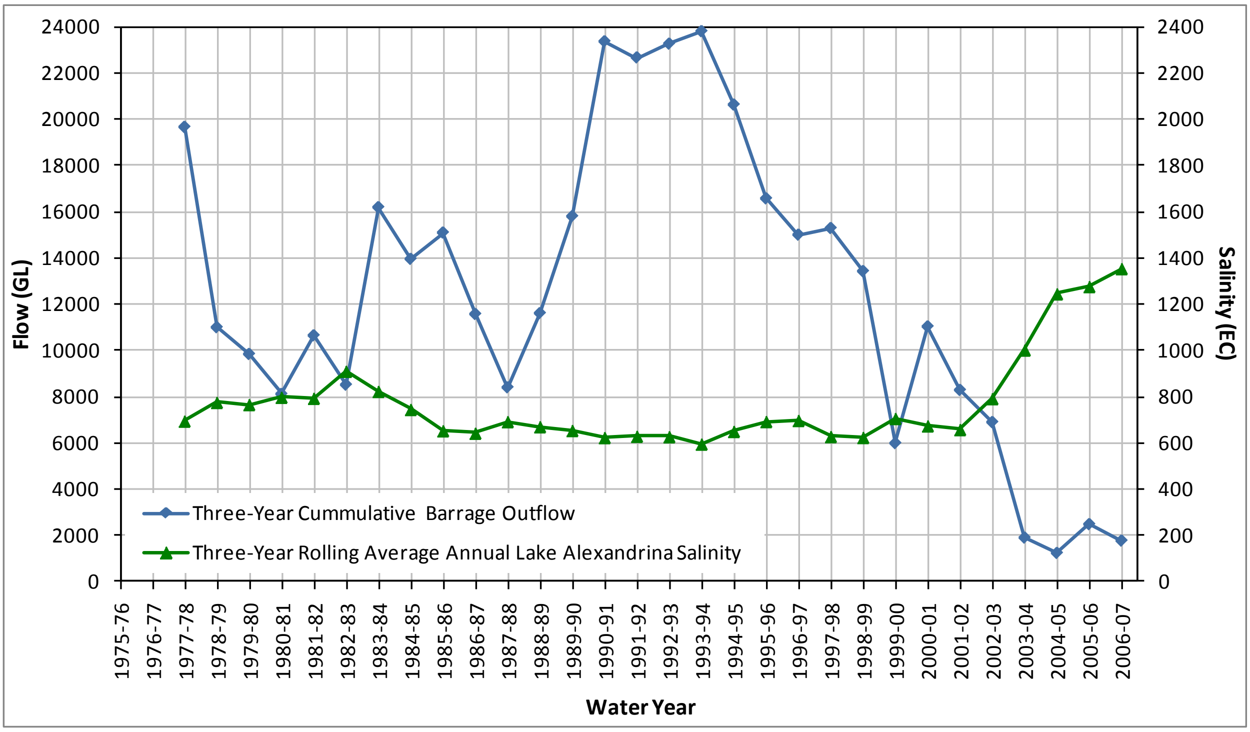



**Figure 35 Three-Year Cumulative Barrage Outflow and Average Salinity in Lake Alexandrina**

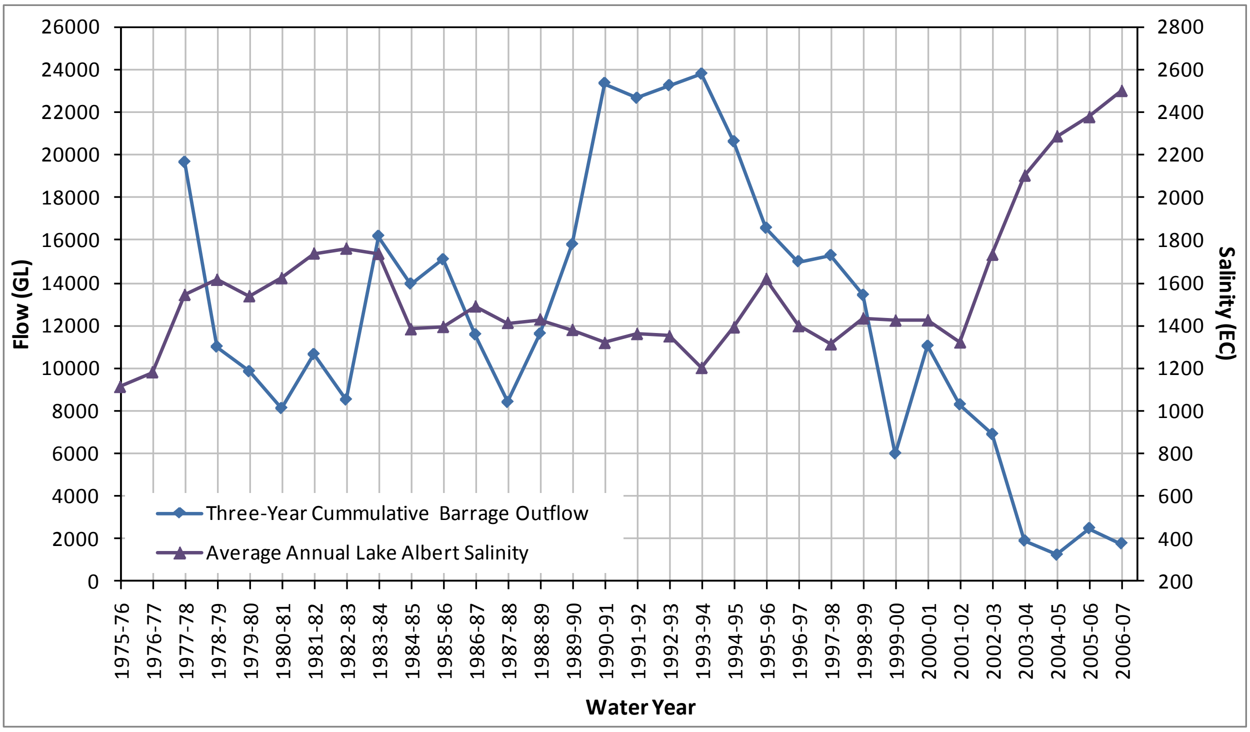



**Figure 36 Three-Year Cumulative Barrage Outflow and Average Annual Salinity in Lake Albert**

Figure 23 showed that the intra-annual distribution of identical total annual inflows has limited impact on the salinity response within Lake Alexandrina, particularly when the majority of the inflow occurs within periods of lower losses (winter to spring). The analysis above shows that inter-annually, the Lower Lakes' system has a short memory. Therefore, the benefit of lowering salinity during high inflow and outflow years is only provided for a maximum of one to two years. This is consistent with the behaviour of other storages in that the salinity memory is a function of throughflow relative to the storage capacity of the lake, that is, the residence time of the water.

The combined intra- and inter-annual analysis indicates that consideration of inflow and outflow requirements over multi-year sequences and particularly over one, two and three years, is likely to be critical in maintaining a salinity threshold.

The analysis also suggests that it is not appropriate to manage salinity based on a long-term average outflow. However, an estimate of the average annual inflow and outflow requirements does provide a guide to the magnitude of throughflow needed to manage salinity and is determined in Section 3.4.

## *3.4. AVERAGE ANNUAL INFLOW AND OUTFLOW REQUIREMENTS*

The model was first run to determine the required Lake Alexandrina average annual inflow and hence average annual barrage outflow, to maintain salinities below the three salinity threshold levels of 700, 1000 and 1500 EC.

The MDBA has assumed a barrage operating level of 0.778m AHD in their current conditions model setup. When inflows result in lake levels increasing above 0.778m AHD, any excess is assumed to be released through the barrages. This assumption was considered appropriate for this study.

The combined total of annual losses and diversions from Lake Alexandrina and Lake Albert generated by the modified historical model was 850 GL. Therefore, the minimum barrage outflow required in each year to maintain the threshold salinity levels can be approximated as 850 GL less than the minimum inflow required. In reality, the actual inflow needed to deliver the required barrage outflow will depend on actual losses and diversions within a given year.

For the 1000 and 1500 EC thresholds, the average annual inflow volume was calculated as the inflow that kept maximum peak salinities below the 1000 and 1500 EC thresholds, rounded to the nearest 50 GL. To achieve lower salinity threshold targets, incrementally larger flows are required to achieve the same step decrease in salinity. Therefore, in relation to the 700 EC threshold target, the average annual inflow volume was calculated as the inflow, rounded to the nearest 50 GL, that kept average salinities below the 700 EC threshold. Significantly higher volumes were required to ensure a maximum of 700 EC.

A range of initial average salinity levels in Lake Alexandrina were used, from low salinity levels of less than 500 EC to high salinity levels of up to 2000 EC. Despite the large variation in initial conditions, the modelled time to equilibrium, using the application of the annual volumes shown in Sections 3.4.1 to 3.4.3, was consistent in each case. The equilibrium level reached with higher salinity starting conditions was slightly higher than with the lower salinity starting conditions but all values were within five percent. Low salinity levels (300 EC in Lake Alexandrina and 1100 EC in Lake Albert) were used as the initial conditions for the results shown in Sections 3.4.1 to 3.4.3. These were the salinity levels following a high flow event in late 1974 and provide some insight into the length of time that the salinity benefit from such high flow events can be sustained.

### 3.4.1. 1000 EC THRESHOLD

An inflow of 2850 GL per year was required, which equates to a barrage discharge of 2000 GL per year, to maintain salinity in Lake Alexandrina below 1000 EC. Figure 37 shows the resulting average, maximum and minimum salinities in Lake Alexandrina from this annual inflow and outflow. Figure 38 shows the corresponding salinity response in Lake Albert and a maximum salinity of around 1800 EC.

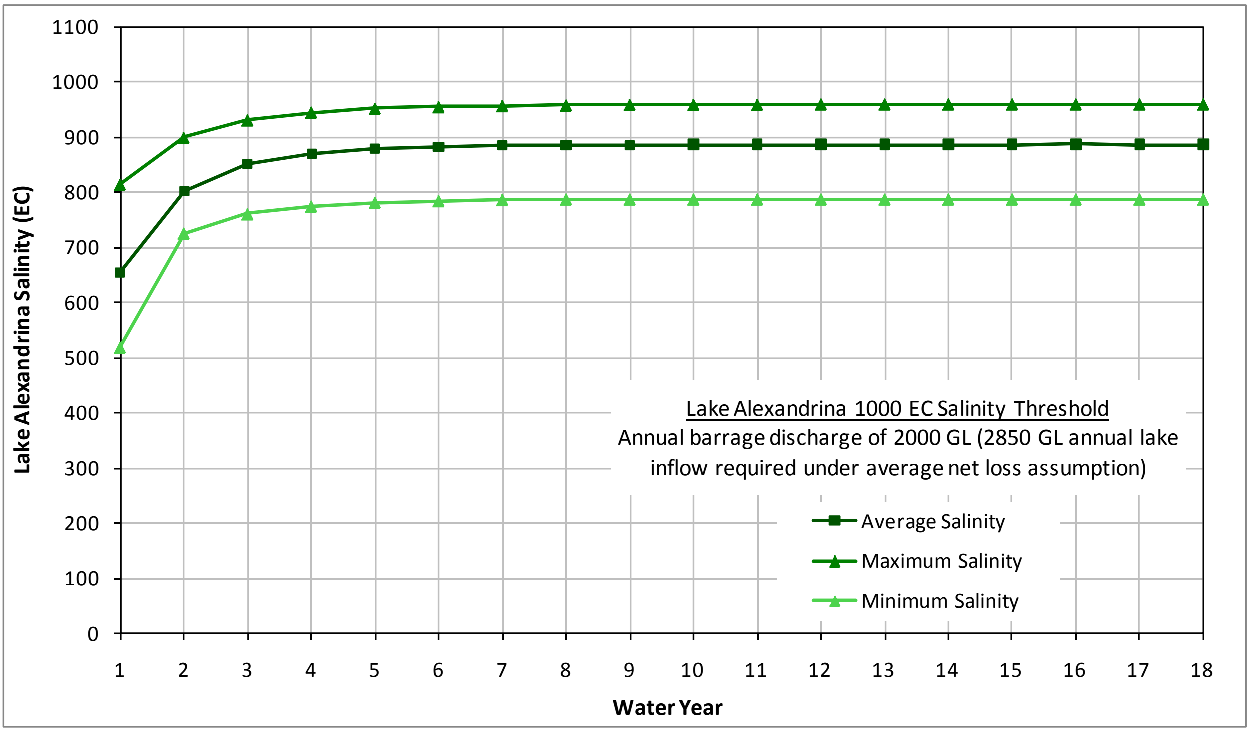



**Figure 37 Lake Alexandrina Salinity with Annual Barrage Outflow of 2000 GL**

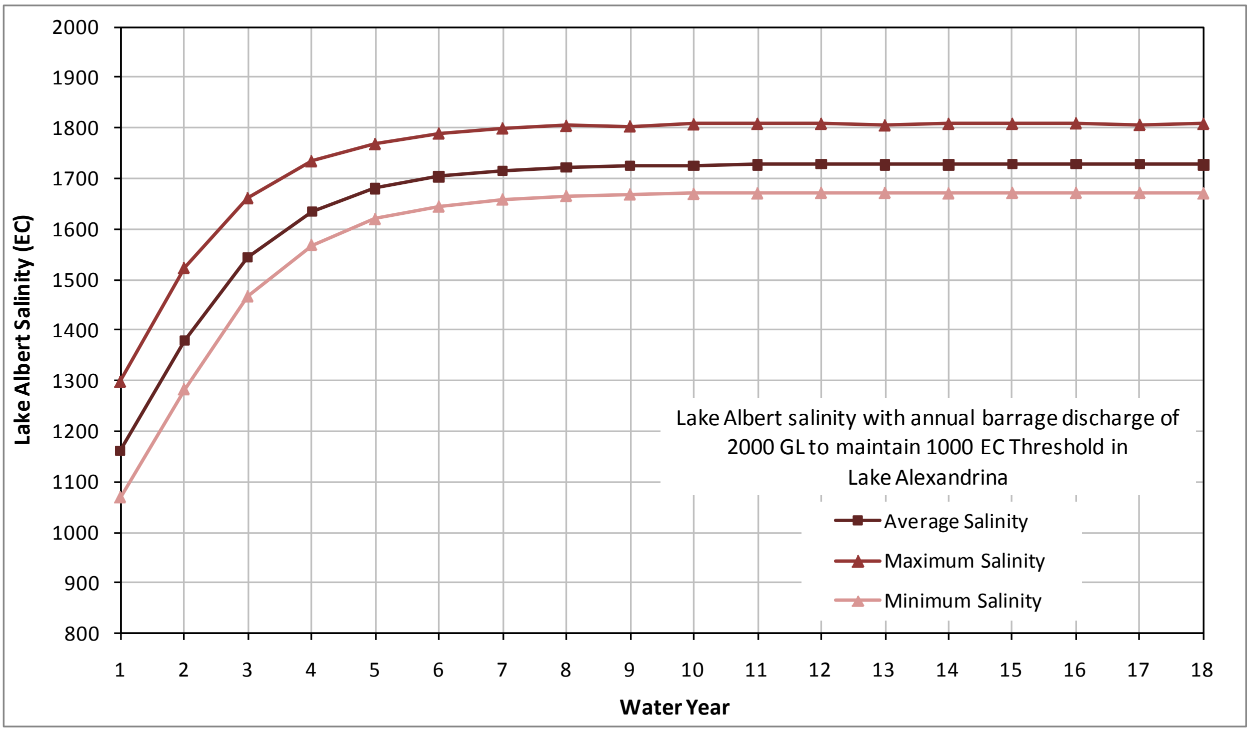



**Figure 38 Lake Albert Salinity with Annual Barrage Outflow of 2000 GL**

### 3.4.2. 700 EC THRESHOLD

An inflow of 4850 GL per year was required, which equates to a barrage discharge of 4000 GL per year, to maintain salinity in Lake Alexandrina at around 700 EC. Figure 39 shows the resulting average, maximum and minimum salinities in Lake Alexandrina from this annual inflow and outflow. Figure 40 shows the corresponding salinity response in Lake Albert and a maximum salinity of around 1400 EC.

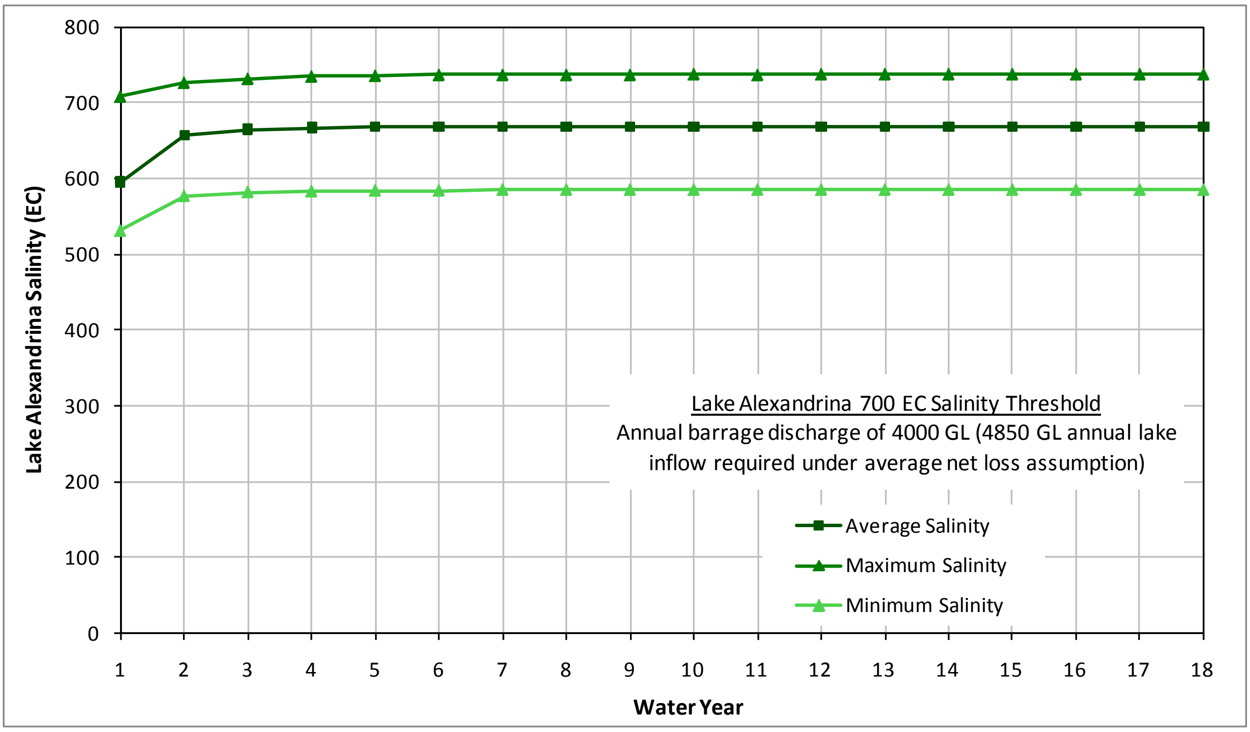



**Figure 39 Lake Alexandrina Salinity with Annual Barrage Outflow of 4000 GL**

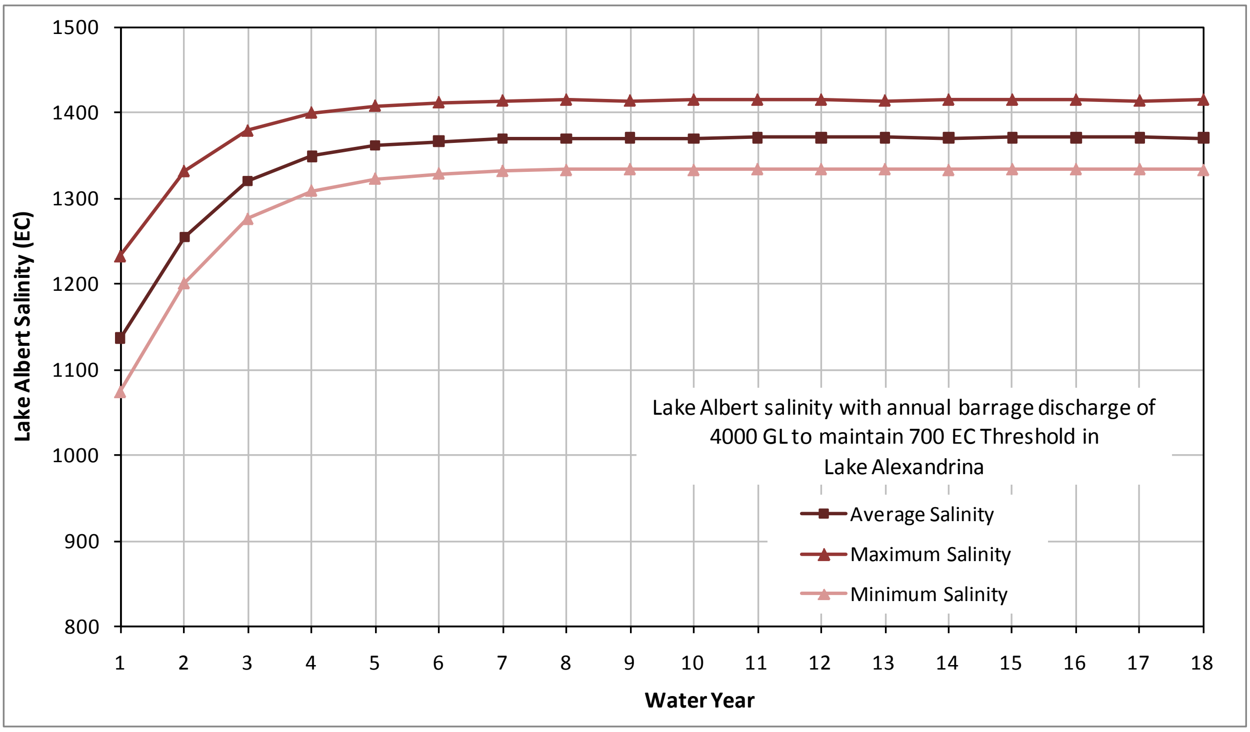



**Figure 40 Lake Albert Salinity with Annual Barrage Outflow of 4000 GL**

### 3.4.3. 1500 EC THRESHOLD

An inflow of 1850 GL per year was required, which equates to a barrage discharge of 1000 GL per year, to maintain salinity in Lake Alexandrina below 1500 EC. Figure 41 shows the resulting average, maximum and minimum salinities in Lake Alexandrina from this annual inflow and outflow. Figure 42 shows the corresponding salinity response in Lake Albert and a maximum salinity of around 2550 EC.

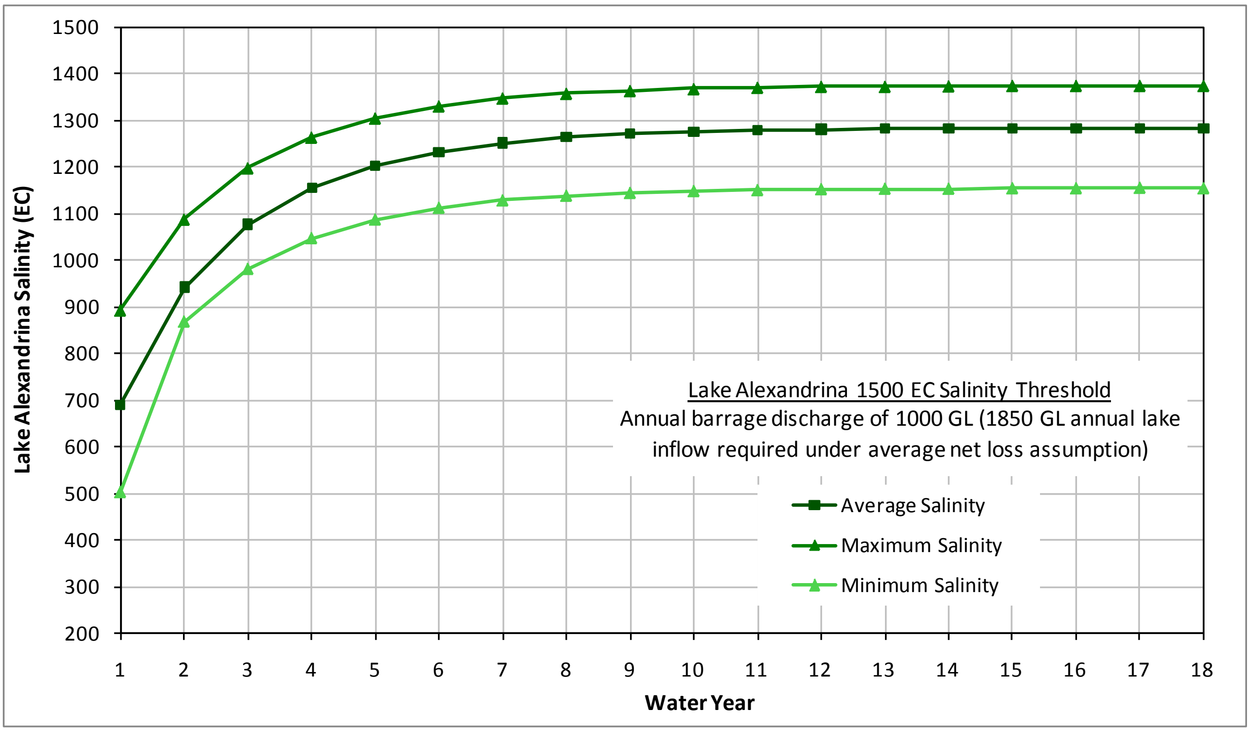



**Figure 41 Lake Alexandrina Salinity with Annual Barrage Outflow of 1000 GL**

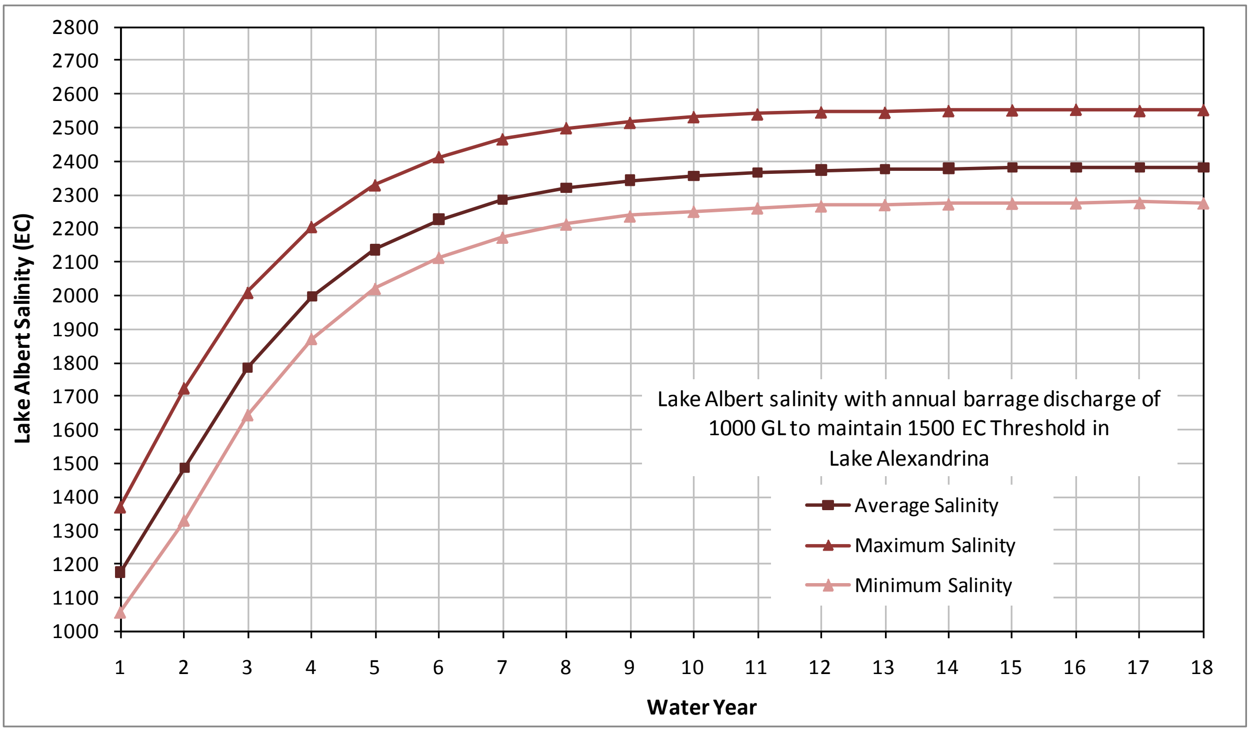



**Figure 42 Lake Albert Salinity with Annual Barrage Outflow of 1000 GL**

Figure 43 highlights that as the salinity in Lake Alexandrina decreases, incrementally larger annual average barrage outflows are required to continue to achieve the same step decreases in salinity.

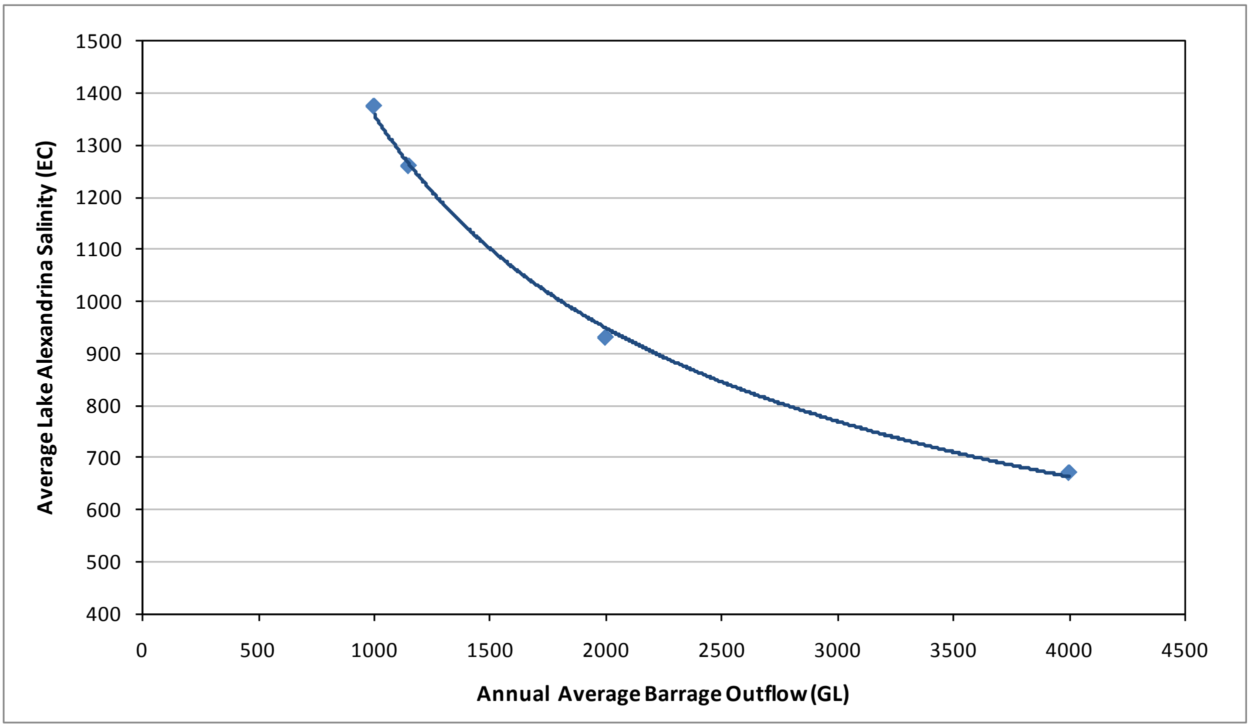



**Figure 43 Indicative Relationship between Average Annual Barrage Outflow and Average Annual Lake Alexandrina Salinity**

## *3.5. SALINITY RESPONSE TO INTER-ANNUAL FLOW VARIATION*

The analysis in Section 3.4 determined the annual average inflow ($I_{AVE}$) and annual average barrage outflow ($B_{AVE}$) required to maintain the salinity in Lake Alexandrina below a range of threshold values (700, 1000 and 1500 EC). However, given the high variability of historical inflow to Lake Alexandrina and through to the Coorong and Murray Mouth, it is not appropriate to define a flow regime in terms of a constant annual inflow or outflow target. In addition, an annual average outflow target is not suitable for defining a flow regime that would support ecological function throughout the CLLMM Ramsar site because the likely flow variability around an average value may not ensure that salinity continuously remains below a given threshold.

In this section, results from analysis of the influence of the high variability in inter-annual inflows to the Lower Lakes and associated barrage outflows is presented. This analysis guided the development of the provided flow regimes, including rules for multi-year flow sequences, to ensure salinities remain below a given threshold.

The value of $I_{AVE}$ for each salinity threshold provided the starting point for the development of a flow regime, with the following issues requiring resolution:

- What influence does high lake inflows and barrage outflows in a given year have on the required lake inflows and barrage outflows in following years?
- What is the minimum lake inflow and barrage outflow needed in a given year to maintain salinity below a given threshold?

An iterative process was undertaken to address the above issues for the chosen salinity thresholds and provide the basis for the development of flow regimes. This is illustrated in the following for the 1000 EC threshold.

Theoretical sequences of high and low inflows were modelled through the Lower Lakes and the effect on salinity examined. It was confirmed that high inflows and consequently high barrage outflows, lowered salinity but the short memory of the system meant that raised salinity levels in Lake Alexandrina resulted quickly from subsequent years of low or no outflows. This supports the conclusion (Section 3.3) that the system cannot be managed based on a long-term average outflow.

Figure 44 shows the output from the model for a theoretical sequence of very high and very low inflows and outflows, chosen to demonstrate the response of the system in relation to Lake Alexandrina salinity levels. It shows that:

- while the barrage outflow is at 2000 GL/year ($B_{AVE}$), the salinity remains just below 1000 EC.
- a high barrage outflow of over 9000 GL significantly reduces the salinity of Lake Alexandrina. In years of high inflows and outflows, the salinity of Lake Alexandrina will tend towards the salinity of the river inflows.
- despite a high outflow in one year, a low outflow in the following year of 150 GL results in a sharp increase in salinity above the 1000 EC threshold.

Figure 44, again the output of an iterative approach to examine a number of theoretical inflow patterns to determine a scenario in which the salinity targets were generally maintained, shows that:

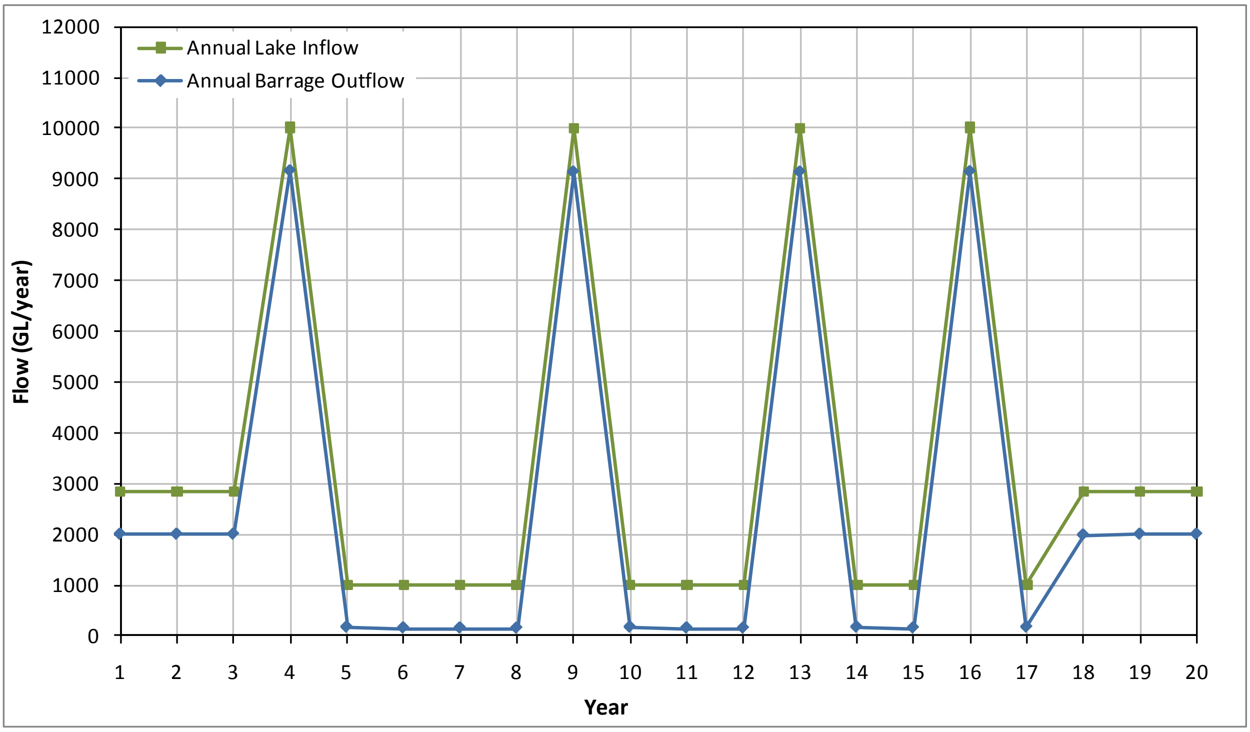
- Lake Alexandrina salinity can be maintained below 1000 EC for a lake inflow of 1500 GL if the inflow in the previous year was around 4200 GL. This corresponded approximately to a minimum barrage outflow of 650 GL with an outflow in the previous year of 3350 GL. That is, the total inflow over the two year period is 5700 GL with a corresponding outflow of 4000 GL.
- the lake inflow in the year following the 1500 GL minimum inflow must be higher than the average annual inflow of 2850 GL to maintain salinity below 1000 EC in that year.

The iterative approach was followed to determine what minimum lake inflow was needed in a given year to ensure that the target salinity was maintained following the largest likely annual inflow for the previous year. An inflow of 10,000 GL was selected for this scenario as there is little difference in Lake Alexandrina salinity in comparisons of inflows at this magnitude or larger. The process identified that for inflows less than 1500 GL, the 1000 EC target could not be maintained for any previous year's inflow.

A similar iterative process was then undertaken to determine what was the minimum inflow required in the year preceding a year in which only the minimum 1500 GL inflow was achieved. This result is shown in Figure 45, which shows that 5700 GL is required over any two-year period to maintain the 1000 EC target. This set the total two-year inflow required to maintain the salinity target, given a minimum required annual inflow of 1500 GL in the second year.

Finally, the iterative approach was used to vary the inflow for the two years following a minimum inflow to determine the minimum inflow required to maintain the salinity target. The inflow requirement above for 5700 GL over two years was found to maintain the salinity target for the first two years. However, for the third year to also remain below the 1000 EC target, an inflow in that year above the minimum 1500 GL was required. So, while a three-year sequence of 1500, 4200, 1500 GL satisfied the two-year required inflow over 5700 GL, this sequence was not sufficient to maintain the salinity target. The analysis determined that a total inflow over three years of 8550 GL was required.

The results of this analysis are flow regimes for each of the chosen salinity threshold targets and are presented and discussed in Section 3.6.



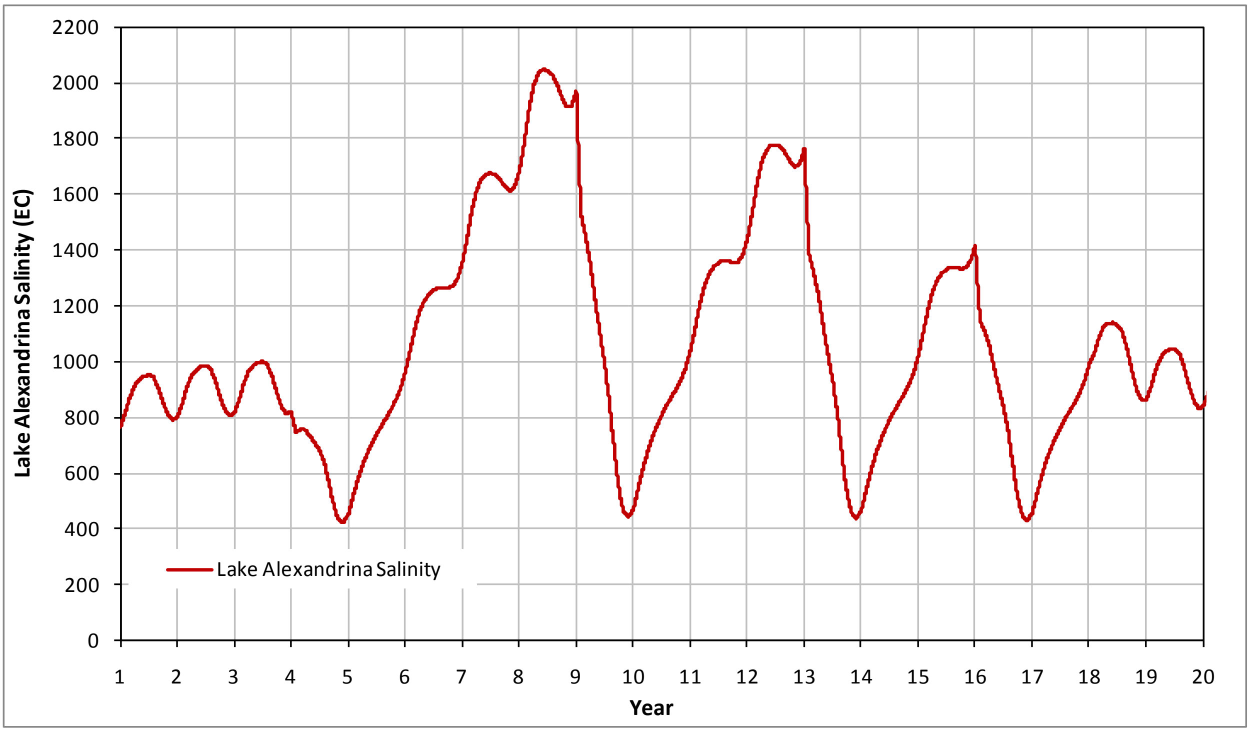
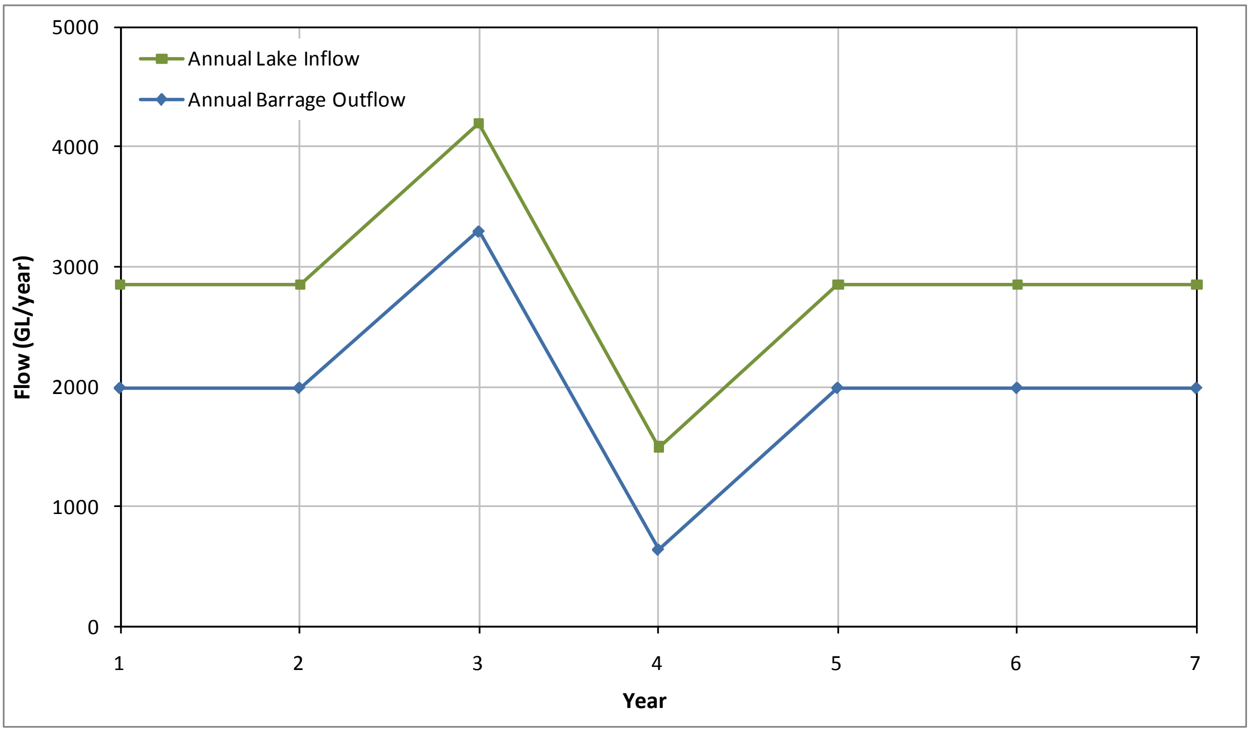




**Figure 44 Theoretical Inflow Regime and Corresponding Lake Alexandrina Salinity Response for High Lake Inflows (Greater than 10,000 GL) followed by Low Lake Inflows (1000 GL)**



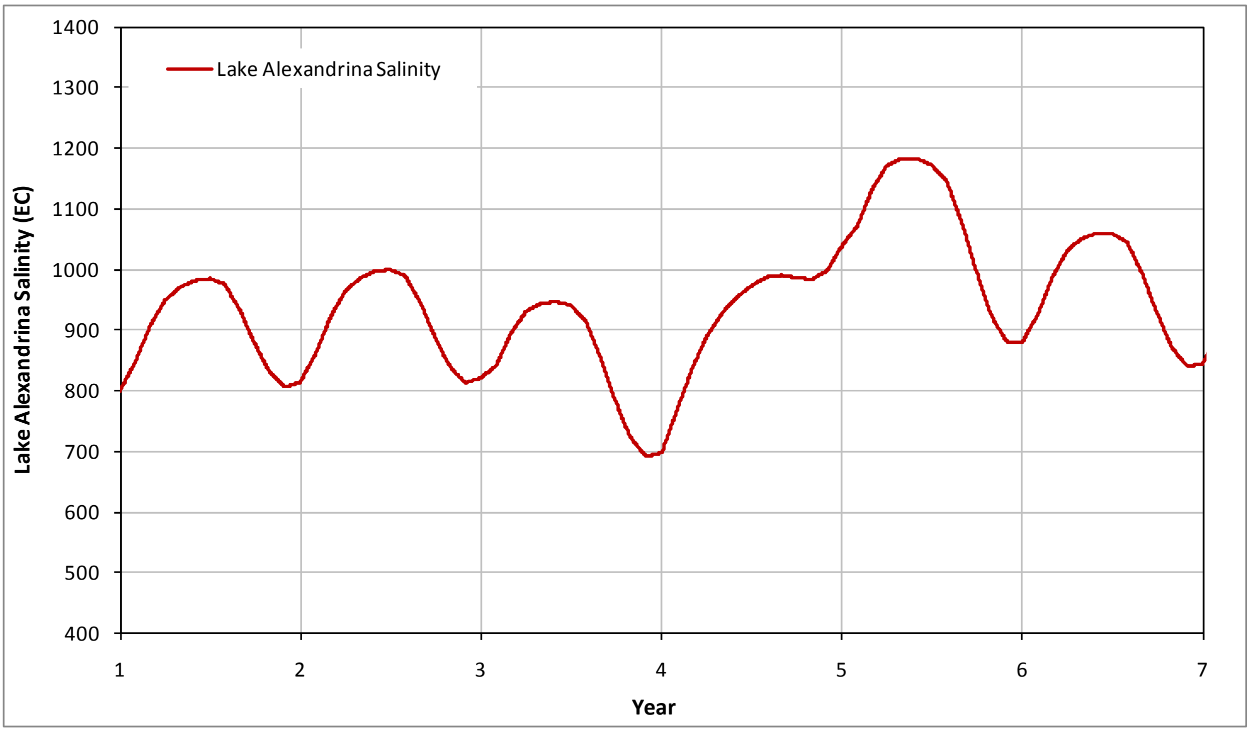




**Figure 45 Theoretical Inflow Regime and Corresponding Lake Alexandrina Salinity Response for Minimum One, Two and Three-Year Lake Inflow Requirements**

## 3.6. DEVELOPMENT OF REQUIRED FLOW REGIMES FOR SALINITY MANAGEMENT IN LAKE ALEXANDRINA

Historically, the flows to South Australia that would deliver lake inflows and barrage outflows equal or greater than the annual average requirements for a given salinity threshold have been comprised primarily of unregulated flows. An unregulated flow is a flow that cannot be captured in storages upstream of the South Australian Border. Therefore, in years when flows are greater than that required to maintain salinities it is generally not possible to re-direct the excess flow elsewhere for use during drier years. This is also undesirable as the higher flows provide other environmental benefits along the length of the river and within the CLLMM Ramsar site.

The development of a flow regime that can be managed annually to ensure that salinity threshold levels can be maintained continuously needs to account for this flow variability. It cannot be achieved by adopting an annual average inflow or outflow target. It is also necessary to ensure that during periods of scarce water resources the available water is used in the most efficient way possible.

The analysis in Section 3.5 of the inter-annual variability highlighted the importance of considering one, two and three-year inflow and outflow sequences in order to effectively manage salinity. The analysis of historical outflows in Section 3.3 also demonstrated that sustained inflows and barrage outflows greater than the annual average required for a given salinity threshold have a short-term effect on maintaining salinities below that threshold.

Barrage outflows are the key driver for managing salinity levels in Lake Alexandrina. However, barrage outflows are the result of lake inflows and losses and diversions across the lakes. To determine the barrage requirements to manage salinity levels and for use in the analysis of environmental water requirements for the Coorong, the inflow requirements were determined first assuming constant annual losses. In practice, inflows may need to be adjusted based on actual losses and diversions each year.

From these analyses a set of criteria was developed to define the minimum lake inflow required in a given year, defined as $Q_X$. The rules require cumulative lake inflow parameters to be determined for one, two and three-year sequences for each salinity threshold, with:

- $I_1$ being the minimum lake inflow in any given year;
- $I_2$ being the minimum cumulative lake inflow over two years; and
- $I_3$ being the minimum cumulative lake inflow over three years.

The minimum lake inflow required in any year ($Q_X$) to maintain the salinity in Lake Alexandrina below a prescribed threshold, given the actual annual lake inflow for the previous two years ($Q_{X-1}$ and $Q_{X-2}$), is then the greater of:

1. $I_1$
2. $I_2 - Q_{X-1}$
3. $I_3 - Q_{X-1} - Q^*_{X-2}$ (where $Q^*_{X-2}$ is equal to the minimum of $Q_{X-2}$ or $I_{AVE}$)

Corresponding sets of barrage outflow parameters can then be calculated by considering the 850 GL average annual losses and diversions across the lakes applied in the modified historical model. The minimum barrage outflow required in a given year, $F_X$, is determined using similar parameters and criteria for cumulative barrage outflow parameters for one, two and three-year sequences for each salinity threshold, with:

- $B_1$ being the minimum barrage outflow in any given year;
- $B_2$ being the minimum cumulative barrage outflow over two years; and
- $B_3$ being the minimum cumulative barrage outflow over three years.

The minimum barrage outflow required in any year ($F_X$) to maintain the salinity in Lake Alexandrina below a prescribed threshold, given the actual annual barrage outflows for the previous two years ($F_{X-1}$ and $F_{X-2}$), is then the greater of:

1. $B_1$
2. $B_2 - F_{X-1}$
3. $B_3 - F_{X-1} - F^*_{X-2}$ (where $F^*_{X-2}$ is equal to the minimum of $F_{X-2}$ or $B_{AVE}$)

Most modelling investigations have rarely reported on salinity prior to 1975, or undertaken analysis of salinity over longer and more variable inflow sequences. In this case, because lake inflow salinity was calculated using the relationship established in Section 2.4.4, it was possible to generate a salinity time-series and validate the flow regimes developed from 1891/92 to 2007/08.

### 3.6.1. 1000 EC THRESHOLD

For a 1000 EC threshold in Lake Alexandrina the cumulative lake inflow parameters have been determined as follows: $I_1$ = 1500 GL, $I_2$ = 5700 GL and $I_3$ = 8550 GL. $I_{AVE}$ is 2850 GL.

Hence, the minimum lake inflow required in a given year ($Q_X$) to maintain Lake Alexandrina salinity below 1000 EC is equal to the greater of:

1. 1500 GL
2. 5700 GL - $Q_{X-1}$
3. 8550 GL - $Q_{X-1} - Q^*_{X-2}$ (where $Q^*_{X-2}$ is min($Q_{X-2}$, 2850 GL))

The above criteria was translated into corresponding cumulative barrage outflow parameters as follows: $B_1$ = 650 GL, $B_2$ = 4000 GL and $B_3$ = 6000 GL. $B_{AVE}$ is 2000 GL.

As a result, the minimum barrage outflow required in a given year ($F_X$) to maintain Lake Alexandrina salinity below 1000 EC is equal to the greater of:

1. 650 GL
2. 4000 GL - $F_{X-1}$
3. 6000 GL - $F_{X-1} - F^*_{X-2}$ (where $F^*_{X-2}$ is min($F_{X-2}$, 2000 GL))

The above criteria accommodate lower system water availability in a given year through a 1500 GL minimum inflow each year, which is less than the average annual inflow required. In the following year however, Lake Alexandrina requires a higher inflow to meet the minimum requirement of 5700 GL over 2 years ($Q_{X-1}$, $Q_X$), thereby ensuring that salinities remain below the threshold. The minimum inflow of 8550 GL over 3 years ($Q_{X-2}$, $Q_{X-1}$, $Q_X$) preserves the long-term average outflow requirements and ensures a minimum outflow of 1500 GL cannot occur every second year. The latter would result in salinities above the 1000 EC threshold. Incorporation of the limited benefit that inflows greater than the average annual inflow provide is achieved by ensuring that any inflow greater than 2850 GL two years prior to the current year is only considered equivalent to 2850 GL for the purposes of the above calculations.

Under the historical inflow and outflow sequence, in which these rules are not applied, salinities rise above 1000 EC. To test the rules through application to the historical data, the historical inflows to Lake Alexandrina a given year ($H_X$) were adjusted to equal the greater of:

1. max ($H_X$, 1500)
   i.e. the larger of the historical inflow and 1500 GL
2. max ($H_X$, 5700- $H_{X-1}$)
   i.e. the larger of the historical inflow and 5700 GL minus inflow from previous year
3. max ($H_X$, 8550- $H_{X-1}$ - $H^*_{X-2}$) where $H^*_{X-2}$ = min ($H_{X-2}$, 2850)
   i.e. the larger of the historical inflow or 8550 GL minus inflow from previous two years and where $H_{X-2}$ is equal to the lesser of actual outflow 2 years prior to the current year or 2850 GL

### 3.6.2. 700 EC THRESHOLD

To achieve lower salinity threshold targets, significantly larger flows are required to achieve the same step decrease in salinity and the lake salinity becomes more dependent on the salinity of river inflows. For the period from 1975/76 to 2006/07, the modelled average salinity of inflow to Lake Alexandrina was approximately 570 EC and the mean observed salinity in Lake Alexandrina was 800 EC. Given this data and the significantly higher volumes required to ensure a maximum of 700 EC, it was not considered reasonable to maintain salinities below 700 EC at all times. The 700 EC threshold rules have therefore been designed to maintain an average annual salinity in Lake Alexandrina at (or below) 700 EC (refer Section 3.4.2).

With this objective, the cumulative lake inflow parameters have been determined as follows: $I_1$ = 4000 GL, $I_2$ = 9700 GL and $I_3$ = 14550 GL. $I_{AVE}$ is 4850 GL.

Hence, the minimum lake inflow required in a given year ($Q_X$) to maintain the average Lake Alexandrina salinity below 700 EC is equal to the greater of:

1. 4000 GL
2. 9700 GL - $Q_{X-1}$
3. 14550 GL - $Q_{X-1}$ - $Q^*_{X-2}$ (where $Q^*_{X-2}$ is min($Q_{X-2}$, 4850 GL))

The above criteria was translated into corresponding cumulative barrage outflow parameters as follows: $B_1$ = 3150 GL, $B_2$ = 8000 GL and $B_3$ = 12000 GL. $B_{AVE}$ is 4000 GL.

As a result, the minimum barrage outflow required in a given year ($F_X$) to maintain the average Lake Alexandrina salinity below 700 EC is equal to the greater of:

1. 3150 GL
2. 8000 GL - $F_{X-1}$
3. 12000 GL - $F_{X-1}$ - $F^*_{X-2}$ (where $F^*_{X-2}$ is min($F_{X-2}$, 4000 GL))

To test the rules through application to the historical data, the historical inflows to Lake Alexandrina were modified using the above. The historical inflows to Lake Alexandrina in a given year ($H_X$) were adjusted to equal the greater of:

1. max ($H_X$, 4000)
   i.e. the larger of the historical inflow and 4000 GL
2. max ($H_X$, 9700- $Q_{X-1}$)
   i.e. the larger of the historical inflow and 9700 GL minus inflow from previous year
3. max ($H_X$, 14550- $H_{X-1}$ - $H^*_{X-2}$) where $H^*_{X-2}$ = min ($Q_{X-2}$, 4850)
   i.e. the larger of the historical inflow or 14550 GL minus inflow from previous two years and where $Q^*_{X-2}$ is equal to the lesser of actual outflow two years prior to the current year or 4850 GL

If the inflow in given year is adjusted, then this adjusted inflow becomes $Q_{X-1}$ for calculating the required inflow for the next year, replacing the actual historical inflow for that year.

### 3.6.3. 1500 EC THRESHOLD

For a 1500 EC threshold in Lake Alexandrina the cumulative lake inflow parameters have been determined as follows: $I_1$ = 850 GL (inflows delivered to replace losses and diversions), $I_2$ = 3700 GL and $I_3$ = 5550 GL. $I_{AVE}$ is 1850 GL.

Hence, the minimum lake inflow required in a given year ($Q_X$) to maintain Lake Alexandrina salinity below 1500 EC is equal to the greater of:

1. 850 GL (inflows delivered to replace losses and diversions)
2. 3700 GL - $Q_{X-1}$
3. 5550 GL - $Q_{X-1}$ - $Q^*_{X-2}$ (where $Q^*_{X-2}$ is min($Q_{X-2}$, 1850 GL))

The above criteria was translated into corresponding cumulative barrage outflow parameters as follows: $B_1$ = 0 GL, $B_2$ = 2000 GL and $B_3$ = 3000 GL. $B_{AVE}$ is 1000 GL.

As a result, the minimum barrage outflow required in a given year ($F_X$) to maintain Lake Alexandrina salinity below 1500 EC is equal to the greater of:

1. 0 GL (but with inflows delivered to replace losses and diversions)
2. 2000 GL - $F_{X-1}$
3. 3000 GL - $F_{X-1}$ - $F^*_{X-2}$ (where $F^*_{X-2}$ is min($F_{X-2}$, 1000 GL))

To test the rules through application to the historical data, the historical inflows to Lake Alexandrina were modified using the above. The historical inflows to Lake Alexandrina in a given year ($H_X$) were adjusted to equal the greater of:

1. max ($H_X$, 850)
   i.e. the larger of the historical inflow and 850 GL
2. max ($H_X$, 3700- $Q_{X-1}$)
   i.e. the larger of the historical inflow and 3700 GL minus inflow from previous year
3. max ($H_X$, 5550- $H_{X-1}$ - $H^*_{X-2}$) where $H^*_{X-2}$ = min ($Q_{X-2}$, 1850)
   i.e. the larger of the historical inflow or 5550 GL minus inflow from previous two years and where $H^*_{X-2}$ is equal to the lesser of actual outflow two years prior to the current year or 1850 GL

If the inflow in a given year is adjusted, then this adjusted inflow becomes $H_{X-1}$ for calculating the required inflow for the next year, replacing the actual historical inflow for that year.

# 4. VALIDATION OF FLOW REGIMES UNDER HISTORICAL CONDITIONS

## 4.1. 1000 EC THRESHOLD

For a 1000 EC threshold in Lake Alexandrina the cumulative lake inflow parameters have been determined as follows: $I_1$ = 1500 GL, $I_2$ = 5700 GL and $I_3$ = 8550 GL. $I_{AVE}$ is 2850 GL.

Hence, the minimum lake inflow required in a given year ($Q_X$) to maintain Lake Alexandrina salinity below 1000 EC is equal to the greater of:

1. 1500 GL
2. 5700 GL - $Q_{X-1}$
3. 8550 GL - $Q_{X-1}$ - $Q^*_{X-2}$ (where $Q^*_{X-2}$ is min($Q_{X-2}$, 2850 GL))

The above criteria was translated into corresponding cumulative barrage outflow parameters as follows: $B_1$ = 650 GL, $B_2$ = 4000 GL and $B_3$ = 6000 GL. $B_{AVE}$ is 2000 GL.

As a result, the minimum barrage outflow required in a given year ($F_X$) to maintain Lake Alexandrina salinity below 1000 EC is equal to the greater of:

1. 650 GL
2. 4000 GL - $F_{X-1}$
3. 6000 GL - $F_{X-1}$ - $F^*_{X-2}$ (where $F^*_{X-2}$ is min($F_{X-2}$, 2000 GL))

The above criteria accommodate lower system water availability in a given year through a 1500 GL minimum inflow each year, which is less than the average annual inflow required. In the following year however, Lake Alexandrina requires a higher inflow to meet the minimum requirement of 5700 GL over two years ($Q_{X-1}$, $Q_X$), thereby ensuring that salinities remain below the threshold. The minimum inflow of 8550 GL over three years ($Q_{X-2}$, $Q_{X-1}$, $Q_X$) preserves the long-term average outflow requirements and ensures a minimum outflow of 1500 GL cannot occur every second year. The latter would result in salinities above the 1000 EC threshold. Incorporation of the limited benefit that inflows greater than the average annual inflow provide is achieved by ensuring that any inflow greater than 2850 GL two years prior to the current year is only considered equivalent to 2850 GL for the purposes of the above calculations.

Under the historical inflow and outflow sequence, in which these rules are not applied, salinities rise above 1000 EC. To test the rules through application to the historical data, the historical inflows to Lake Alexandrina a given year ($H_X$) were adjusted to equal the greater of:

1. max ($H_X$, 1500)
   i.e. the larger of the historical inflow and 1500 GL
2. max ($H_X$, 5700- $H_{X-1}$)
   i.e. the larger of the historical inflow and 5700 GL minus inflow from previous year
3. max ($H_X$, 8550- $H_{X-1}$ - $H^*_{X-2}$) where $H^*_{X-2}$ = min ($H_{X-2}$, 2850)
   i.e. the larger of the historical inflow or 8550 GL minus inflow from previous two years and where $H_{X-2}$ is equal to the lesser of the actual outflow two years prior to the current year or 2850 GL

If the inflow in a given year is adjusted, then this adjusted inflow becomes $H_{X-1}$ for calculating the required inflow for the next year, replacing the actual historical inflow for that year.

The historical and adjusted inflow sequence is shown in Figure 46. Each year of increased inflow that would have been applied using this method is seen as a departure from the historical sequence.

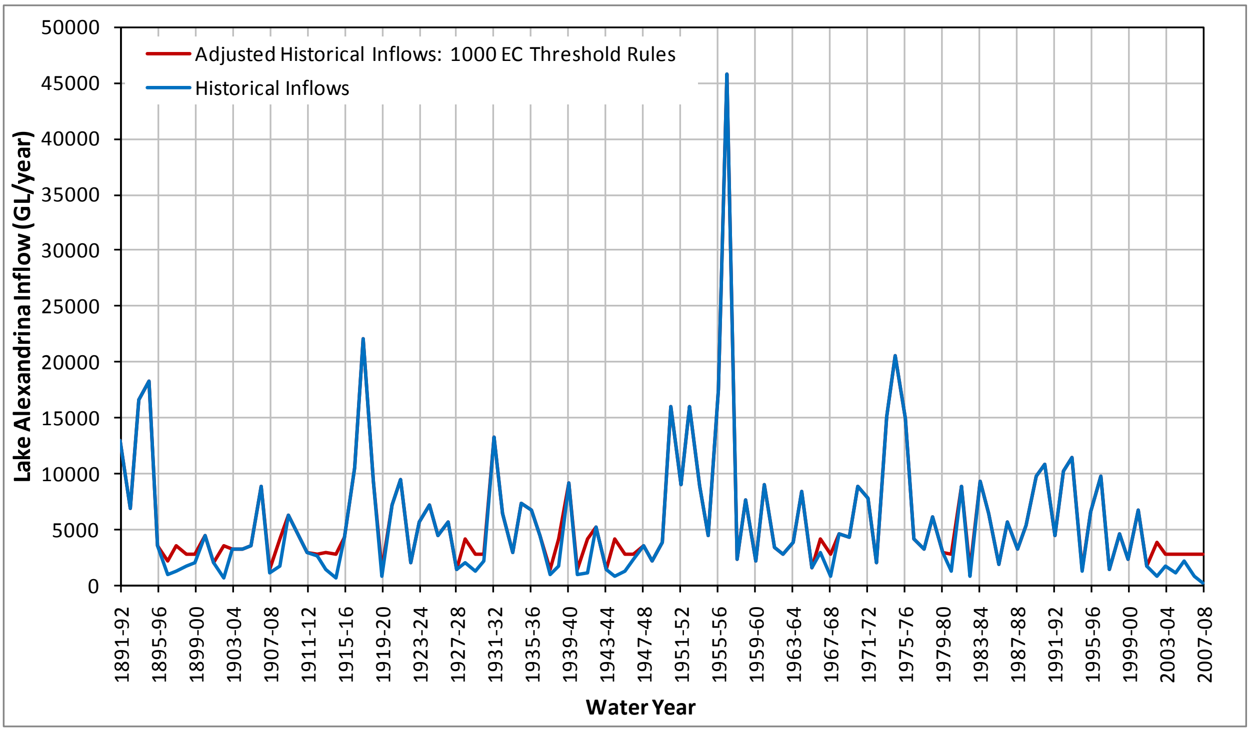



**Figure 46 Adjusted Historical Inflows using 1000 EC Threshold Rules**

A summary of the required additional inflows is shown in Table 7. The majority of increased inflows were required within three periods: 1896/97 to 1914/15 (10 years), 1937/38 to 1946/47 (8 years) and 2002/03 to 2007/08 (6 years). This is consistent with the decadal variability observed in the historical barrage outflow series (Figure 25) in addition to the normal inter-annual variability (Figure 24).

**Table 7 Additional Flows Required for Historical Inflow Sequence: 1000 EC Threshold**

| **Statistics** | |
|---|---|
| Length of Record | 117 years |
| Additional Inflows Required | 33 years |
| Average Annual Inflow Increase | 1455 GL |
| Minimum Annual Inflow Increase | 90 GL |
| Maximum Annual Inflow Increase | 3280 GL |
| **Additional Volume (GL)** | **Number of Years** |
| Min Increase - 500 | 5 |
| 500 - 1000 | 7 |
| 1000 - 2000 | 9 |
| 2000 - 3000 | 9 |
| 3000 - Maximum Increase | 3 |

The particular one, two or three year criteria that governed any required increase in annual flow is demonstrated in Figure 47 for the period from 1895/96 to 1909/10 where increased flows would have been required in seven years:

- The one-year minimum criteria governed the increased flow in only one year (1907/08).
- The two-year cumulative total would have been used in five years (1896/97, 1897/98, 1899/00, 1902/03 and 1908/09).
- The three-year cumulative total would have been used in only one year (1898/99).

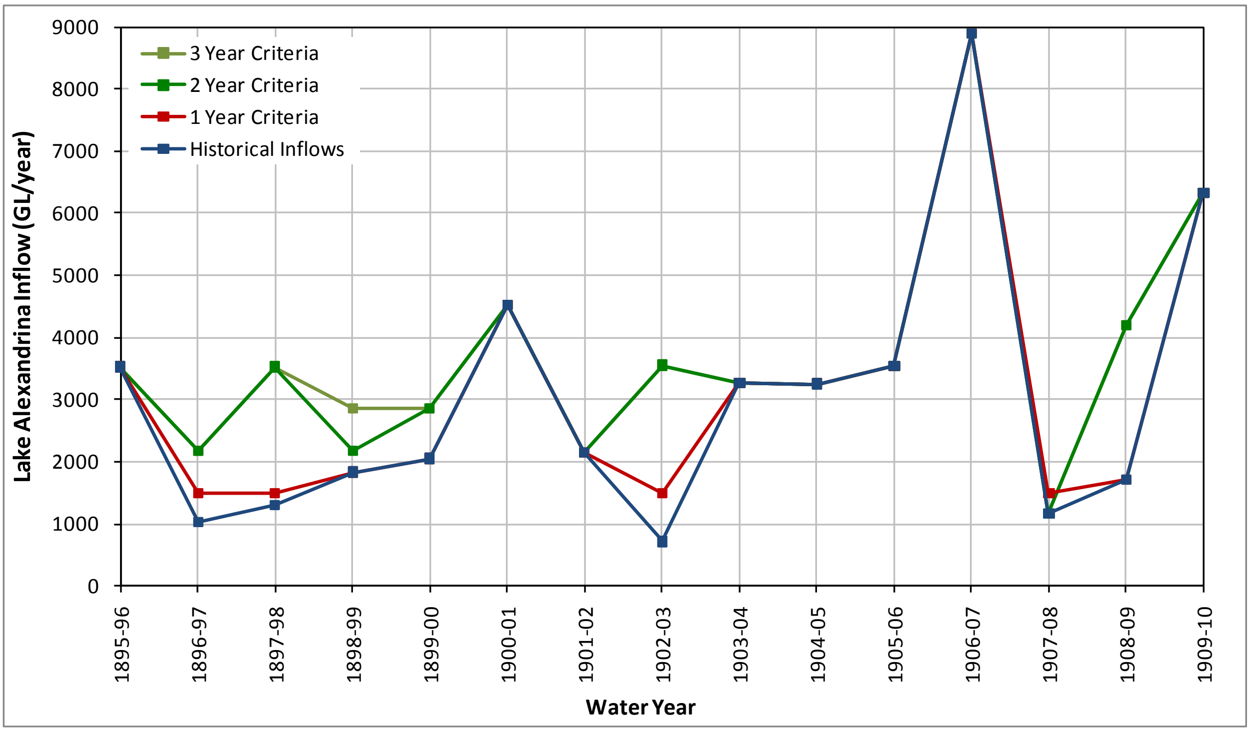



**Figure 47 Demonstration of Criteria for Increased Inflows: 1000 EC Threshold (1895/96 to 1909/10)**

Figures 48 to 50 show the historical and adjusted one, two and three-year cumulative inflow sequences for the period from 1891/92 to 1916/17. These results show that if the flow was managed using the above criteria, the inflows in 10 of the 26 years shown would have been increased. These figures considered in combination assist in identifying which of the three inflow sequence criteria governed the final inflow volume in each year.

Figure 48 shows that of the ten years where inflows were increased, the historical inflows in only five of these ten were less than the 1500 GL minimum ($I_1$). Of these, only the inflow in 1907-08 was needed to be increased to the minimum of 1500 GL to meet the criteria.

For the other nine years, the inflows in the preceding years in conjunction with the annual inflows in those years themselves were not sufficient to maintain the salinity threshold, necessitating the need to increase inflow beyond the minimum inflow criteria.

The sequence of years from 1896/97 to 1899/00 shows a period where the annual inflow in all four years would have needed to be increased. Figure 49 shows that it is the two-year cumulative total in all but 1898-99 that governed the increase needed to the inflow ($I_2$).

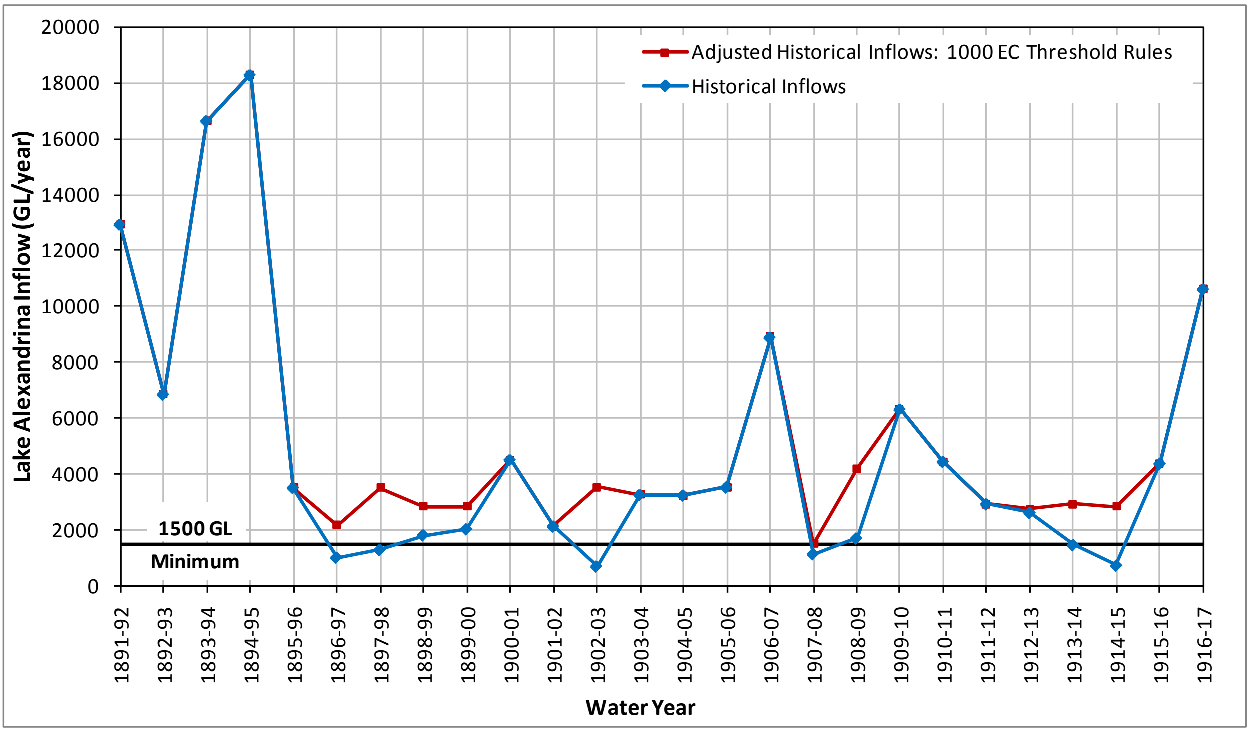



**Figure 48 Adjusted Historical Inflows: 1000 EC Threshold (1891/92 to 1916/17)**

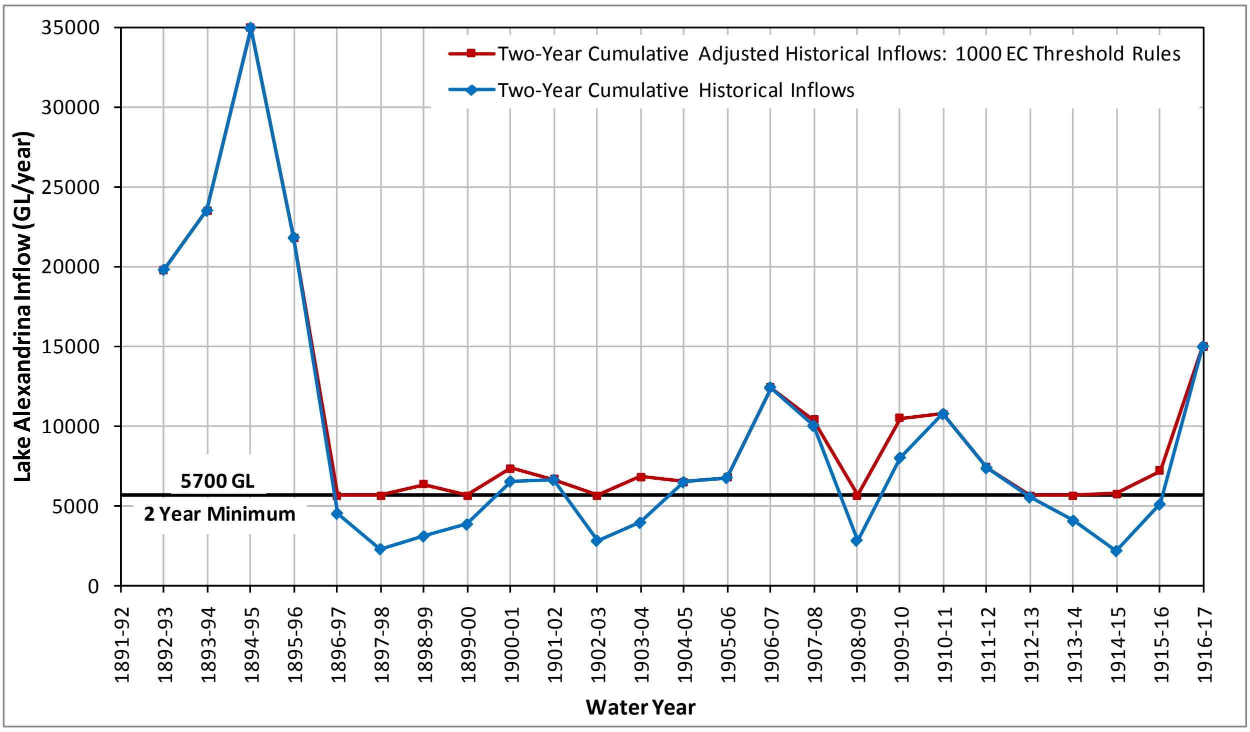



**Figure 49 Two-Year Cumulative Adjusted Historical Inflows: 1000 EC Threshold (1891/92 to 1916/17)**

Figure 50 in comparison to Figure 49 shows that in 1898/99, further increasing the annual inflow was required based on the three-year cumulative requirement ($I_3$).

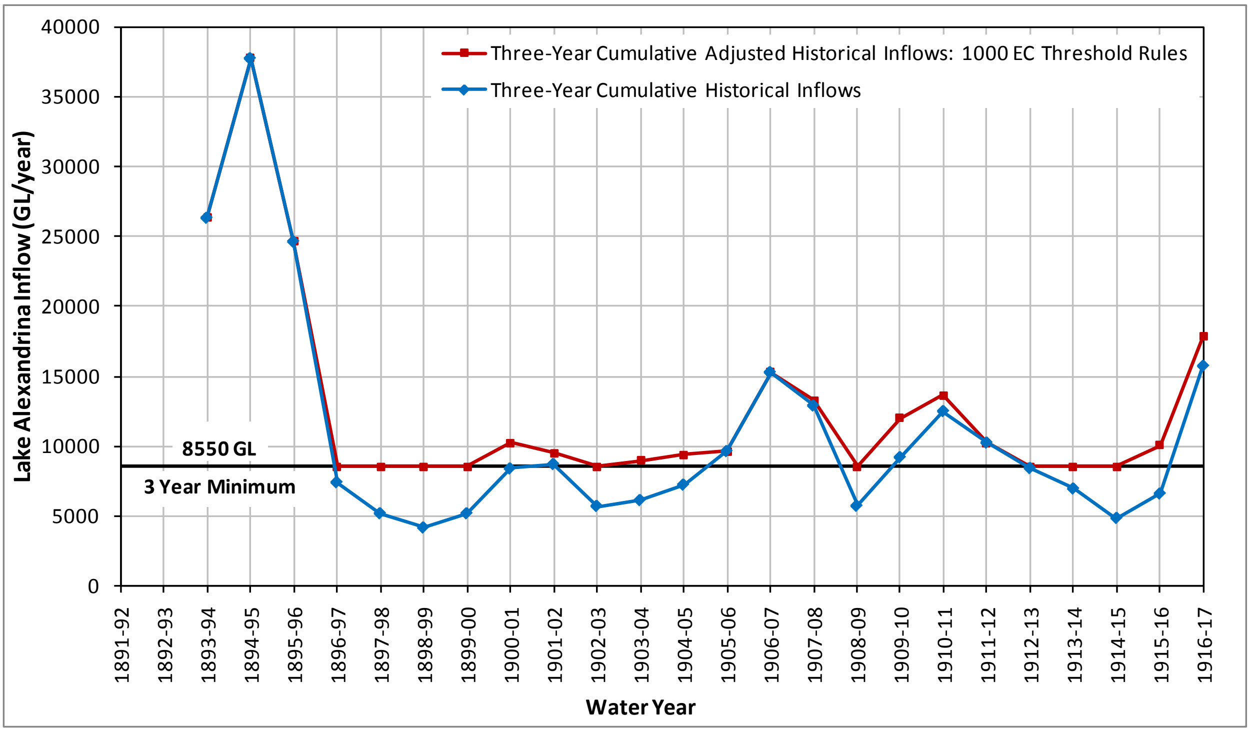



**Figure 50 Three-Year Cumulative Adjusted Historical Inflows: 1000 EC Threshold (1891/92 to 1916/17)**

Similar requirements are seen in Figures 51 to 53 for the period from 1978/79 to 2007/08:

- Figure 51 shows that of the nine years that would have required increased inflows, in only two years did an inflow increase to the minimum 1500 GL then ensure that all three criteria were met (1982/83, 1994/95).
- Figure 52 shows that during the period 2002/03 to 2007/08, the two-year cumulative total in all but 2003-04 would have been used to manage the inflow.
- Figure 53 shows that in 2003-04, a further increase in the annual inflow was required to meet the three-year cumulative requirement.

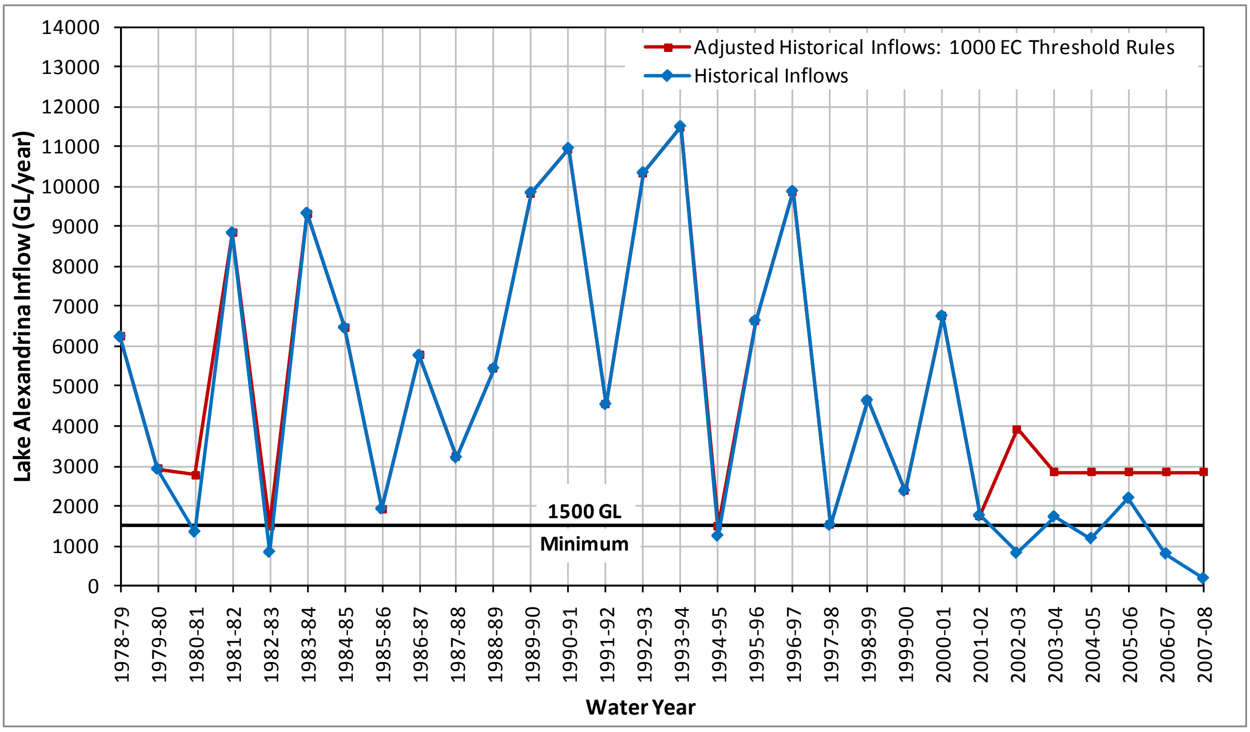



**Figure 51 Adjusted Historical Inflows: 1000 EC Threshold (1978/79 to 2007/08)**

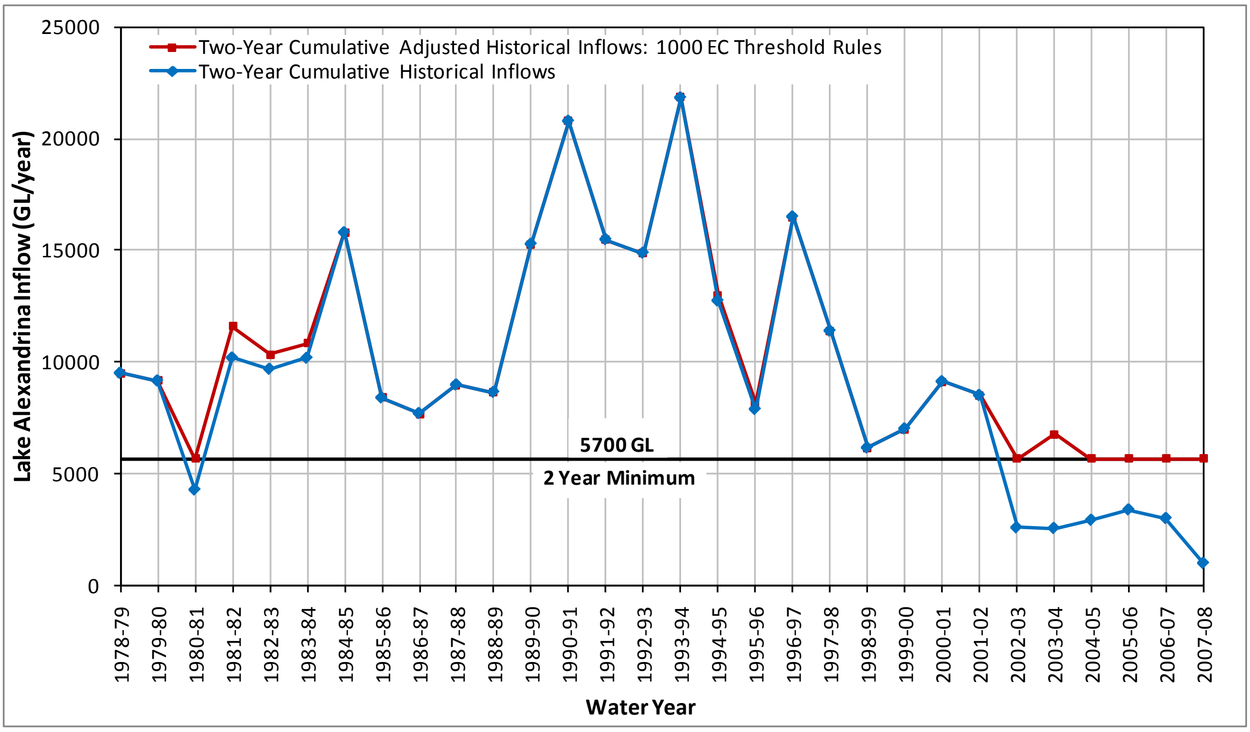



**Figure 52 Two-Year Cumulative Adjusted Historical Inflows: 1000 EC Threshold (1978/79 to 2007/08)**

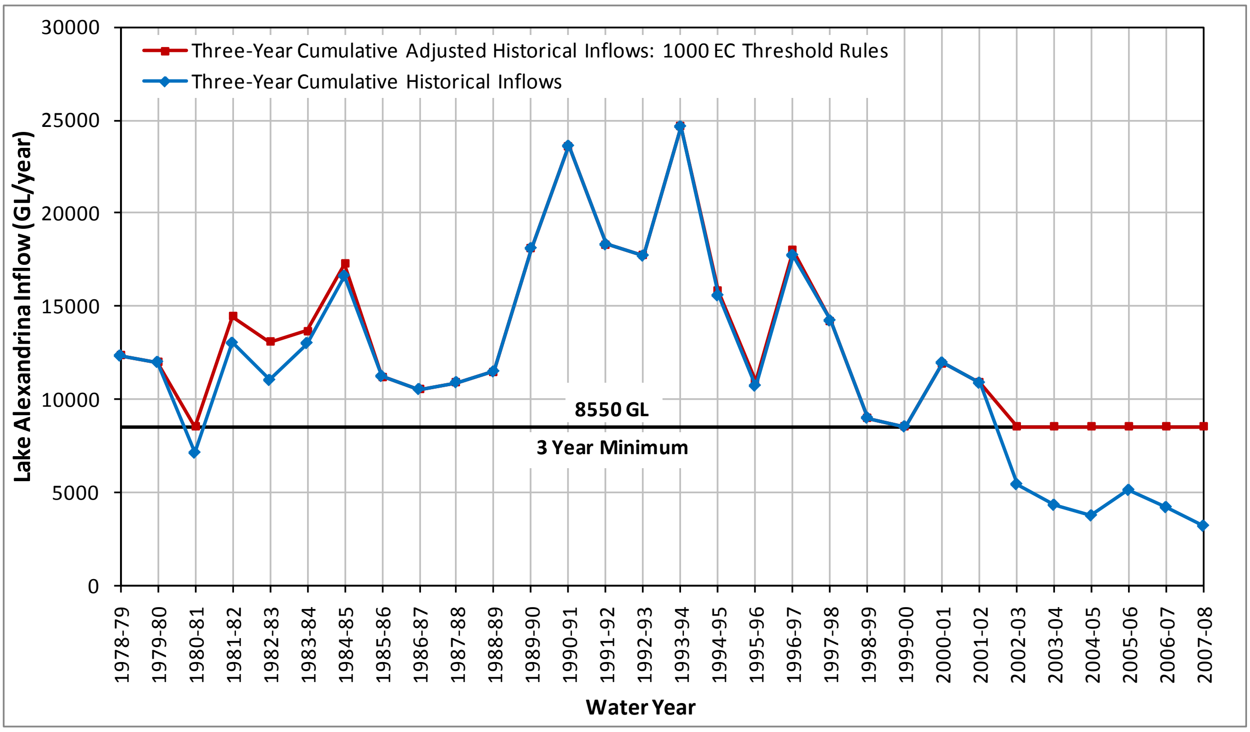



**Figure 53 Three-Year Cumulative Adjusted Historical Inflows: 1000 EC Threshold (1978/79 to 2007/08)**

Table 8 shows the annual barrage outflow statistics under historical and adjusted conditions. Both the mean and median outflows have increased slightly, but the main changes are increases to the lower outflow statistics (minimum and 10th percentile).

**Table 8 Historical and Adjusted (1000 EC Threshold) Barrage Outflow Statistics (1891/92 to 2007/08)**

| Statistics | Annual Barrage Outflow (GL) | |
|---|---|---|
| | Historical | Adjusted (1000 EC Threshold) |
| Mean | 4925 | 5340 |
| Median | 3020 | 3220 |
| Minimum | 0 | 780 |
| Maximum | 44850 | 44725 |
| 10th Percentile | 260 | 1180 |
| 90th Percentile | 11215 | 11235 |

Figure 54 shows the additional barrage outflows that result from the modified inflow sequence to create the flow regime needed to maintain salinity in Lake Alexandrina under the 1000 EC criteria. It is noted that there are some small increases in barrage discharge during years when lake inflows were not increased. This generally occurred during high inflow years that followed one or more very low inflow years. Because the inflows were increased during the low years, lake levels were higher prior to the beginning of the next water year and hence less inflow was required before barrage outflows occurred.

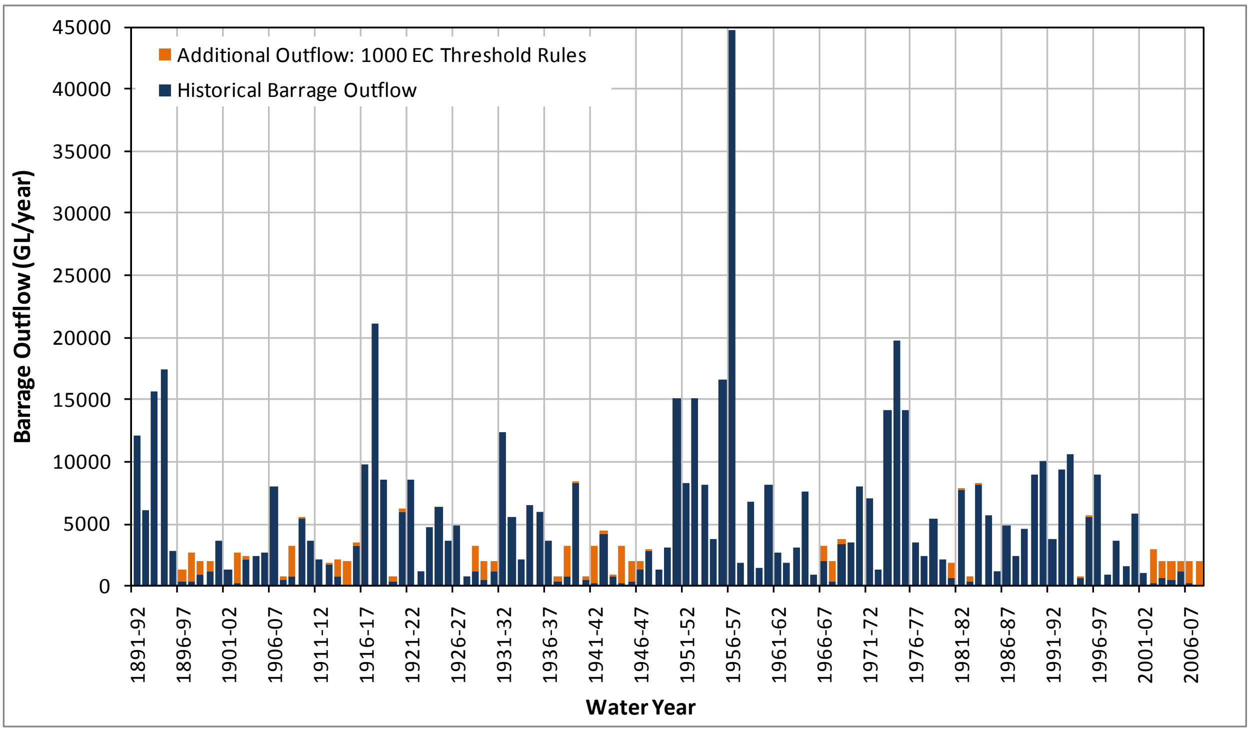



**Figure 54 Additional Barrage Outflows (Historical): 1000 EC Threshold**

Figure 55 shows the change to the historical barrage outflow frequency curve, highlighting that most increases in outflow required to manage salinity are to historical outflows that are less than the median.

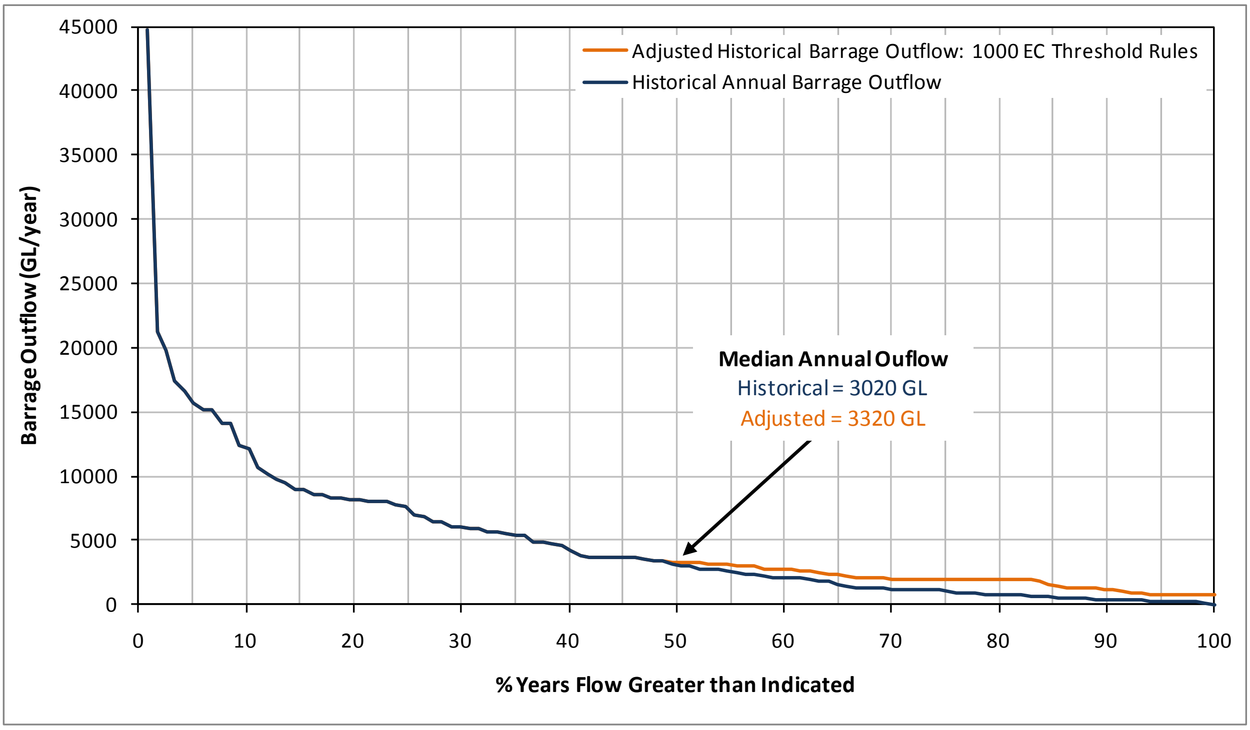



**Figure 55 Historical and Adjusted Annual Barrage Outflow Frequency Curves: 1000 EC Threshold**

Figure 56 shows the adjusted historical annual barrage outflows that result from the 1000 EC Threshold rules for the period from 1891/92 to 1916/17. Figures 57 and 58 show the resultant Lake Alexandrina and Lake Albert salinity time-series responses.

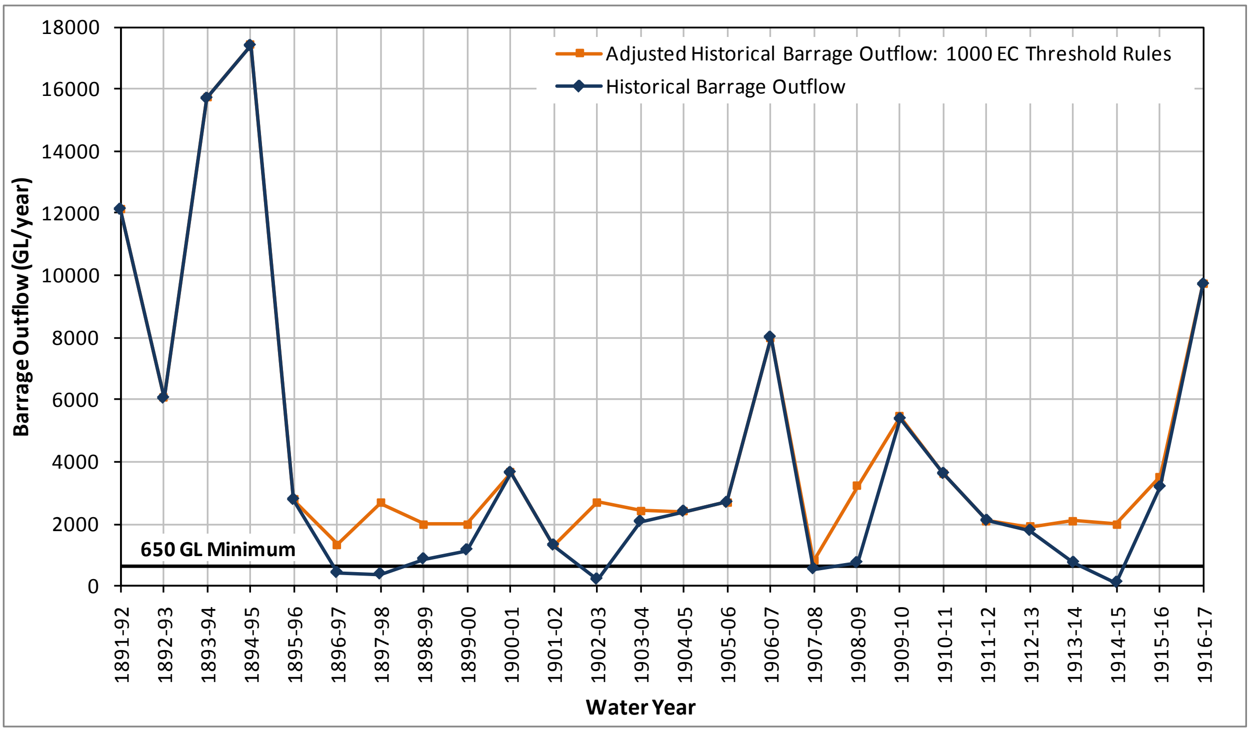



**Figure 56 Adjusted Annual Barrage Outflows: 1000 EC Threshold (1891/92 to 1916/17)**

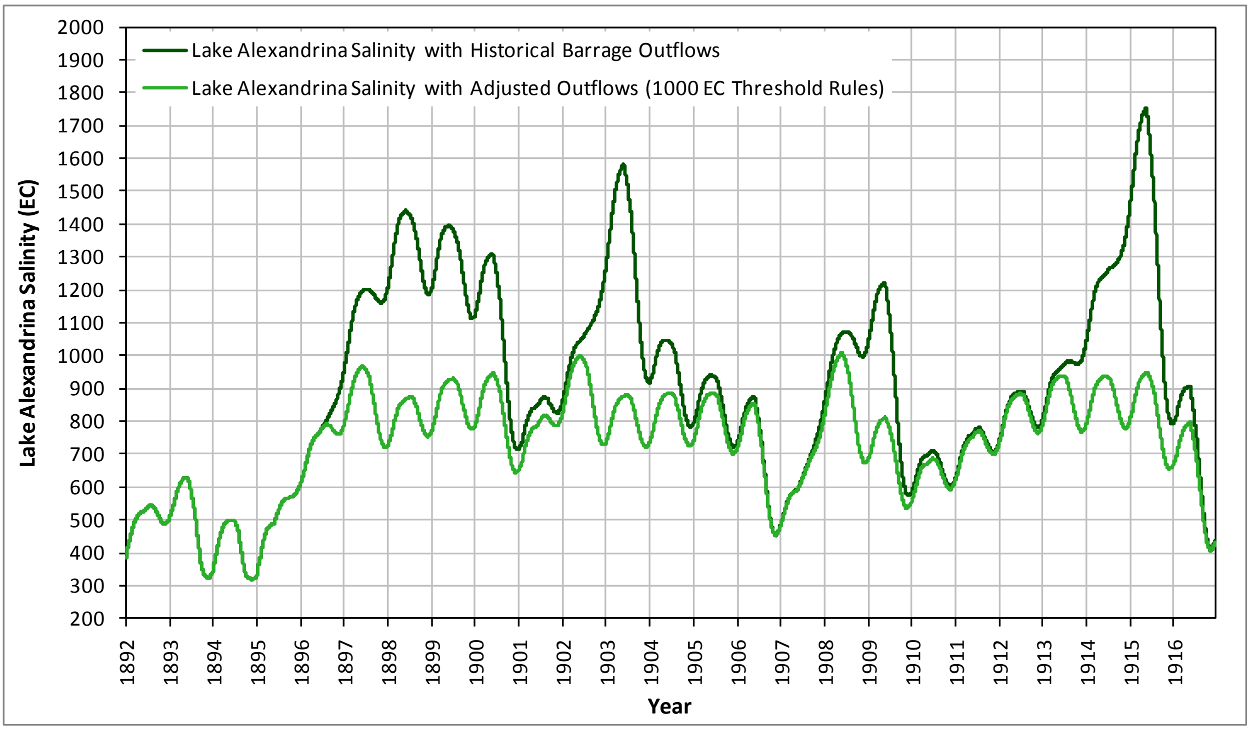



**Figure 57 Lake Alexandrina Salinity with Adjusted Barrage Outflows: 1000 EC Threshold (1892 to 1916)**

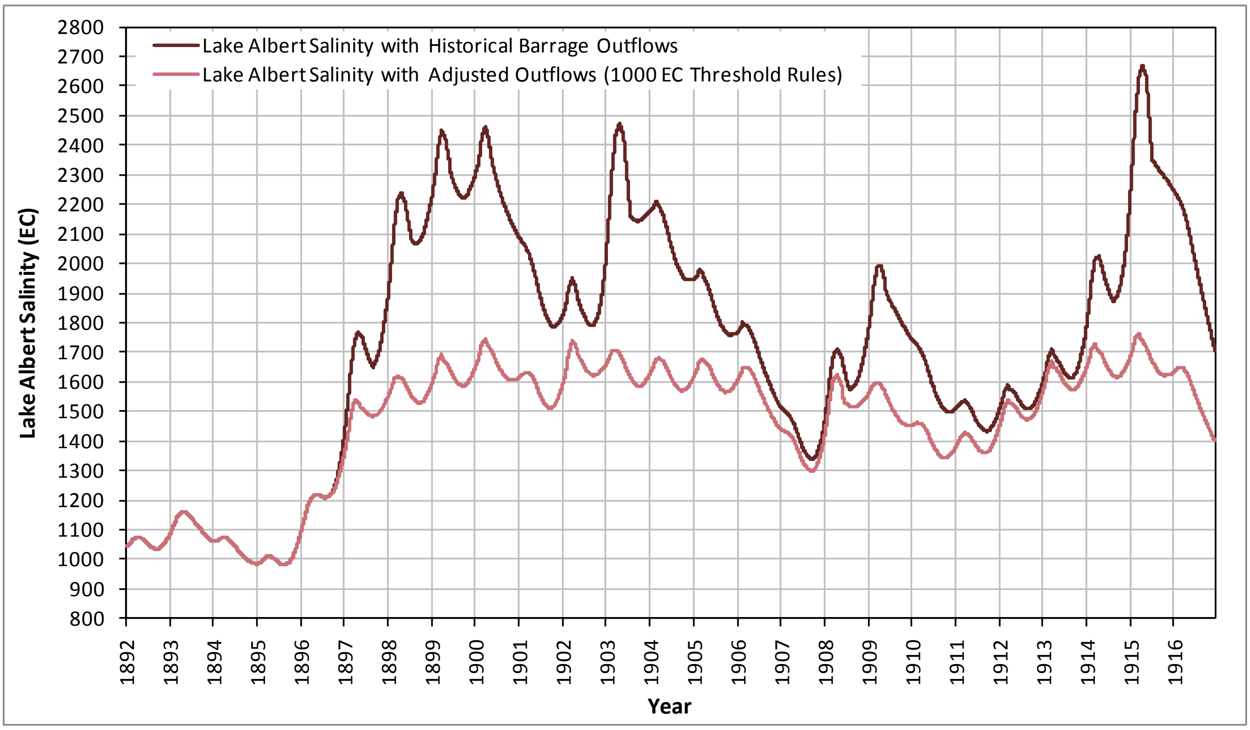



**Figure 58 Lake Albert Salinity with Adjusted Barrage Outflows: 1000 EC Threshold (1892 to 1916)**

Figure 59 shows the adjusted historical annual barrage outflows that result from the 1000 EC Threshold rules for the period from 1975/76 to 2007/08. Figures 60 and 61 show the resultant Lake Alexandrina and Lake Albert salinity time-series responses.

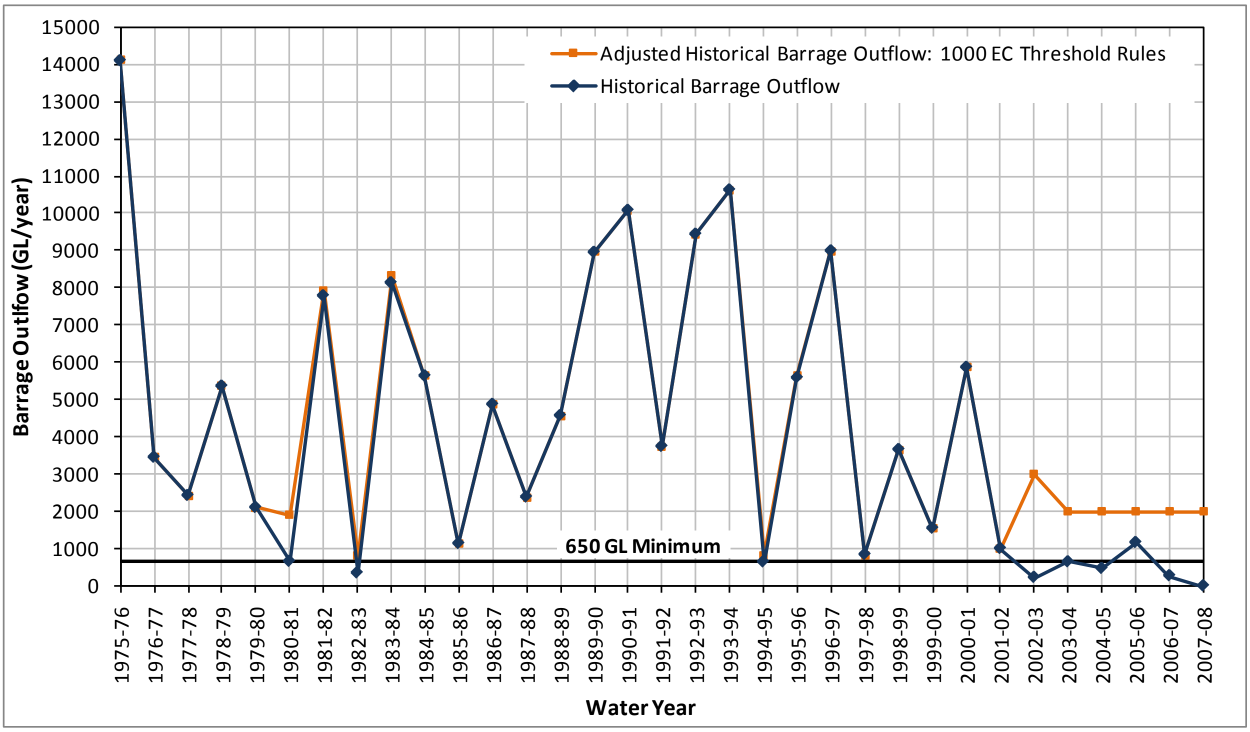



**Figure 59 Adjusted Annual Barrage Outflows: 1000 EC Threshold (1975/76 to 2007/08)**

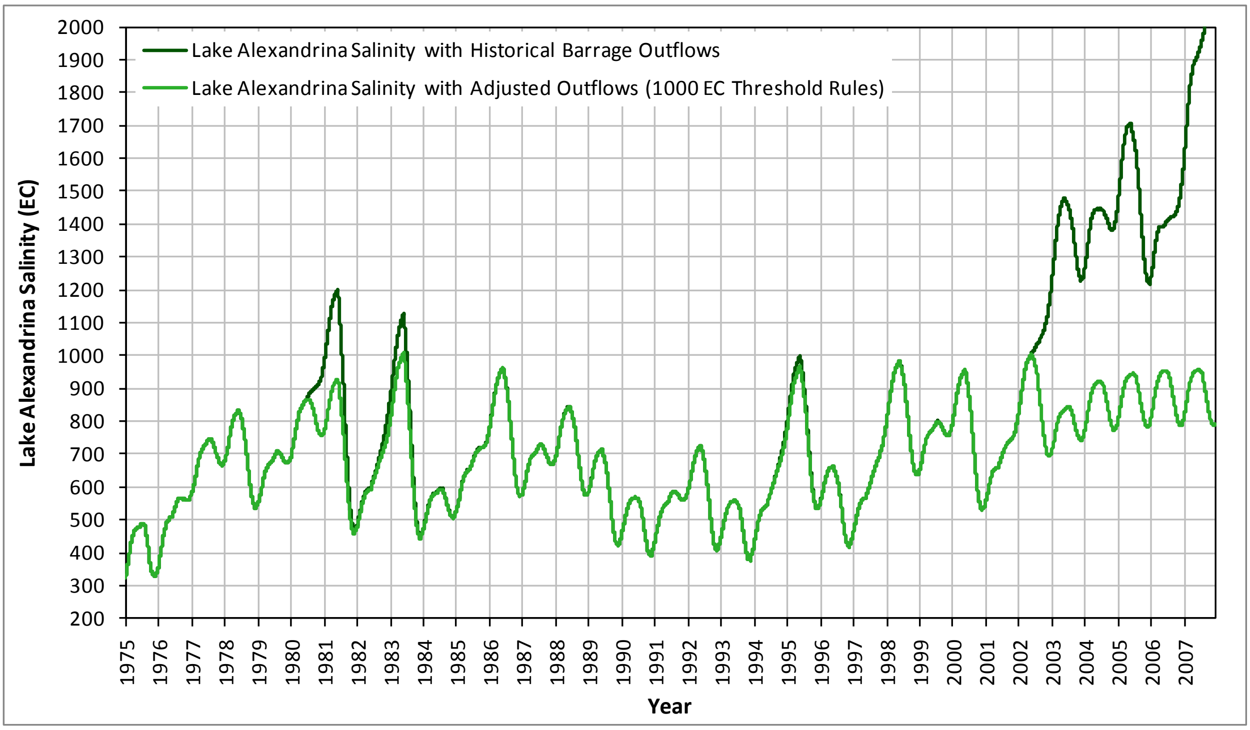



**Figure 60 Lake Alexandrina Salinity with Adjusted Barrage Outflows: 1000 EC Threshold (1975 to 2007)**

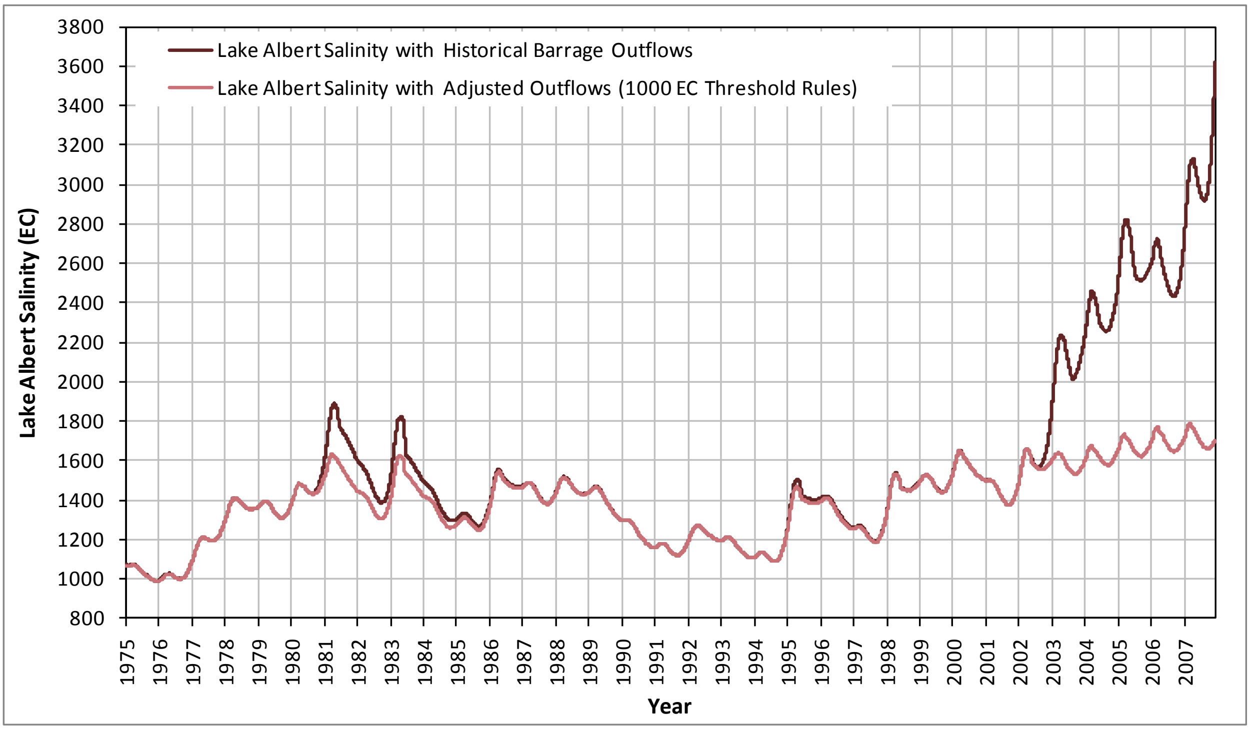



**Figure 61 Lake Albert Salinity with Adjusted Barrage Outflows: 1000 EC Threshold (1975 to 2007)**

## 4.2. 700 EC THRESHOLD

To achieve lower salinity threshold targets, significantly larger flows are required to achieve the same step decrease in salinity and the lake salinity becomes more dependent on the salinity of river inflows. For the period from 1975/76 to 2006/07, the modelled average salinity of inflow to Lake Alexandrina was approximately 570 EC and the mean observed salinity in Lake Alexandrina was 800 EC. Given this data and the significantly higher volumes required to ensure a maximum of 700 EC, it was not considered reasonable to maintain salinities below 700 EC at all times. The 700 EC threshold rules have therefore been designed to maintain an average annual salinity in Lake Alexandrina at (or below) 700 EC (refer Section 3.4.2).

With this objective, the cumulative lake inflow parameters have been determined as follows: $I_1$ = 4000 GL, $I_2$ = 9700 GL and $I_3$ = 14550 GL. $I_{AVE}$ is 4850 GL.

Hence, the minimum lake inflow required in a given year ($Q_X$) to maintain the average Lake Alexandrina salinity below 700 EC is equal to the greater of:

1. 4000 GL
2. 9700 GL - $Q_{X-1}$
3. 14550 GL - $Q_{X-1}$ - $Q^*_{X-2}$ (where $Q^*_{X-2}$ is min($Q_{X-2}$, 4850 GL))

The above criteria was translated into corresponding cumulative barrage outflow parameters as follows: $B_1$ = 3150 GL, $B_2$ = 8000 GL and $B_3$ = 12000 GL. $B_{AVE}$ is 4000 GL.

As a result, the minimum barrage outflow required in a given year ($F_X$) to maintain the average Lake Alexandrina salinity below 700 EC is equal to the greater of:

1. 3150 GL
2. 8000 GL - $F_{X-1}$
3. 12000 GL - $F_{X-1}$ - $F^*_{X-2}$ (where $F^*_{X-2}$ is min($F_{X-2}$, 4000 GL))

To test the rules through application to the historical data, the historical inflows to Lake Alexandrina were modified using the above. The historical inflows to Lake Alexandrina in a given year ($H_X$) were adjusted to equal the greater of:

1. max ($H_X$, 4000)
   i.e. the larger of the historical inflow and 4000 GL
2. max ($H_X$, 9700- $Q_{X-1}$)
   i.e. the larger of the historical inflow and 9700 GL minus inflow from the previous year
3. max ($H_X$, 14550- $H_{X-1}$ - $H^*_{X-2}$) where $H^*_{X-2}$ = min ($Q_{X-2}$, 4850)
   i.e. the larger of the historical inflow or 14550 GL minus inflow from the previous two years and where $Q^*_{X-2}$ is equal to the lesser of the actual outflow two years prior to the current year or 4850 GL

If the inflow in a given year is adjusted, then this adjusted inflow becomes $Q_{X-1}$ for calculating the required inflow for the next year, replacing the actual historical inflow for that year.

The historical and adjusted inflow sequence is shown in Figure 62. Each year of increased inflow that would have been applied using this method is seen as a departure from the historical sequence.

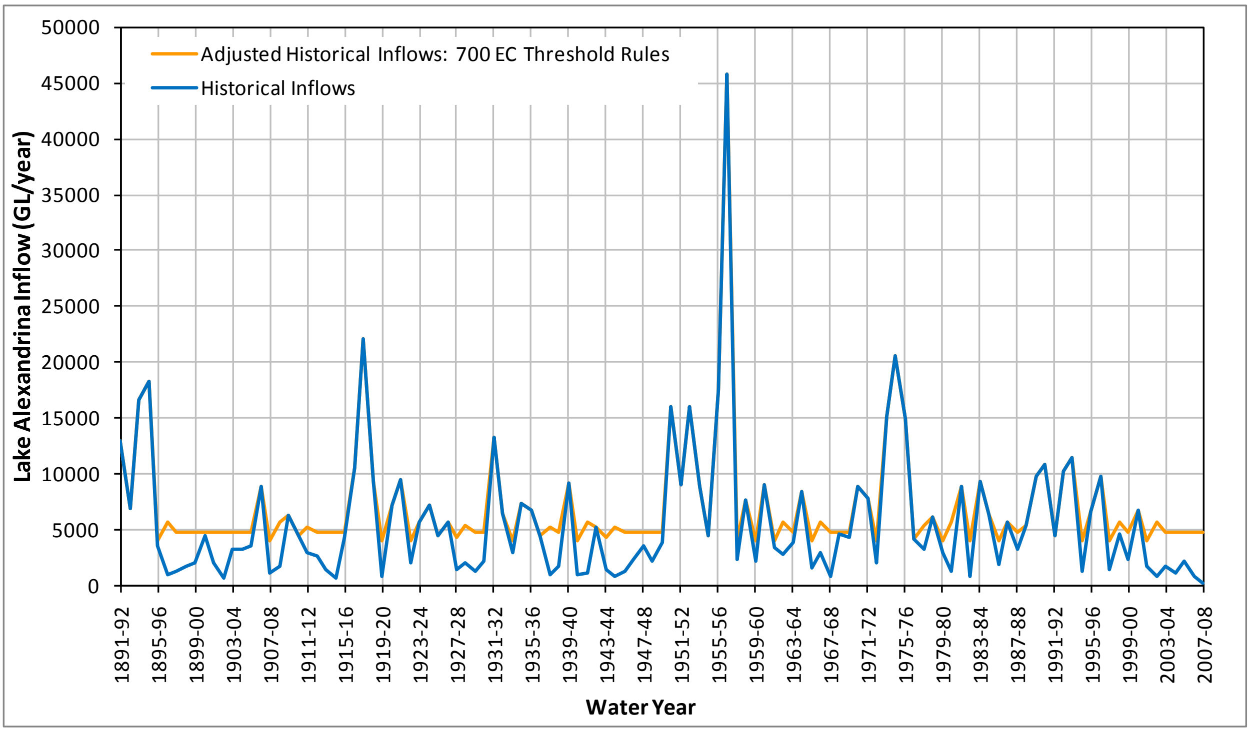



**Figure 62 Adjusted Historical Inflows using 700 EC Threshold Rules**

A summary of the required additional inflows is shown in Table 9. It is evident that a significantly greater number of years required inflow adjustments than with the 1000 EC salinity threshold criteria, with significantly increased volumes.

**Table 9 Additional Flows Required for Historical Inflow Sequence: 700 EC Threshold**

| **Statistics** | |
|---|---|
| Length of Record | 117 years |
| Additional Inflows Required | 65 years |
| Average Annual Inflow Increase | 2535 GL |
| Minimum Annual Inflow Increase | 25 GL |
| Maximum Annual Inflow Increase | 4870 GL |
| **Additional Volume (GL)** | **Number of Years** |
| Min Increase - 500 | 6 |
| 500 - 1000 | 4 |
| 1000 - 2000 | 11 |
| 2000 - 3000 | 21 |
| 3000 - 4000 | 12 |
| 4000 - Maximum Increase | 11 |

Figures 63 to 65 show the historical and adjusted one, two and three-year cumulative inflow sequences for the period from 1975/76 to 2007/08:

- Figure 63 shows that of the 16 years that would have required increased inflows, in only 6 years did an inflow increase to the minimum 4000 GL then ensure that all three criteria were met (1979/80, 1982/83, 1986/86, 1994/95, 1997/98, 2001/02).

- Figure 64 shows that for the period 2002/03 to 2007/08, where all years required increased inflows, the two-year cumulative criteria in all but 2003/04 would have been used.
- Figure 65 shows that in 2003/04, a further increase in the annual inflow was required to meet the three-year cumulative requirement.

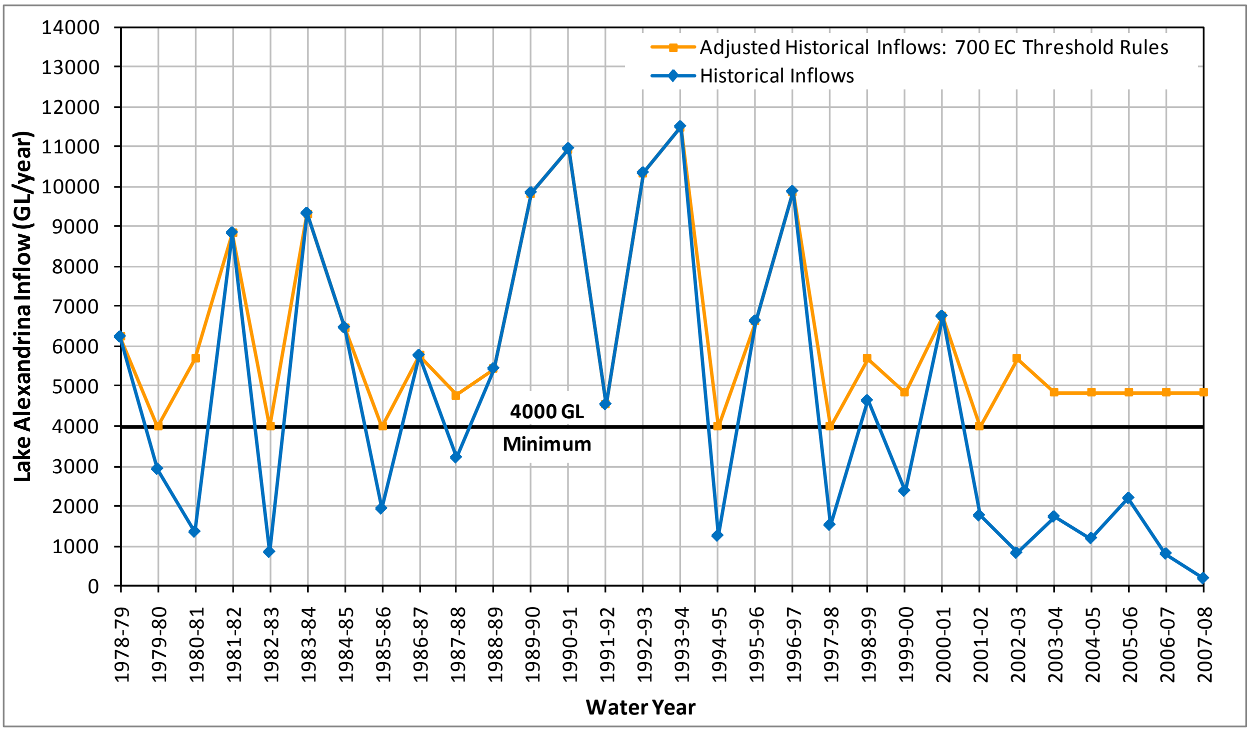



**Figure 63 Adjusted Historical Inflows: 700 EC Threshold (1978/79 to 2007/08)**

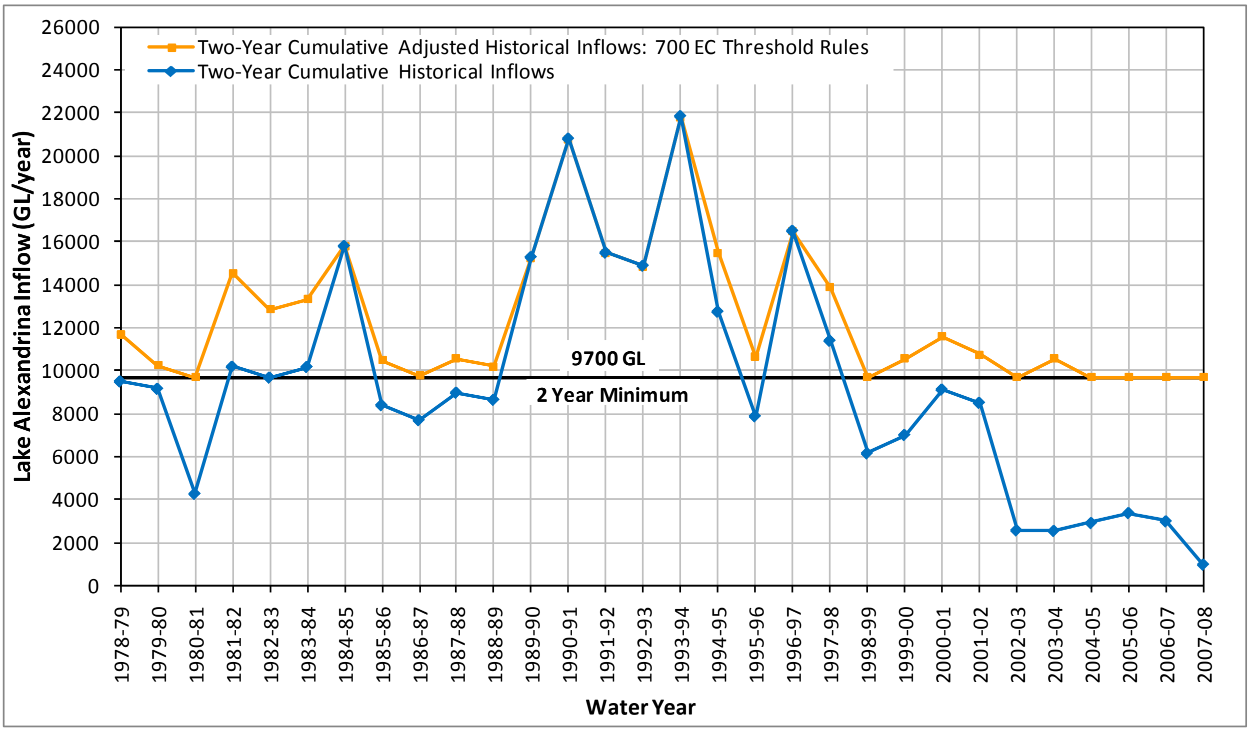



**Figure 64 Two-Year Cumulative Adjusted Historical Inflows: 700 EC Threshold (1978/79 to 2007/08)**

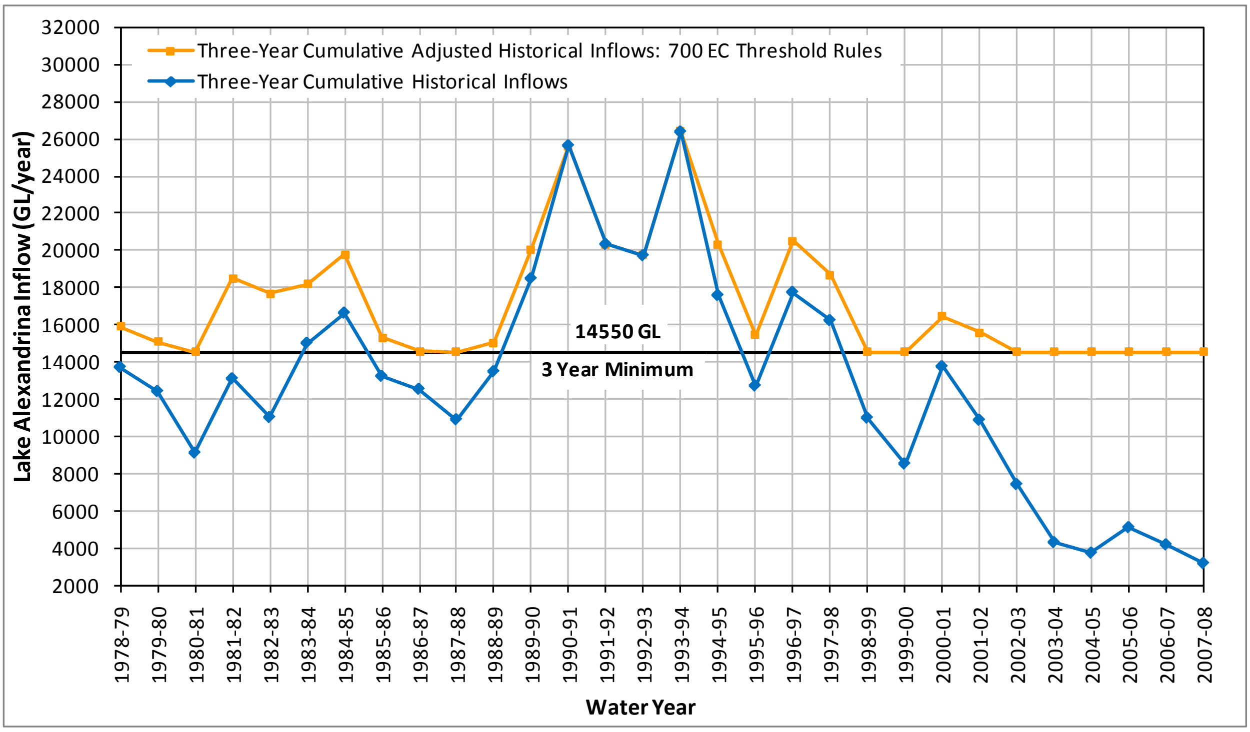



**Figure 65 Three-Year Cumulative Adjusted Historical Inflows: 700 EC Threshold (1978/79 to 2007/08)**

Table 10 shows the annual barrage outflow statistics under historical and adjusted conditions. The mean, median, minimum and 10th percentile outflows have increased significantly from both the historical inflows and those adjusted using the 1000 EC threshold rules. The minimum annual barrage outflow under the adjusted flow sequence is slightly greater than the 3150 GL required.

**Table 10 Historical and Adjusted (700 EC Threshold) Barrage Outflow Statistics (1891/92 to 2007/08)**

| Statistics | Annual Barrage Outflow (GL) | |
|---|---|---|
| | Historical | Adjusted (700 EC Threshold) |
| Mean | 4925 | 6335 |
| Median | 3020 | 4390 |
| Minimum | 0 | 3165 |
| Maximum | 44850 | 44725 |
| 10th Percentile | 260 | 3190 |
| 90th Percentile | 11215 | 11235 |

Figure 66 shows the additional barrage outflows that result from the modified inflow sequence to create the flow regime needed to maintain average salinity in Lake Alexandrina under the 700 EC criteria.

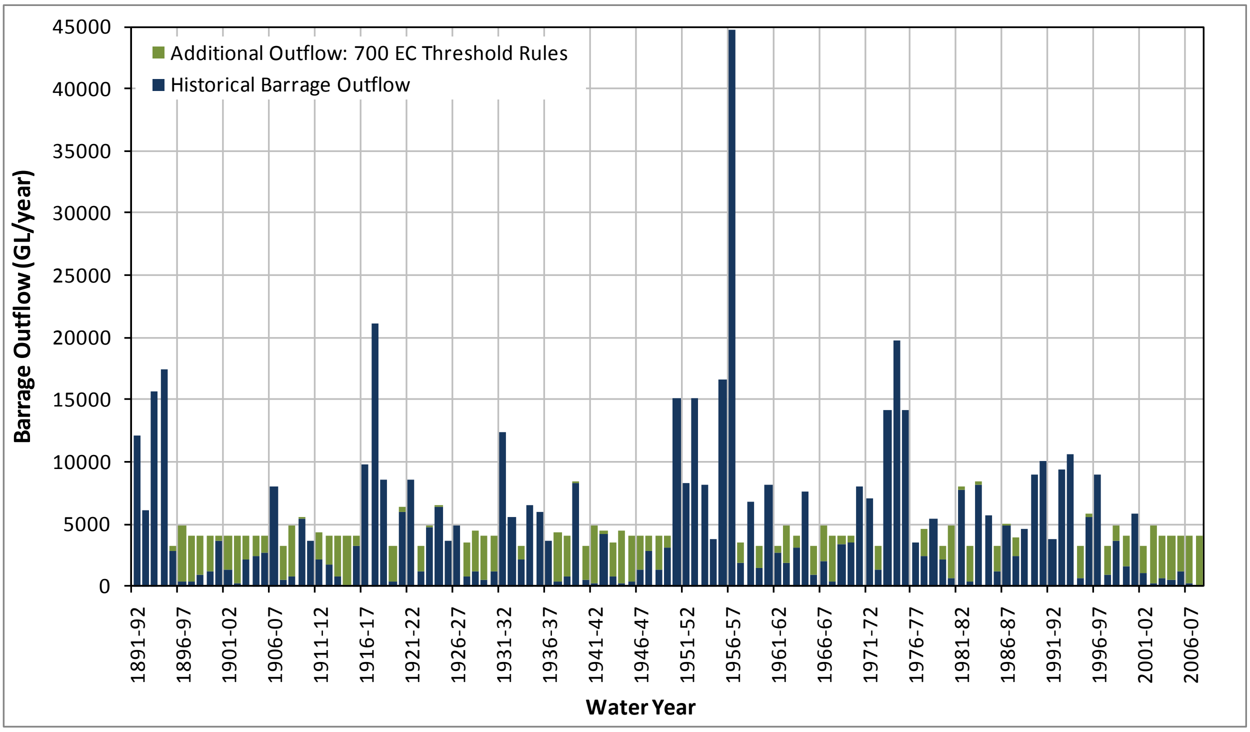



**Figure 66 Additional Barrage Outflows (Historical): 700 EC Threshold**

Figure 67 shows the change to the historical barrage outflow frequency curve. In comparison to the adjusted barrage frequency curve for the 1000 EC threshold criteria, increases in inflows and hence outflows are required across a larger range of outflow magnitudes.

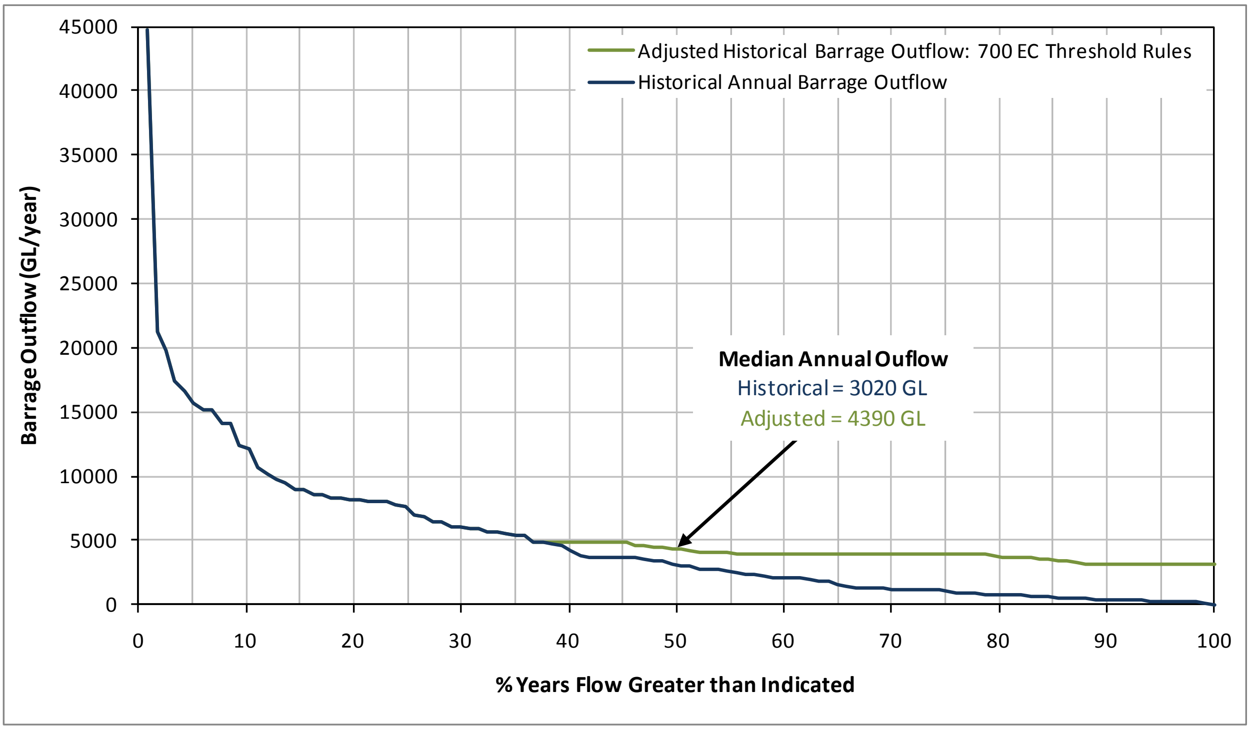



**Figure 67 Historical and Adjusted Annual Barrage Outflow Frequency Curves: 700 EC Threshold**

Figure 68 shows the adjusted historical annual barrage outflows that result from the 700 EC Threshold rules for the period from 1891/92 to 1916/17. Figures 69 and 70 show the resultant Lake Alexandrina and Lake Albert salinity time-series responses.

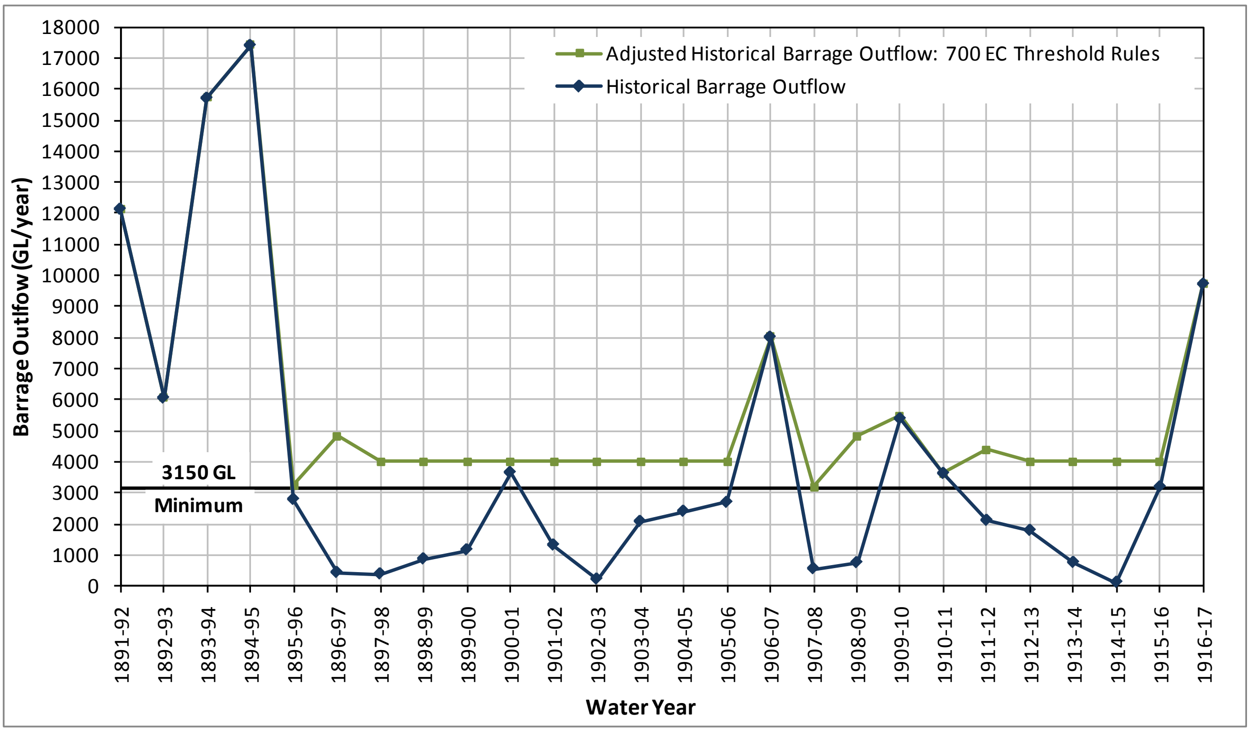



**Figure 68 Adjusted Annual Barrage Outflows: 700 EC Threshold (1891/92 to 1916/17)**

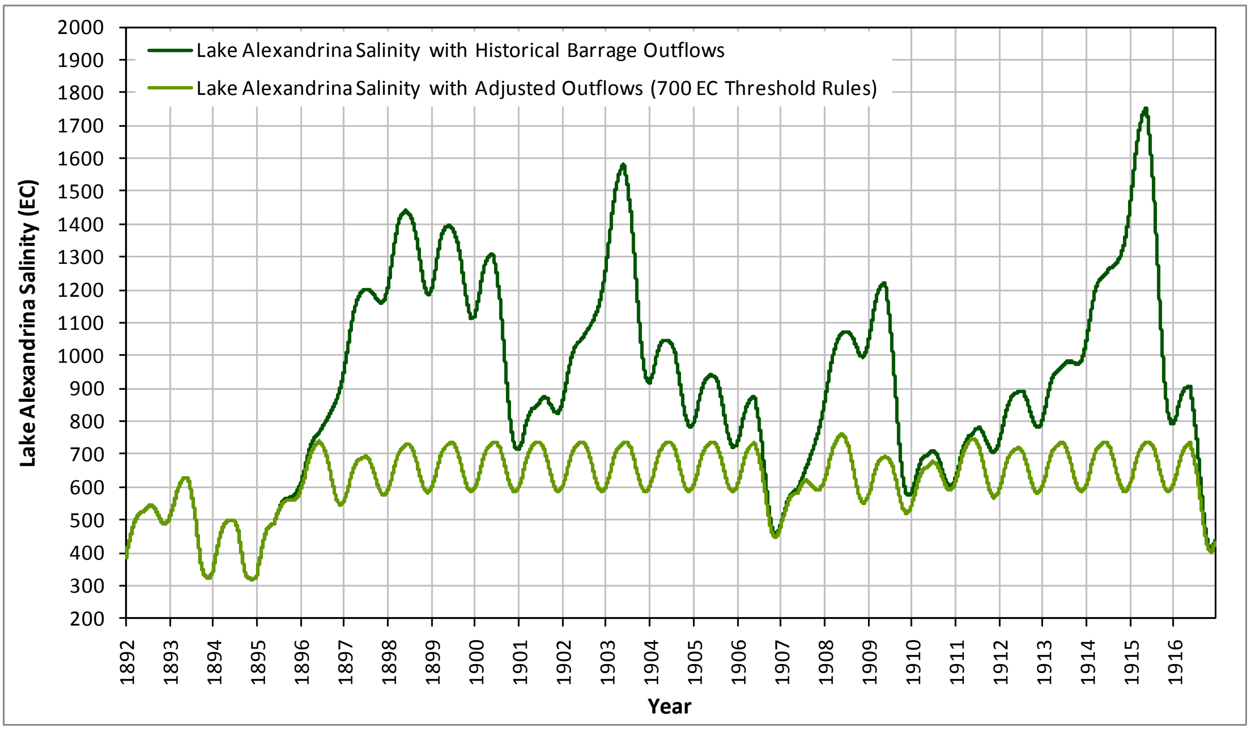



**Figure 69 Lake Alexandrina Salinity with Adjusted Barrage Outflows: 700 EC Threshold (1892 to 1916)**

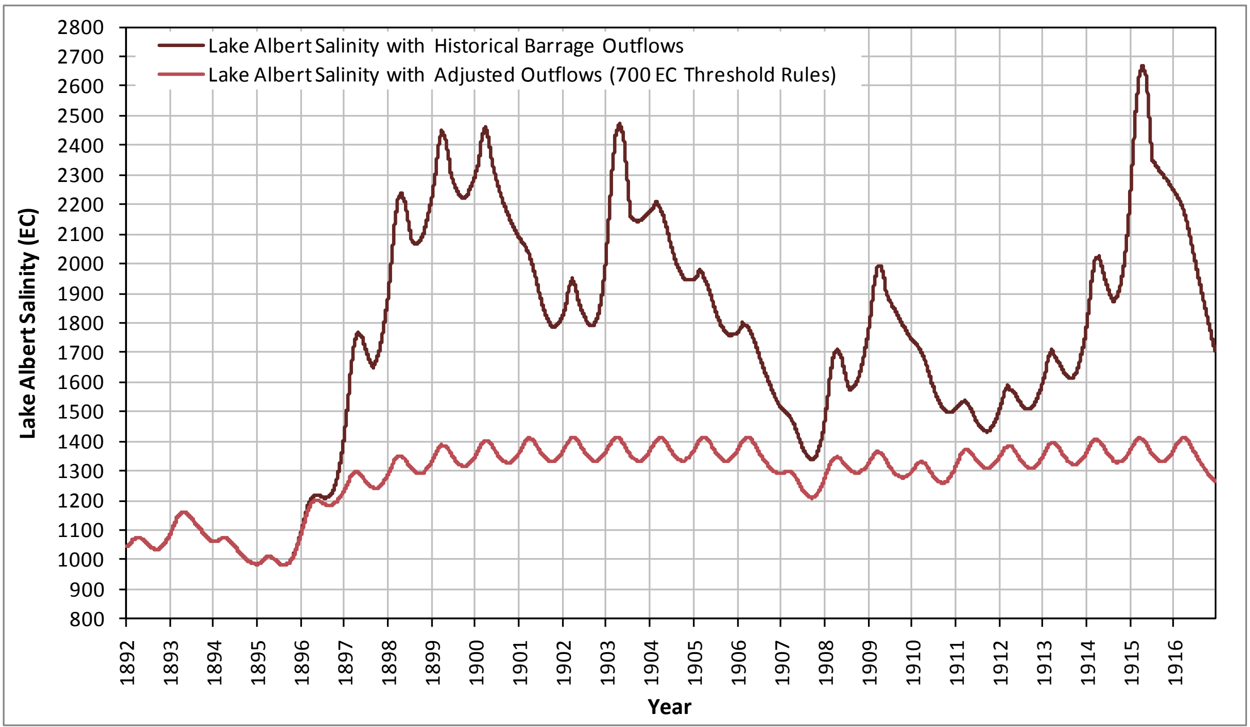



**Figure 70 Lake Albert Salinity with Adjusted Barrage Outflows: 700 EC Threshold (1892 to 1916)**

Figure 71 shows the adjusted historical annual barrage outflows that result from the 700 EC Threshold rules for the period from 1975/76 to 2007/08. Figures 72 and 73 show the resultant Lake Alexandrina and Lake Albert salinity time-series responses.

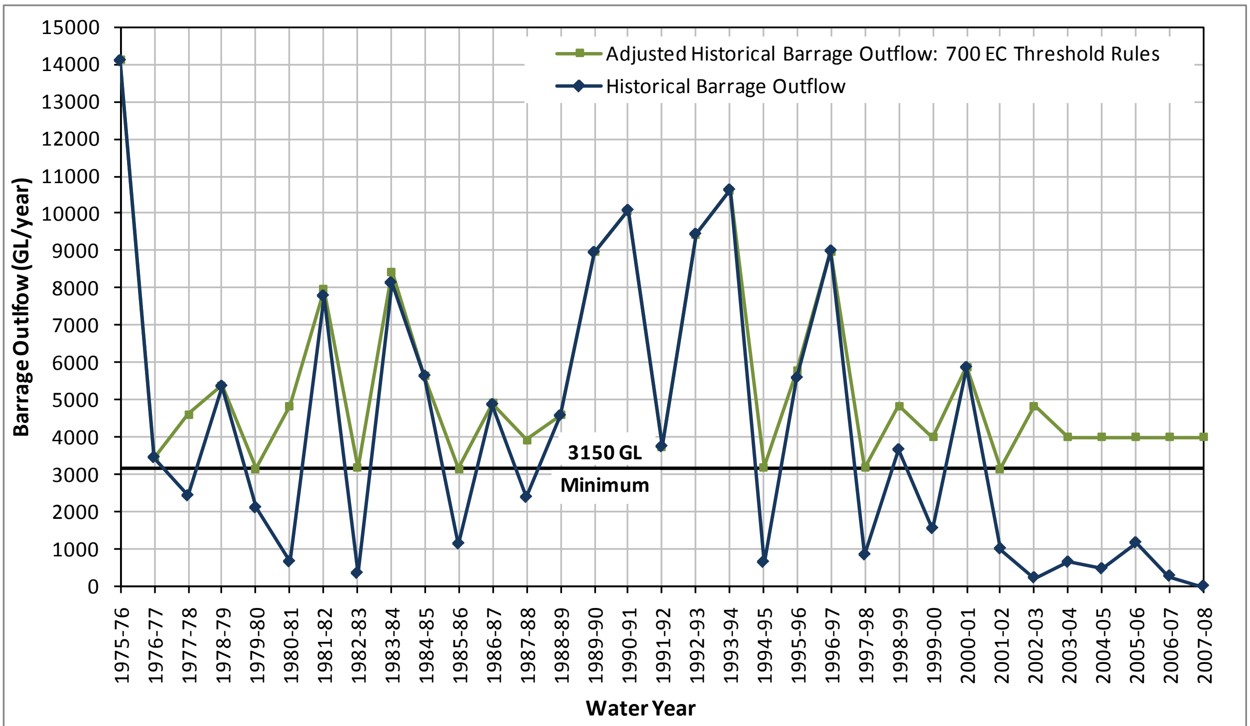



**Figure 71 Adjusted Annual Barrage Outflows: 700 EC Threshold (1975/76 to 2007/08)**

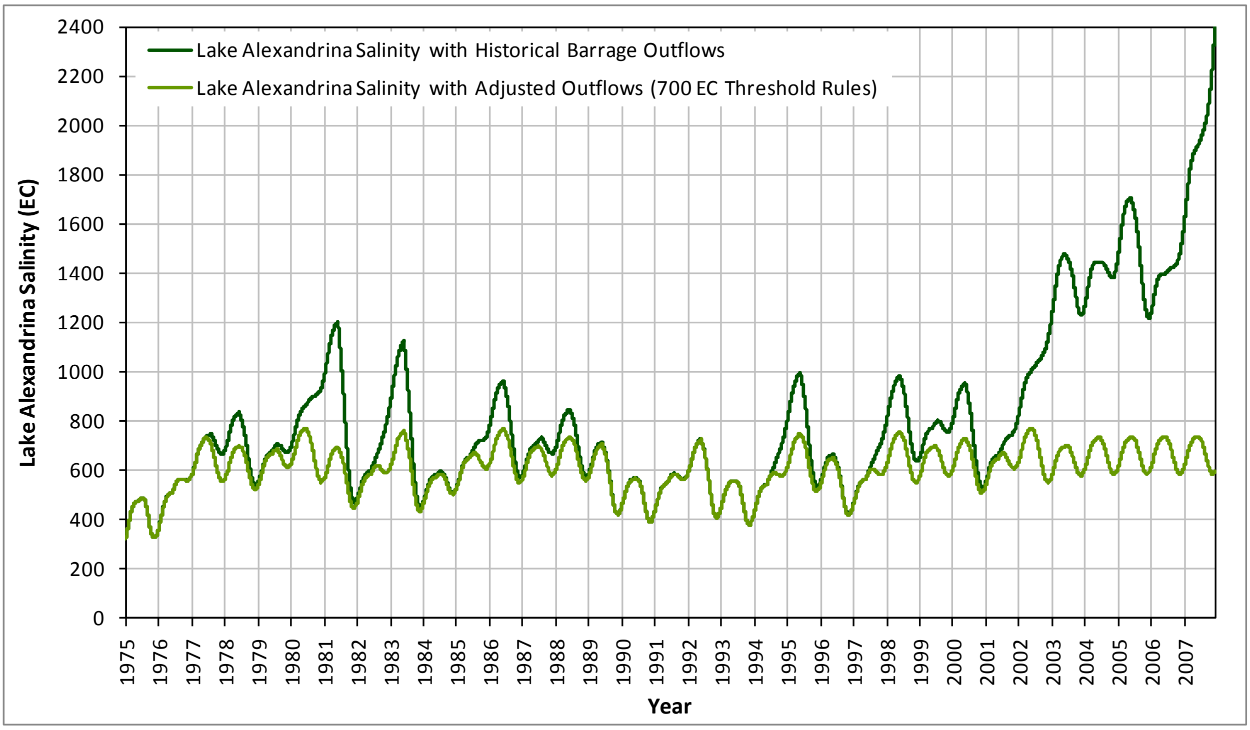



**Figure 72 Lake Alexandrina Salinity with Adjusted Barrage Outflows: 700 EC Threshold (1975 to 2007)**

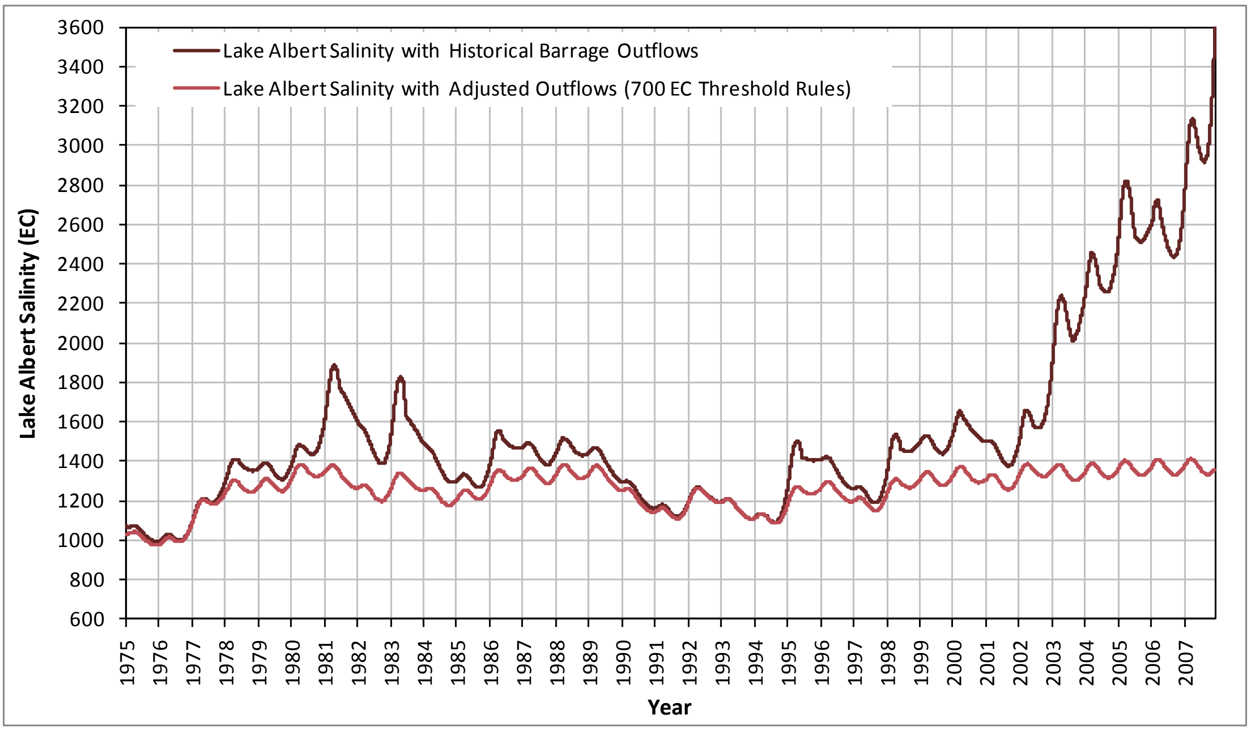



**Figure 73 Lake Albert Salinity with Adjusted Barrage Outflows: 700 EC Threshold (1975 to 2007)**

## *4.3. 1500 EC THRESHOLD*

For a 1500 EC threshold in Lake Alexandrina the cumulative lake inflow parameters have been determined as follows: $I_1$ = 850 GL (inflows delivered to replace losses and diversions), $I_2$ = 3700 GL and $I_3$ = 5550 GL. $I_{AVE}$ is 1850 GL.

Hence, the minimum lake inflow required in a given year ($Q_X$) to maintain Lake Alexandrina salinity below 1500 EC is equal to the greater of:

1. 850 GL (inflows delivered to replace losses and diversions)
2. 3700 GL - $Q_{X-1}$
3. 5550 GL - $Q_{X-1}$ - $Q^*_{X-2}$ (where $Q^*_{X-2}$ is min($Q_{X-2}$, 1850 GL))

The above criteria was translated into corresponding cumulative barrage outflow parameters as follows: $B_1$ = 0 GL, $B_2$ = 2000 GL and $B_3$ = 3000 GL. $B_{AVE}$ is 1000 GL.

As a result, the minimum barrage outflow required in a given year ($F_X$) to maintain Lake Alexandrina salinity below 1500 EC is equal to the greater of:

1. 0 GL (but with inflows delivered to replace losses and diversions)
2. 2000 GL - $F_{X-1}$
3. 3000 GL - $F_{X-1}$ - $F^*_{X-2}$ (where $F^*_{X-2}$ is min($F_{X-2}$, 1000 GL))

To test the rules through application to the historical data, the historical inflows to Lake Alexandrina were modified using the above. The historical inflows to Lake Alexandrina in a given year ($H_X$) were adjusted to equal the greater of:

1. max ($H_X$, 850)
   i.e. the larger of the historical inflow and 850 GL
2. max ($H_X$, 3700- $Q_{X-1}$)
   i.e. the larger of the historical inflow and 3700 GL minus inflow from previous year
3. max ($H_X$, 5550- $H_{X-1}$ - $H^*_{X-2}$) where $H^*_{X-2}$ = min ($Q_{X-2}$, 1850)
   i.e. the larger of the historical inflow or 5550 GL minus inflow from previous two years and where $H^*_{X-2}$ is equal to the lesser of the actual outflow two years prior to the current year or 1850 GL

If the inflow in a given year is adjusted, then this adjusted inflow becomes $H_{X-1}$ for calculating the required inflow for the next year, replacing the actual historical inflow for that year.

The historical and adjusted inflow sequence is shown in Figure 74. Each year of increased inflow that would have been applied using this method is seen as a departure from the historical sequence, with few increases required for this salinity management target.

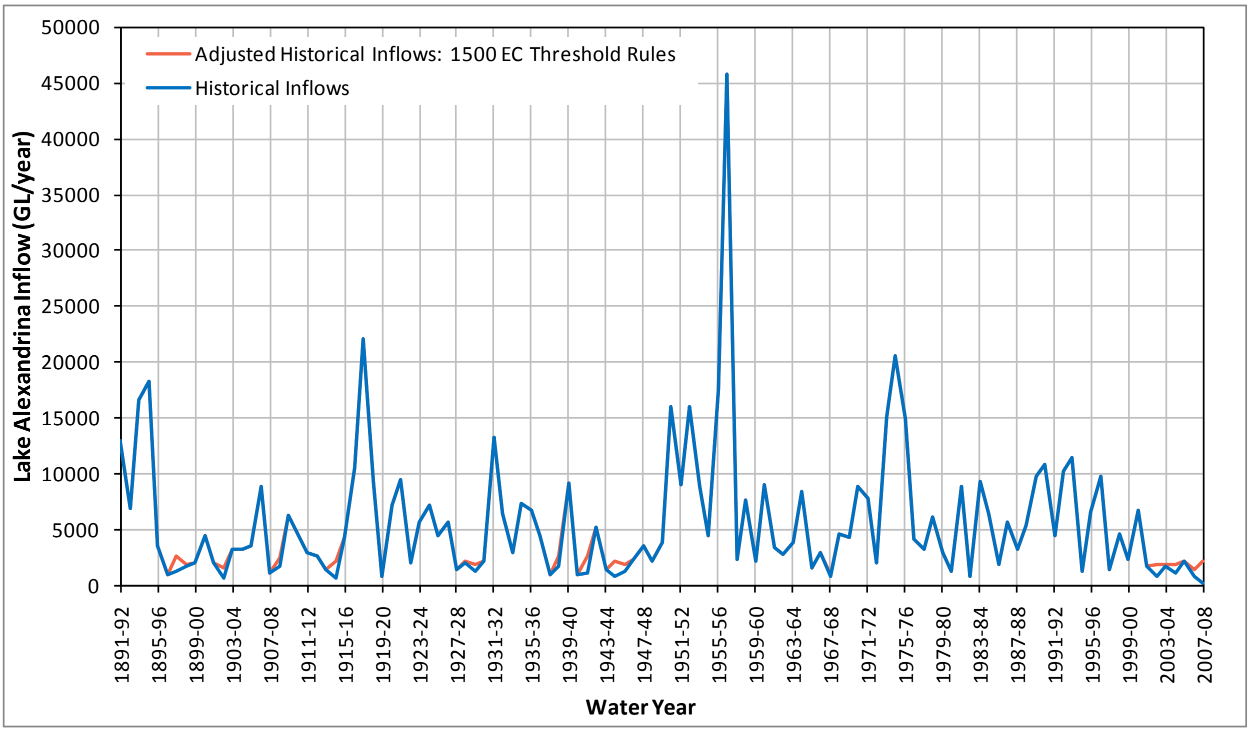



**Figure 74 Adjusted Historical Inflows using 1500 EC Threshold Rules**

A summary of the required additional inflows is shown in Table 11. The majority of increased inflows were required within three periods: 1897/98 to 1914/15 (5 years), 1938/9 to 1945/46 (4 years) and 2002/03 to 2007/08 (5 years).

**Table 11 Additional Flows Required for Historical Inflow Sequence: 1500 EC Threshold**

| **Statistics** | |
|---|---|
| Length of Record | 117 years |
| Additional Inflows Required | 18 years |
| Average Annual Inflow Increase | 790 GL |
| Minimum Annual Inflow Increase | 1 GL |
| Maximum Annual Inflow Increase | 2008 GL |
| **Additional Volume (GL)** | **Number of Years** |
| Min Increase - 500 | 5 |
| 500 - 1000 | 7 |
| 1000 - 2000 | 5 |
| 2000 - Maximum Increase | 1 |

Figures 75 to 77 show the historical and adjusted one, two and three-year cumulative inflow sequences for the period from 1891/92 to 1916/17:

- Figure 75 shows that of the four years that would have required increased inflows, in no years did an inflow increase to the minimum 850 GL then ensure that all three criteria were met.
- Figure 76 shows that the two-year cumulative total would have been used to manage the inflow in all four years (1897/98, 1902/03, 1908/09, 1914/15) that would have required increased inflows.

- Figure 77 shows that no further increase to annual inflows were required to meet the three-year cumulative requirement.

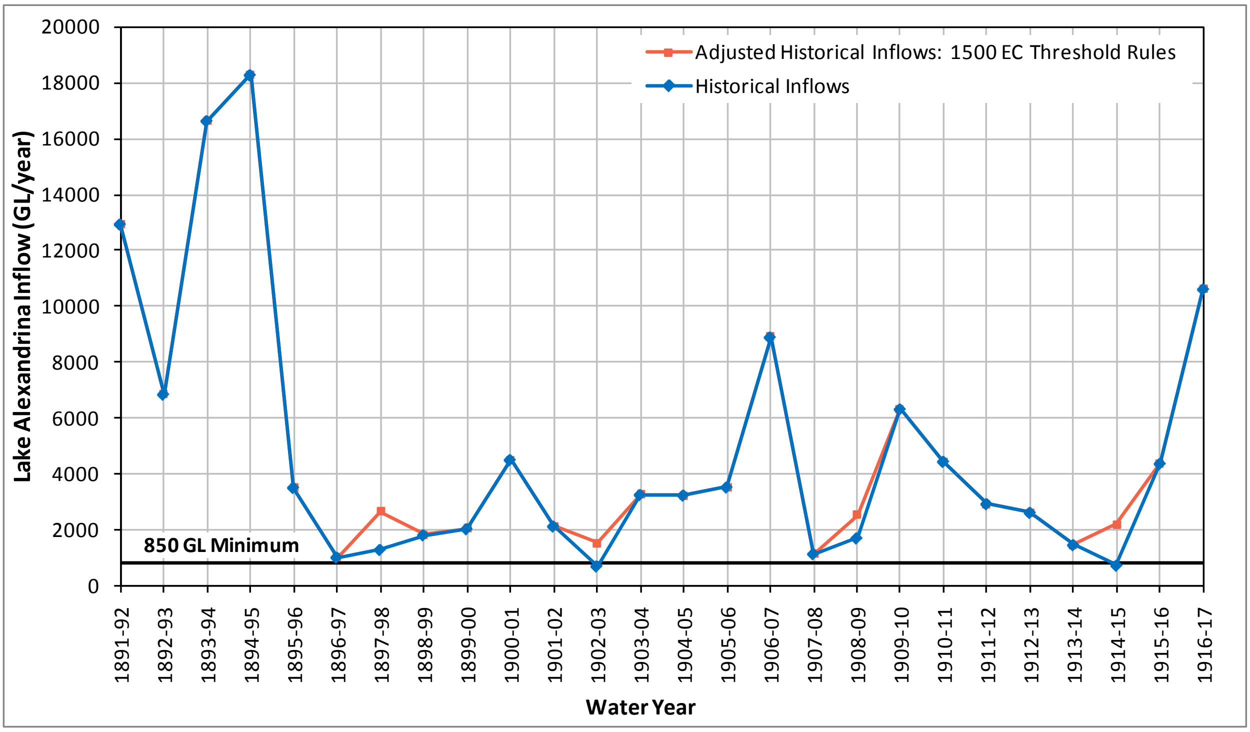



**Figure 75 Adjusted Historical Inflows: 1500 EC Threshold (1891/92 to 1916/17)**

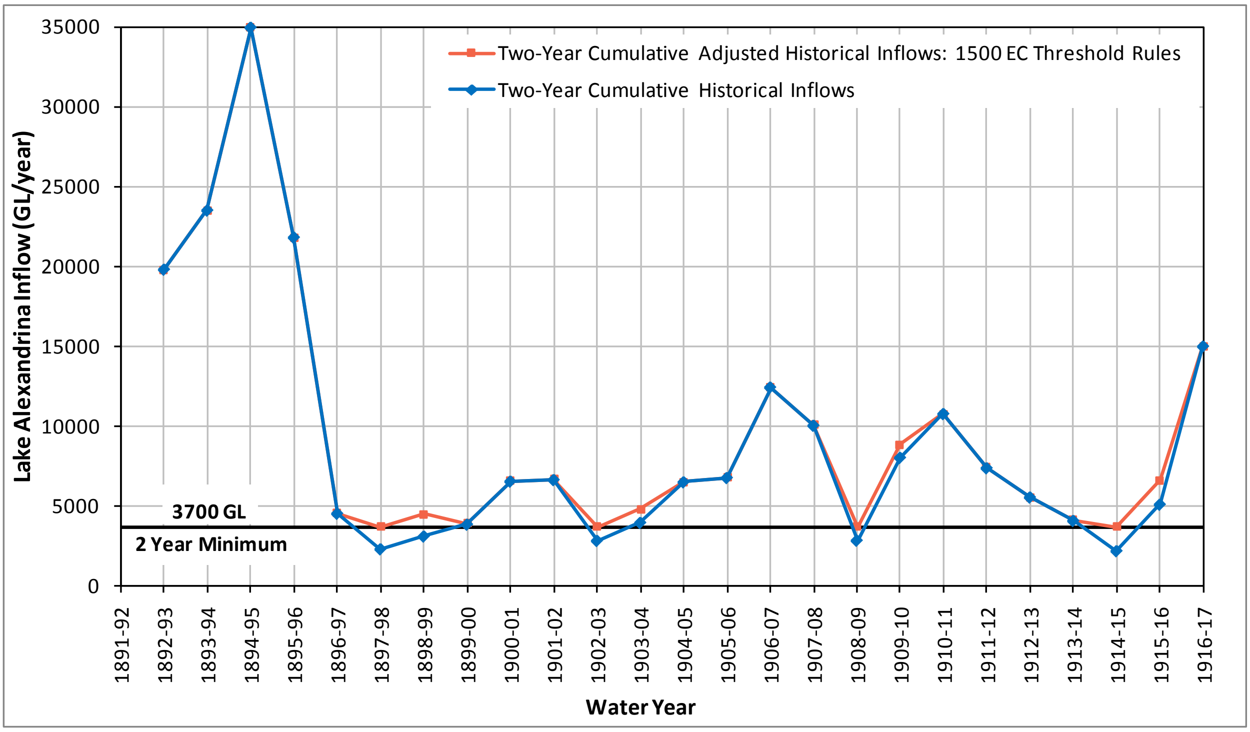



**Figure 76 Two-Year Cumulative Adjusted Historical Inflows: 1500 EC Threshold (1891/92 to 1916/17)**

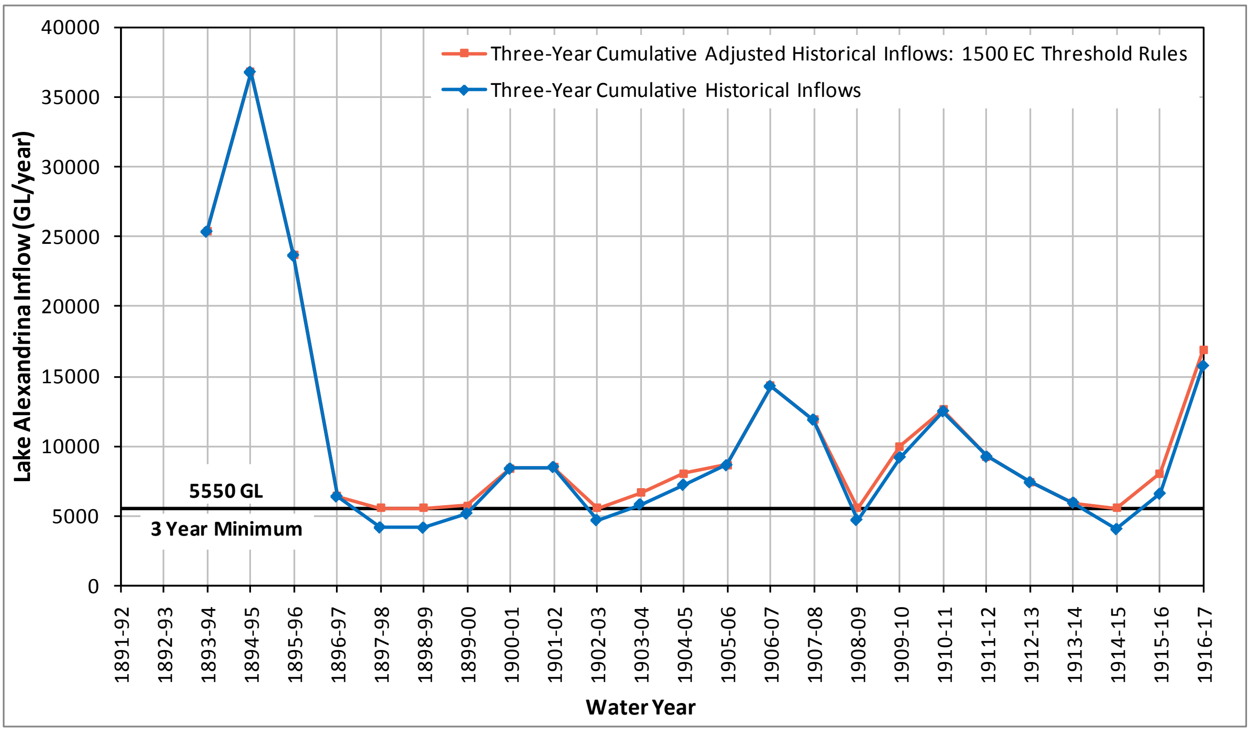



**Figure 77 Three-Year Cumulative Adjusted Historical Inflows: 1500 EC Threshold (1891/92 to 1916/17)**

Table 12 shows the annual barrage outflow statistics under historical and adjusted conditions. Both the mean and median outflows have increased slightly, but the main changes are increases to the lower outflow statistics (minimum and 10th percentile).

**Table 12 Historical and Adjusted (1500 EC Threshold) Barrage Outflow Statistics (1891/92 to 2007/08)**

| Statistics | Annual Barrage Outflow (GL) | |
|---|---|---|
| | Historical | Adjusted (1500 EC Threshold) |
| Mean | 4925 | 5050 |
| Median | 3020 | 3065 |
| Minimum | 0 | 345 |
| Maximum | 44850 | 44725 |
| 10th Percentile | 260 | 790 |
| 90th Percentile | 11215 | 11235 |

Figure 78 shows the additional barrage outflows that result from the modified inflow sequence to create the flow regime needed to maintain salinity in Lake Alexandrina under the 1500 EC criteria. Figure 79 then shows that there is very little change to the historical barrage outflow frequency curve.

Figure 80 shows the adjusted historical annual barrage outflows that result from the 1500 EC threshold rules for the period from 1891/92 to 1916/17 with Figures 81 and 82 showing the resultant Lake Alexandrina and Lake Albert salinity time-series responses. Using rounded inflow targets (refer Section 3.4.3) meant that the threshold defined by the rules is closer to 1300 EC than 1500 EC. Lake Alexandrina salinity exceeded 1300 EC under historical conditions between 1897/98 and 1899/00. Given that the salinity during 1897/98 did not exceed 1500 EC and the additional inflows provided lowered salinities to well below 1300 EC, it may be worth exploring the 1500 EC rules further. However, these additional inflows also enabled salinities to remain below 1300 EC for the three-year sequence above, while barrage outflows were still well below average.

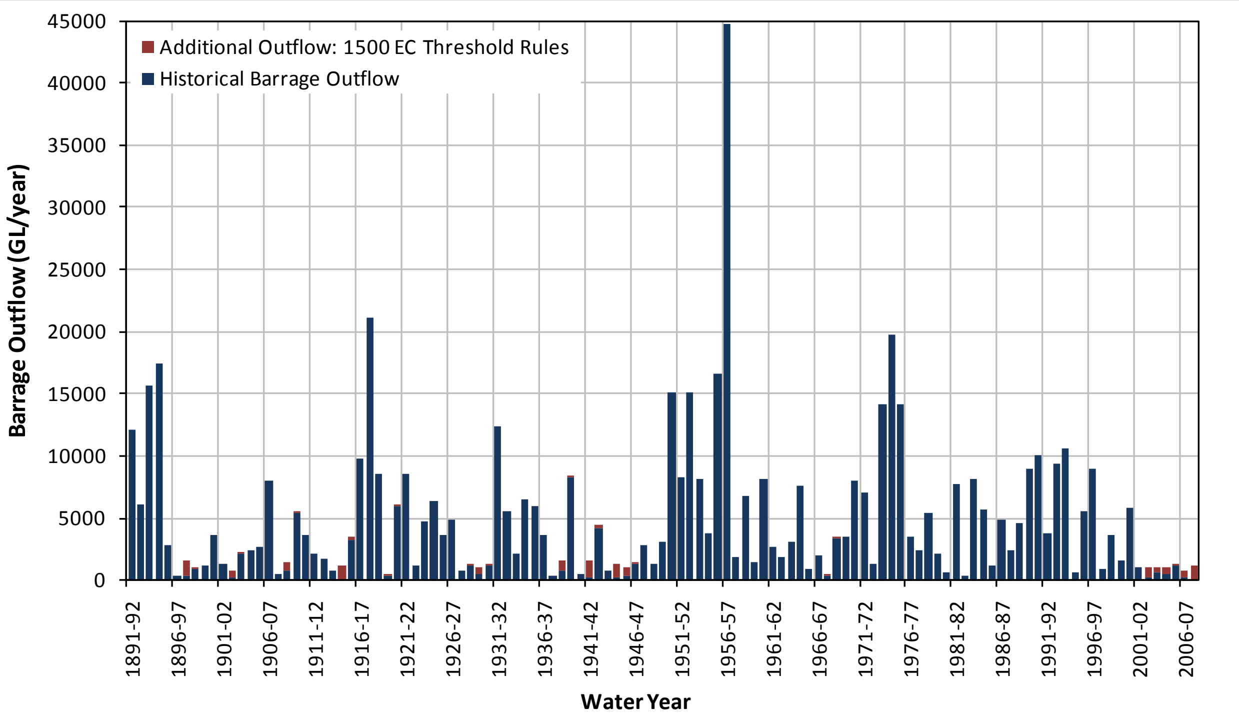



**Figure 78 Additional Barrage Outflows (Historical): 1500 EC Threshold**

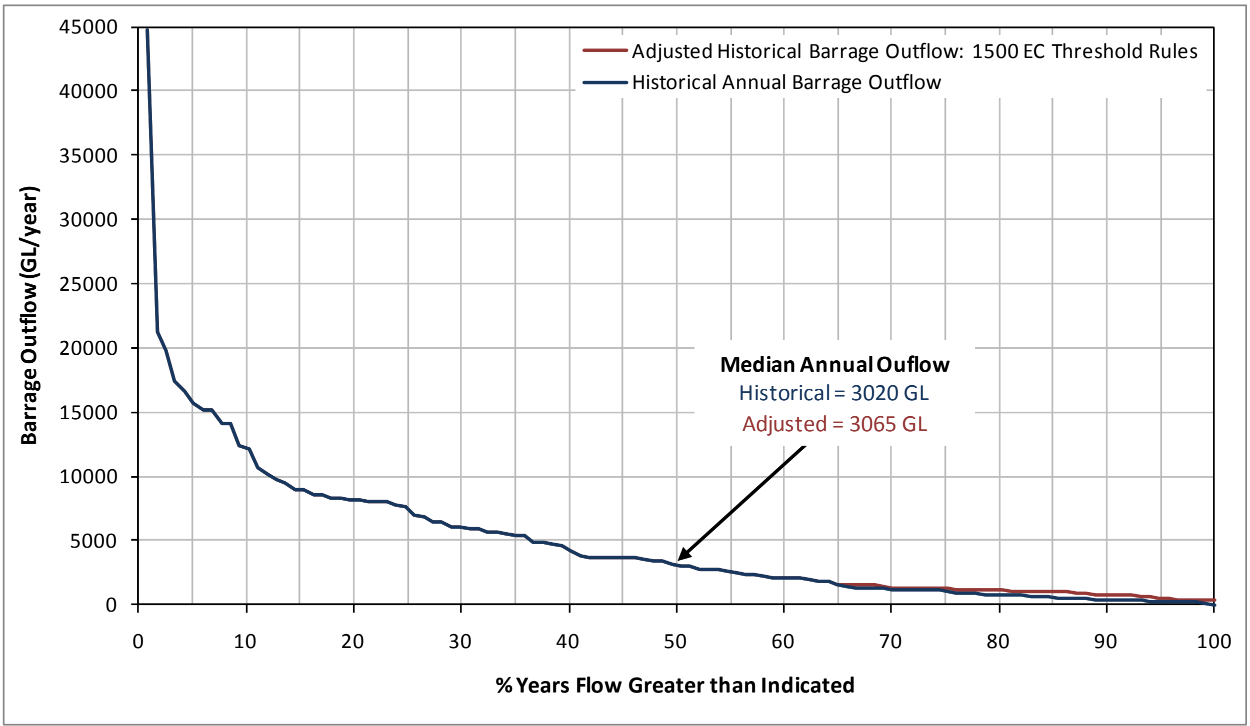



**Figure 79 Historical and Adjusted Annual Barrage Outflow Frequency Curves: 1500 EC Threshold**

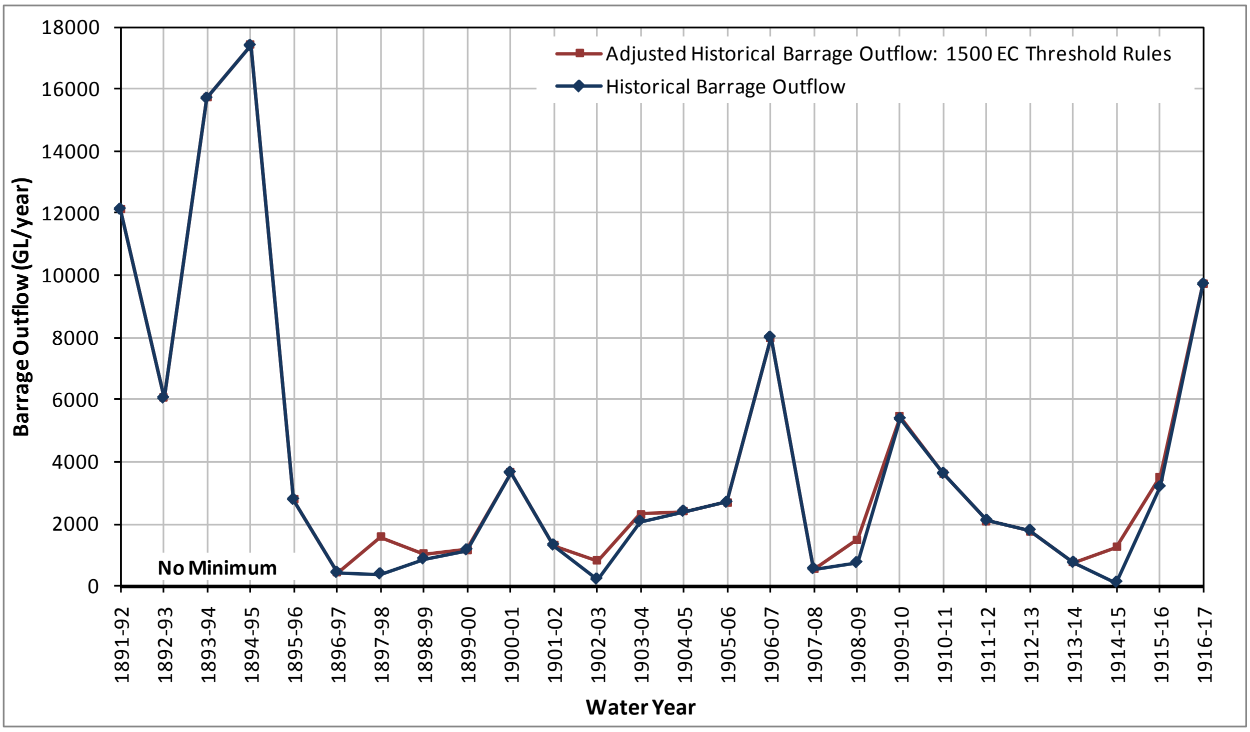



**Figure 80 Adjusted Annual Barrage Outflows: 1500 EC Threshold (1891/92 to 1916/17)**

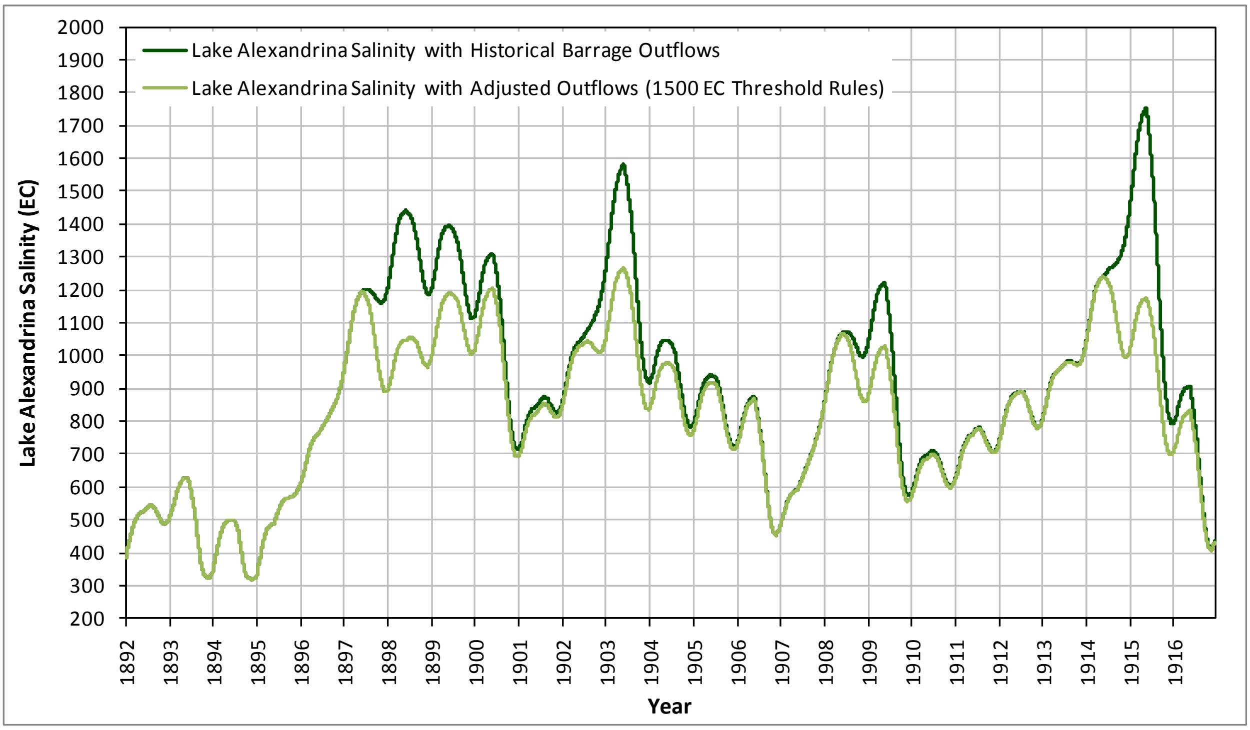



**Figure 81 Lake Alexandrina Salinity with Adjusted Barrage Outflows: 1500 EC Threshold (1892 to 1916)**

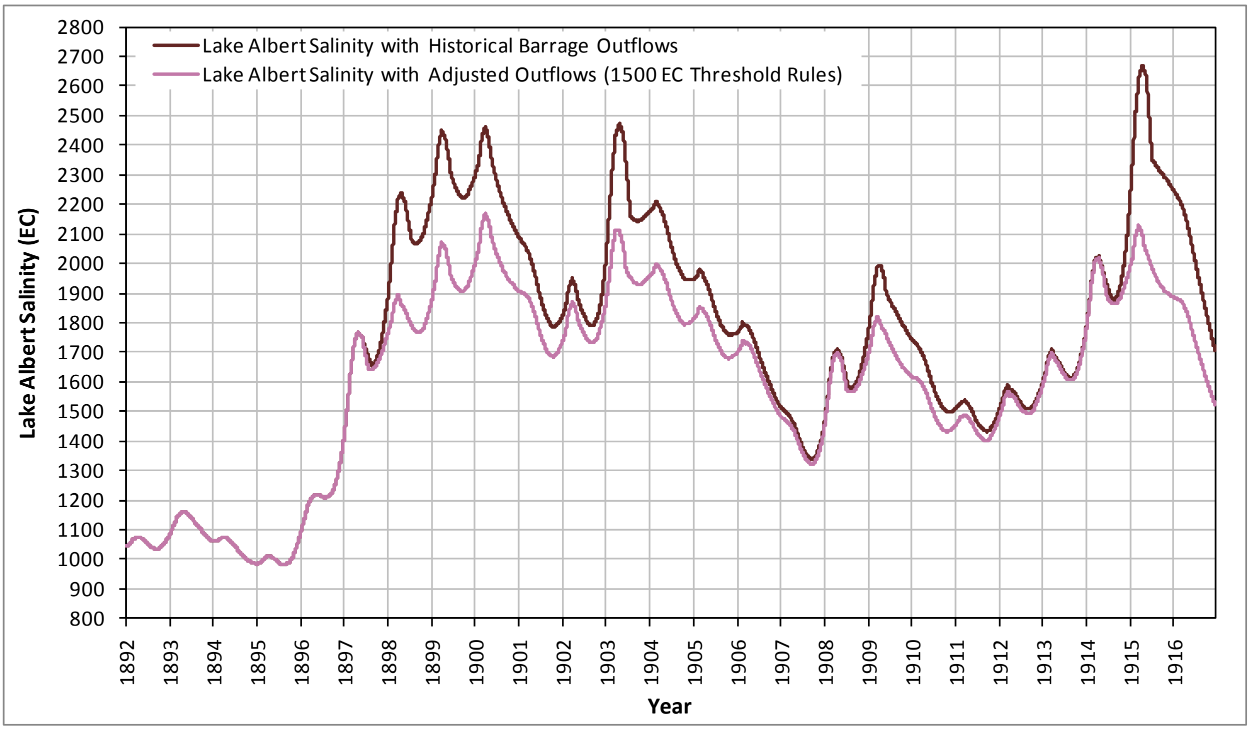



**Figure 82 Lake Albert Salinity with Adjusted Barrage Outflows: 1500 EC Threshold (1892 to 1916)**

Figure 83 shows the adjusted historical annual barrage outflows that result from the 1500 EC threshold rules for the period from 1975/76 to 2007/08. Figures 84 and 85 show the resultant Lake Alexandrina and Lake Albert salinity time-series responses.

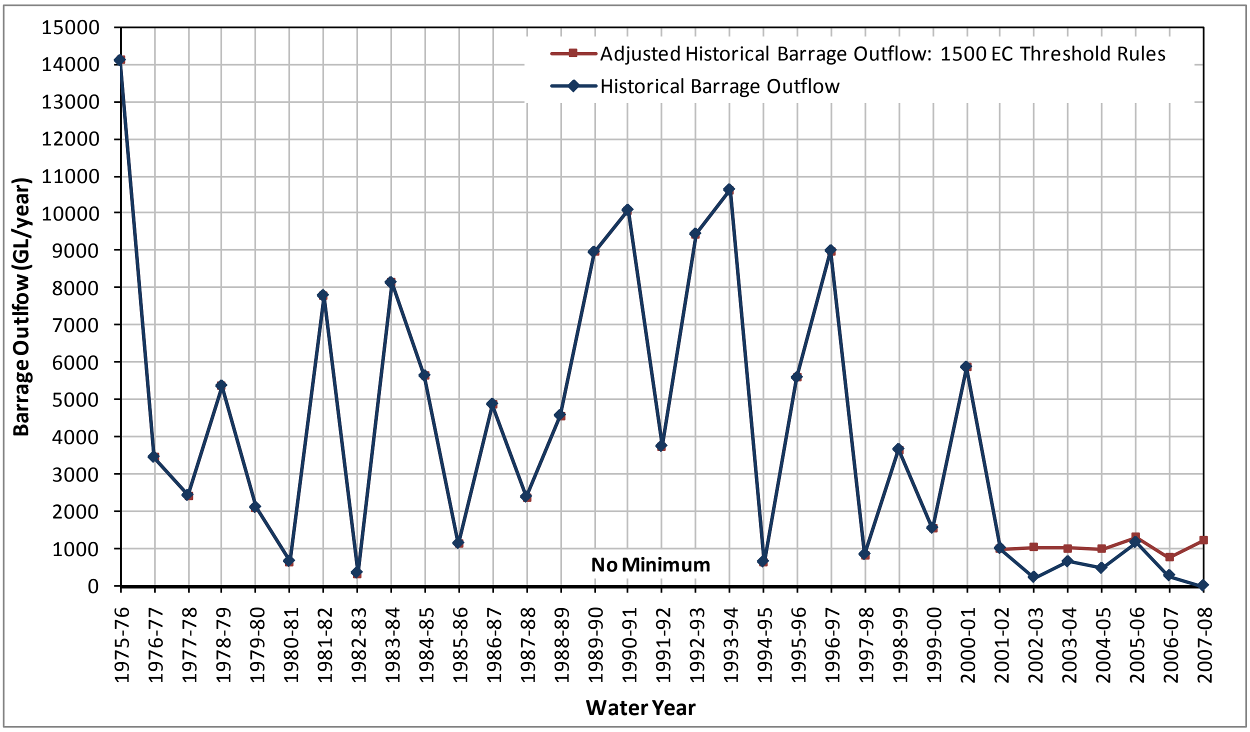



**Figure 83 Adjusted Annual Barrage Outflows: 1500 EC Threshold (1975/75 to 2007/08)**

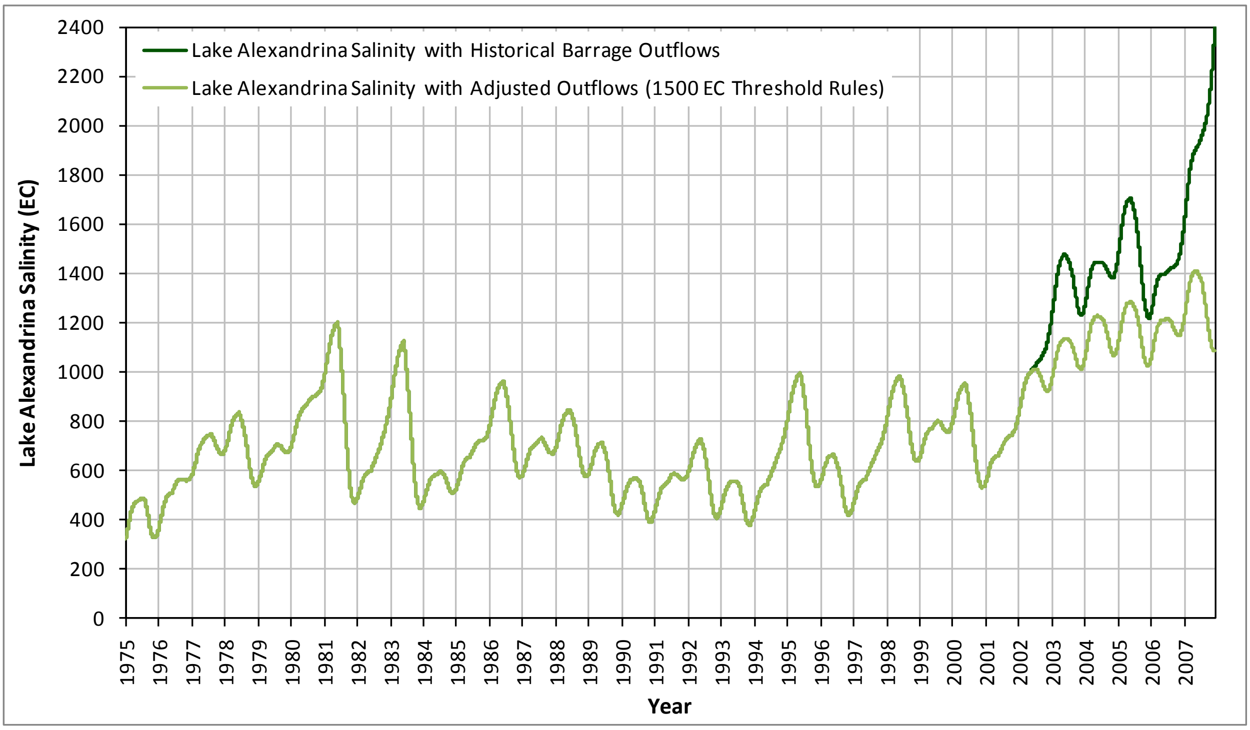



**Figure 84 Lake Alexandrina Salinity with Adjusted Barrage Outflows: 1500 EC Threshold (1975 to 2007)**

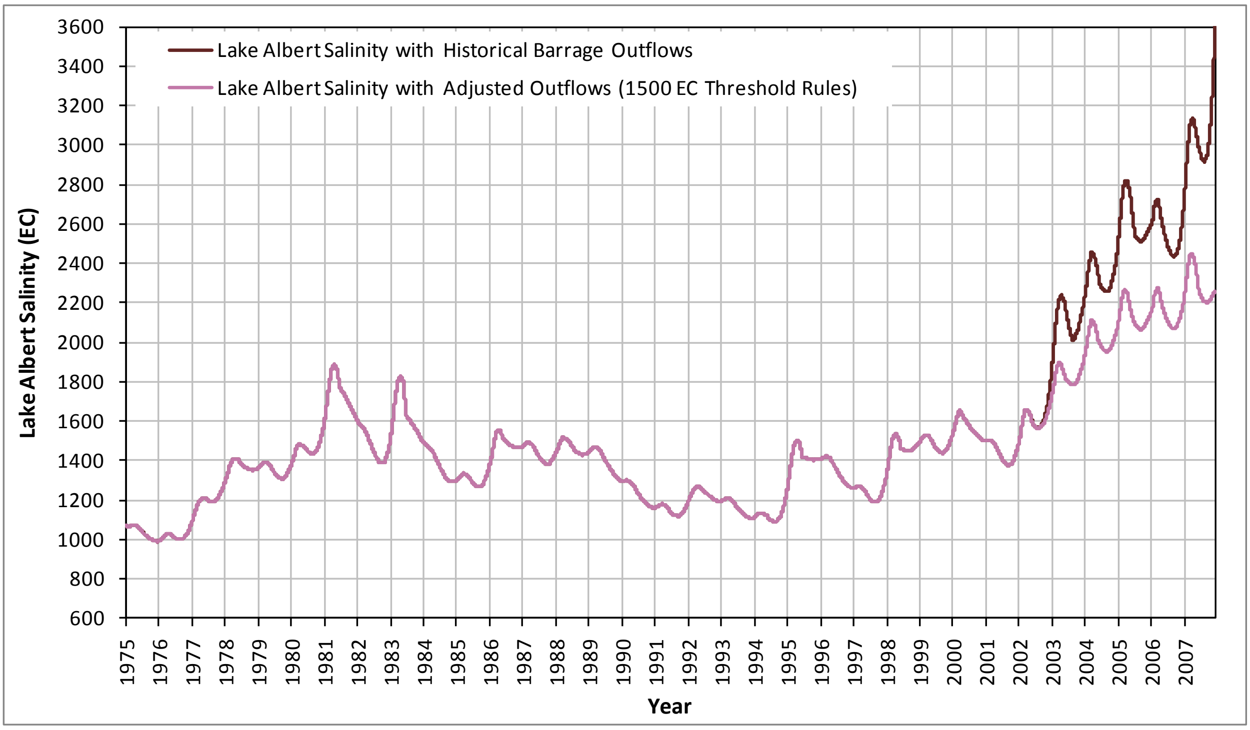



**Figure 85 Lake Albert Salinity with Adjusted Barrage Outflows: 1500 EC Threshold (1975 to 2007)**

Salinities within Lake Alexandrina have remained below 1300 to 1500 EC for around 95% of the observed record from 1975/76 to 2007/08. However, when salinities have risen above these levels they have generally remained high for extended periods. This is evident over the last five years in Figure 84, which also shows that the threshold rules applied in this instance have been successful in managing salinities within the 1200 to 1400 EC range.

# 5. VALIDATION OF FLOW REGIMES UNDER REDUCED WATER AVAILABILITY

## 5.1. POTENTIAL IMPACT OF CMID AND CDRY CONDITIONS

The flow regimes required to maintain the three salinity thresholds in Lake Alexandrina were then evaluated using two climate sequences that simulate reduced water availability. These climate sequences are defined as follows:

1. Cmid – Murray–Darling Basin Sustainable Yields (MDBSY) "Median Dry" climate change scenario, which is a reduction of the historical climate (in terms of rainfall and Murray System inflows) to account for the 2030 median climate change projection from the MDBSY project.
2. Cdry – Murray–Darling Basin Sustainable Yields (MDBSY) "Extreme Dry" climate change scenario, which is a reduction of the historical climate (in terms of rainfall and Murray System inflows) to account for the 2030 dry climate change projection from the MDBSY project.

Under the *MDB Agreement 2008*, South Australia is entitled to a minimum entitlement of 696 GL for Dilution and Loss each year. Under historical conditions this flow volume would deliver no more than 150 GL to Lake Alexandrina. Given the major issues that occurred in the Lower Lakes throughout the recent low water availability years and to ensure that salinity levels remain within tolerable levels at the major pumping stations downstream of Lock 1, the current South Australian Government policy under low flow conditions is to provide a minimum of 896 GL per year at the South Australian Border. This will allow the annual delivery of up to 201 GL of critical human water needs and results in approximately 350 GL flowing into Lake Alexandrina each year. As such, this is considered the new "minimum" flow to Lake Alexandrina in a given year.

In the MDBSY project, this policy was not considered and lake inflows were projected to drop below 350 GL in both the Cmid (one instance) and Cdry (13 instances) sequences from 1891/92 to 2007/08 (CSIRO 2008). For this analysis, the inflows to Lake Alexandrina under these sequences have been adjusted to ensure the minimum 350 GL inflow occurs. This makes very little difference to the overall barrage outflow statistics but does ensure water levels remain higher and hence salinities lower during very low inflow periods than would occur otherwise.

Table 13 compares barrage outflow statistics from the Historical, Cmid and Cdry climate scenarios, showing that there are significant decreases in barrage outflows as the climate conditions become drier, under current water sharing arrangements.

**Table 13 Barrage Outflow Statistics: Historical, Cmid and Cdry Conditions (1891/92 to 2007/08)**

| Statistics | Historical | Cmid | Cdry |
|---|---|---|---|
| Mean | 4925 | 3760 | 1590 |
| Median | 3020 | 2130 | 590 |
| Minimum | 0 | 0 | 0 |
| Maximum | 44850 | 37485 | 21845 |
| 10$^{th}$ Percentile | 260 | 170 | 0 |
| 90$^{th}$ Percentile | 11215 | 8865 | 4335 |

Figures 86 and 87 show the projected annual barrage outflow totals under both Cmid and Cdry conditions. In addition to significant reductions in the outflow totals, the number of no barrage outflow years is increased.

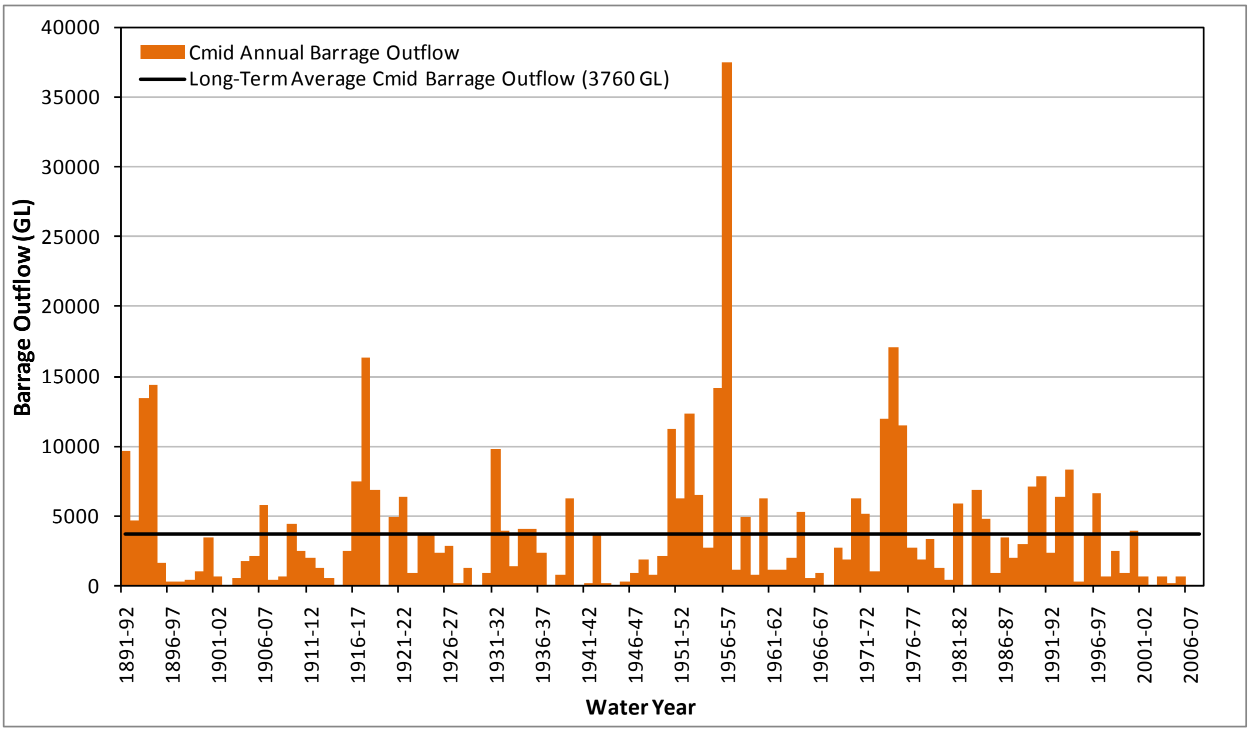



**Figure 86 Cmid Annual Barrage Outflows**

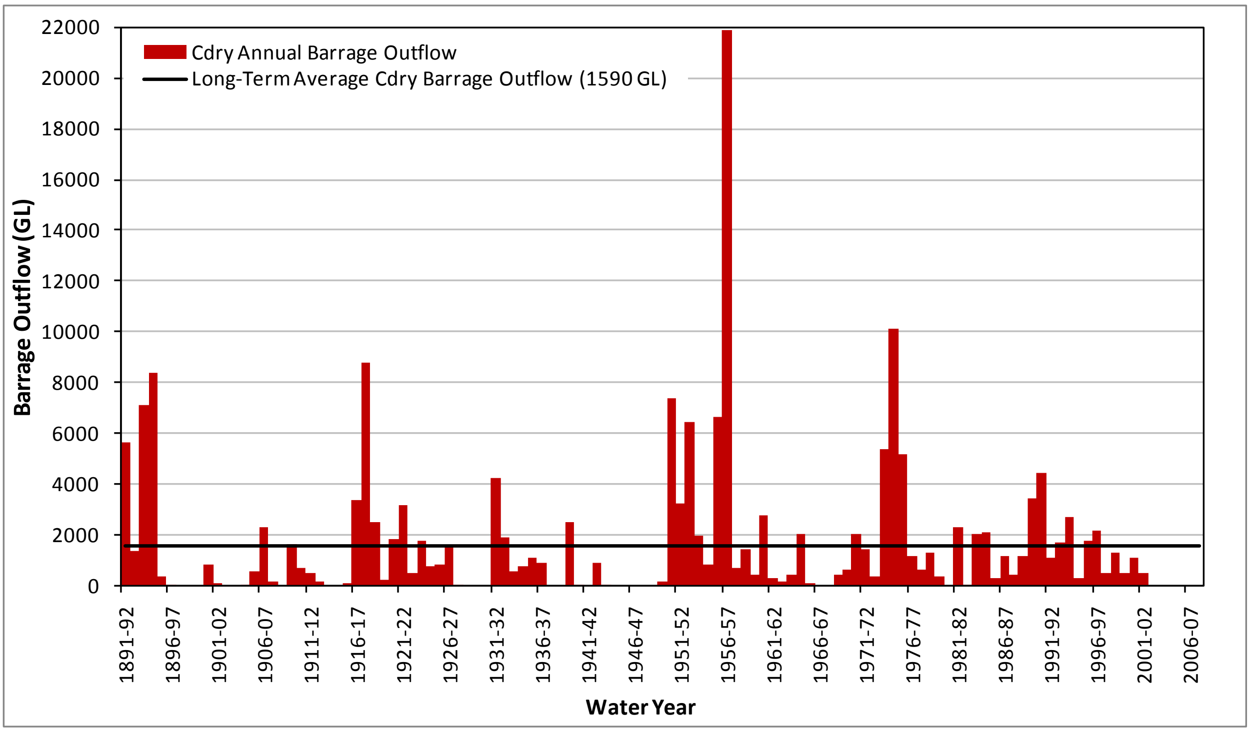



**Figure 87 Cdry Annual Barrage Outflows**

Figure 88 compares the historical annual frequency curves with those from the Cmid and Cdry conditions, highlighting the reductions in the frequencies of increasing barrage outflows. The frequency of zero barrage outflow increases from 1% of years under historical conditions to 3% under Cmid conditions and to 24% under Cdry conditions.

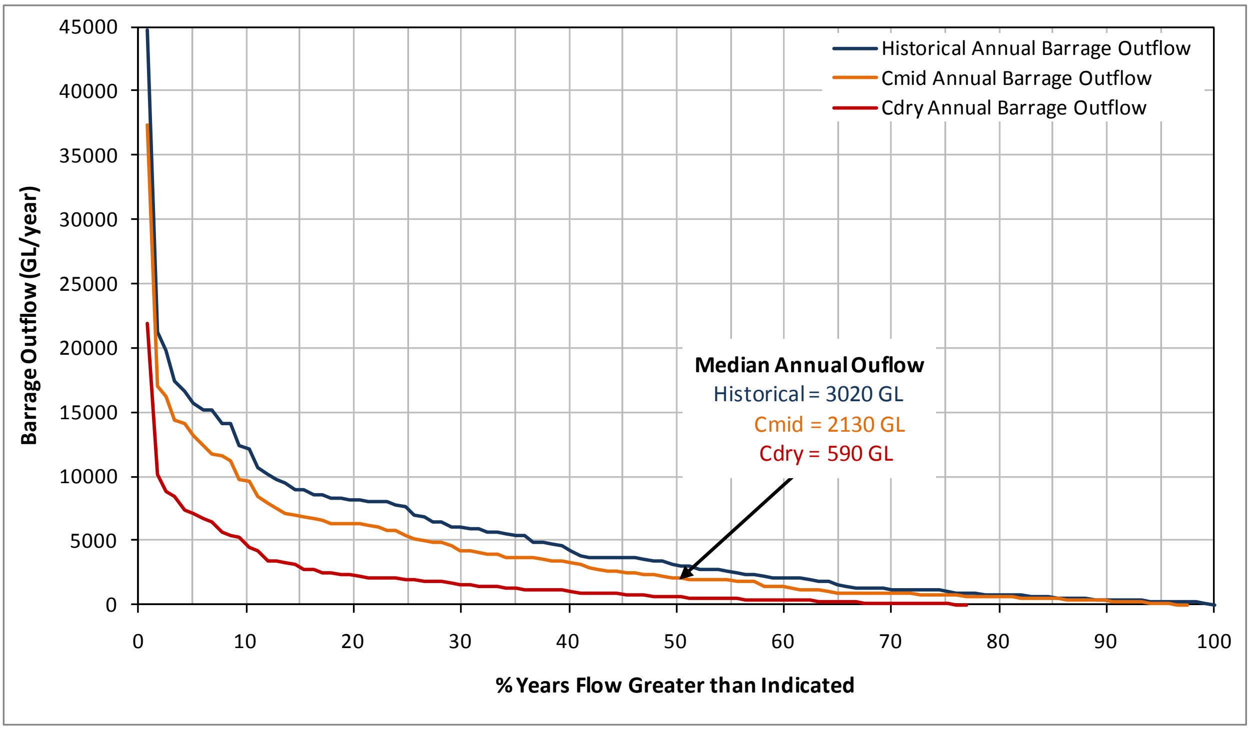



**Figure 88 Annual Barrage Outflow Frequency Curves for Historical, Cmid and Cdry Conditions (1891/92 to 2007/08)**

The reduction in barrage outflows is a consequence of the significant reduction in inflows to Lake Alexandrina, particularly between Cdry conditions and the Historical and Cmid conditions. This translates to major changes to the time-series of water levels and barrage outflows that then impacts on salinity. The following describes the water level ranges prior to the most recent low inflow period since the beginning of 2007 under each of the inflow conditions.

- Historical Conditions: Projected water levels generally rise and fall between the barrage operating level of Lake Alexandrina and +0.3m AHD. Water levels had only fallen below +0.3m AHD on four occasions and had not fallen below +0.1m AHD.
- Cmid Conditions: Projected water level variation is similar to that under historical conditions, with the exception that water levels would likely have fallen below +0.3m AHD on six occasions and on two of these below 0m AHD. Despite falling below 0m AHD, water levels recovered to full supply within a year. Under these conditions, it is unlikely that Lake Albert would become disconnected from Lake Alexandrina.
- Cdry Conditions: Projected water level variation changed significantly compared to Historical and Cmid conditions. Water levels fall below +0.3m AHD regularly and below 0m AHD in more than 20 years. It is probable that Lake Albert would have become disconnected from Lake Alexandrina on nine occasions and, given the shallow nature of the lake, would likely have dried completely without other intervention. The significant decrease in water levels since 2007 observed in the historical and Cmid time-series would likely have been observed as early as 2003 under Cdry conditions.

Figure 89 shows the water level frequency curve, highlighting the significant increase in the number of days that water levels would be below +0.3m AHD, from between 2 to 3% of all days under historical and Cmid conditions, to almost 30% of all days under Cdry conditions. Once water levels fall below +0.3m AHD, it is very difficult to discharge salt through the barrages because of the reverse head generated across the barrages from the Coorong. Similarly, the increase from less than 2% of all days below 0m AHD under historical and Cmid conditions to more than 15% under Cdry conditions, could lead to more regular acid sulphate soils issues needing to be managed, particularly in Lake Albert.

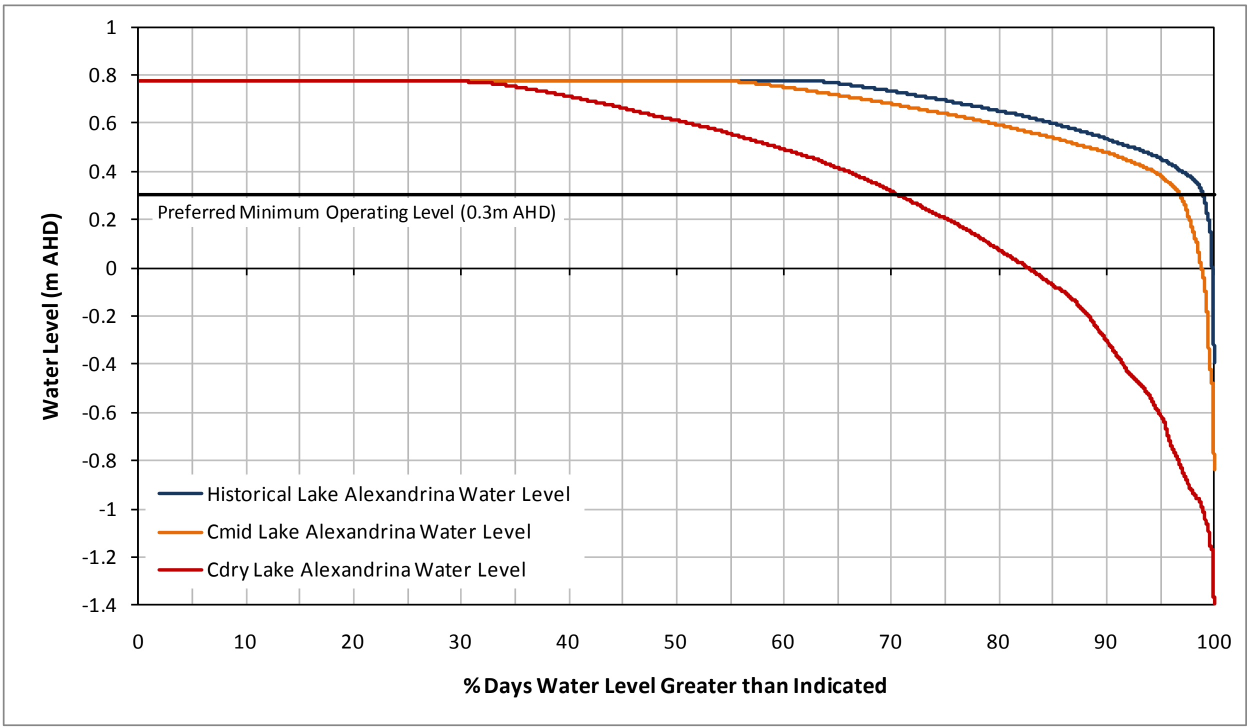



**Figure 89 Daily Water Level Frequency Curves under Historical, Cmid and Cdry Conditions (1891/92 to 2007/08)**

Tables 14 and 15 show the statistics for historical, Cmid and Cdry Lake Alexandrina and Lake Albert salinity. As with the barrage outflows, the change is more significant between the Cmid and Cdry conditions than between the Historical and Cmid conditions.

**Table 14 Lake Alexandrina Salinity Statistics: Historical, Cmid and Cdry Conditions (1975/76 to 2006/07)**

| Statistics | Historical | Cmid | Cdry |
|---|---|---|---|
| Mean | 785 | 905 | 1570 |
| Median | 715 | 780 | 1195 |
| Minimum | 230 | 355 | 520 |
| Maximum | 1765 | 2820 | 7805 |
| 10th Percentile | 460 | 540 | 790 |
| 90th Percentile | 1280 | 1605 | 3230 |

**Table 15 Lake Albert Salinity Statistics: Historical, Cmid and Cdry Conditions (1975/76 to 2006/07)**

| Statistics | Historical | Cmid | Cdry |
|---|---|---|---|
| Mean | 1560 | 1685 | 2695 |
| Median | 1450 | 1555 | 2200 |
| Minimum | 1045 | 1035 | 1295 |
| Maximum | 2960 | 4370 | 13425 |
| 10th Percentile | 1220 | 1235 | 1655 |
| 90th Percentile | 2150 | 2490 | 4725 |

Similarly, the frequency curves in Figures 90 and 91 show the substantial increase in the frequency of higher salinities, particularly under Cdry conditions. For example, Lake Alexandrina salinities greater than 1000 EC increase from 20% of all days under the historical and Cmid conditions to 75% of days under Cdry conditions.

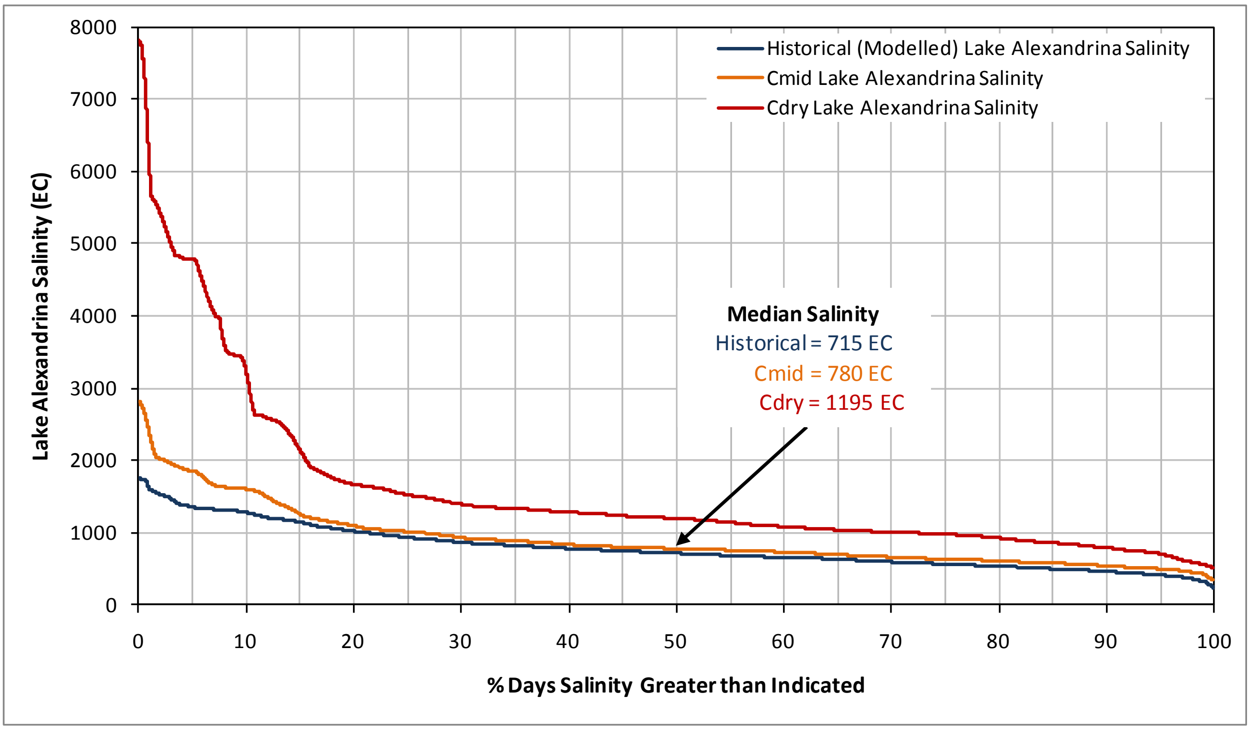



**Figure 90 Daily Salinity Frequency Curve for Lake Alexandrina under Historical, Cmid and Cdry Conditions (1975/76 to 2006/07)**

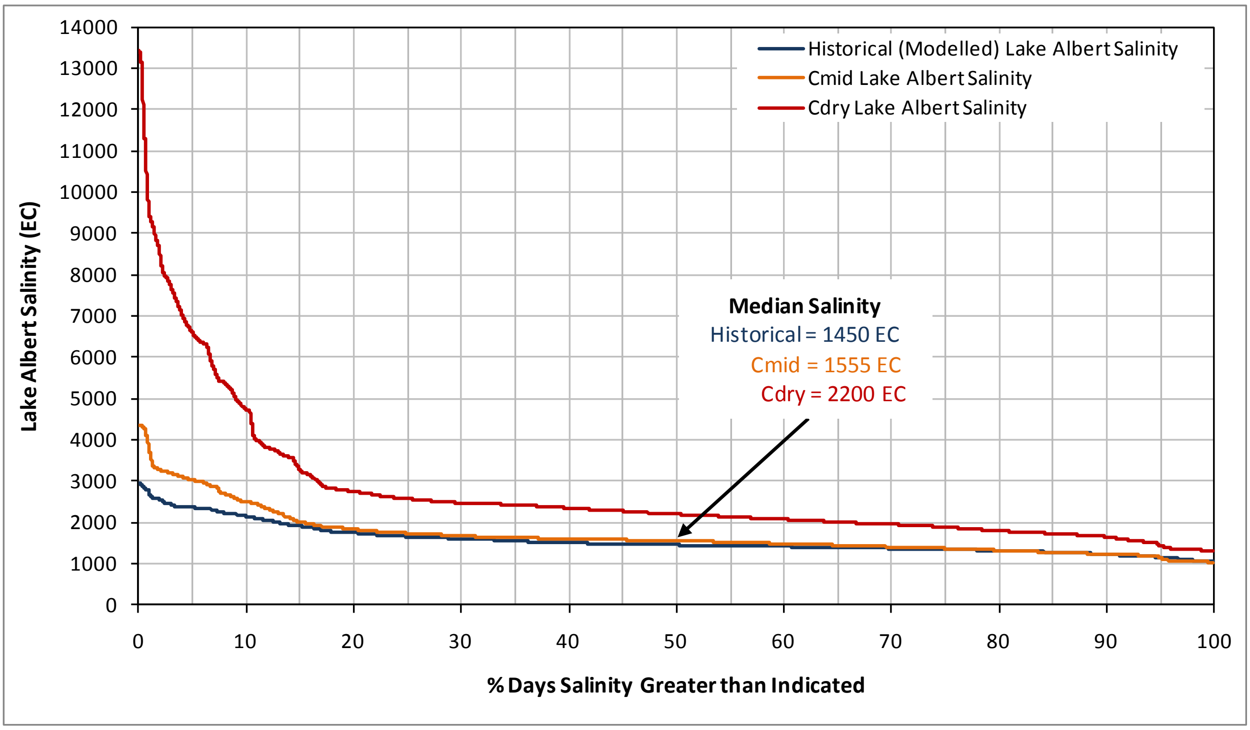



**Figure 91 Daily Salinity Frequency Curve for Lake Albert under Historical, Cmid and Cdry Conditions (1975/76 to 2006/07)**

Figures 92 to 101 compare barrage outflows, water levels and Lake Alexandrina and Lake Albert salinities between the historical, Cmid and Cdry conditions for the lower inflow periods 1910/11 to 1915/16 (Figures 92 to 95), 1936/37 to 1948/49 (Figures 96 to 99) and 2000/01 to 2007/08 (Figures 100 to 103). These highlight the significant differences between the three climate conditions, particularly between the historical and Cmid conditions with the Cdry conditions. Under Cdry conditions, Lake Albert becomes disconnected from Lake Alexandrina during each of these periods at approximately -0.5m AHD. The estimation of salinities at lower water levels should be regarded as indicative only.

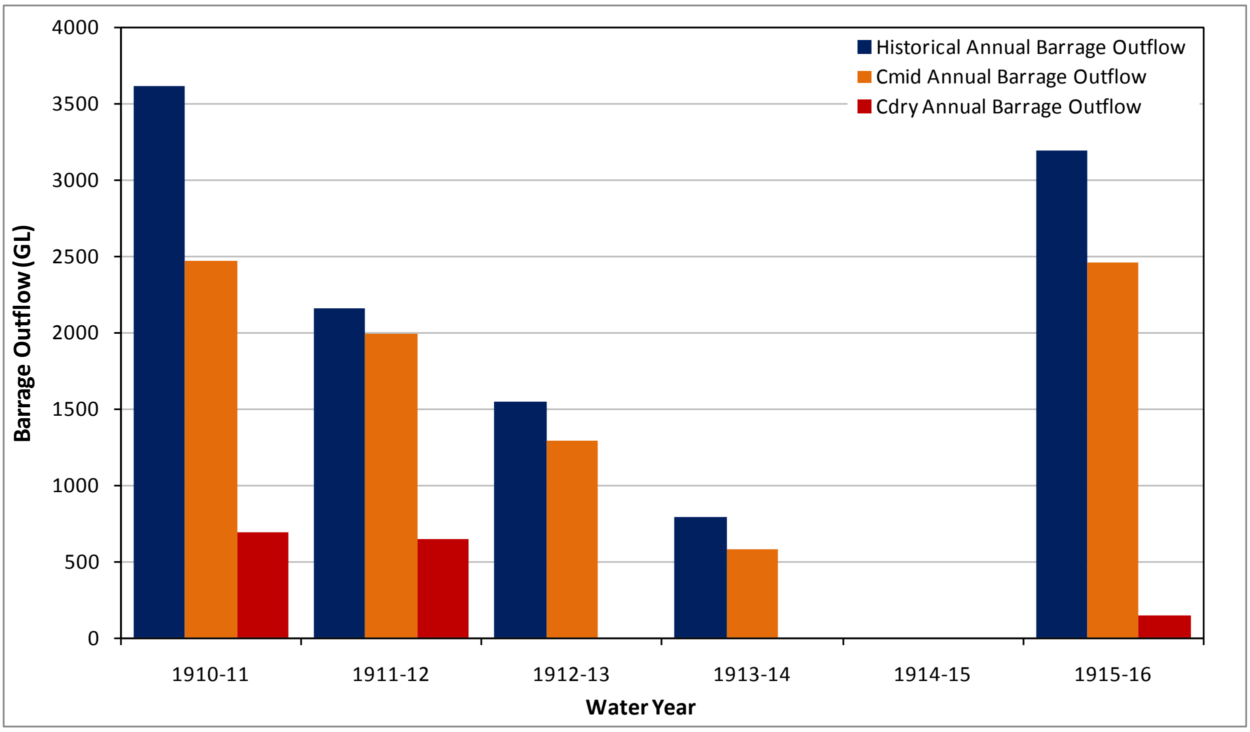



**Figure 92 Barrage Outflows under Historical, Cmid and Cdry Conditions (1910/11 to 1915/16)**

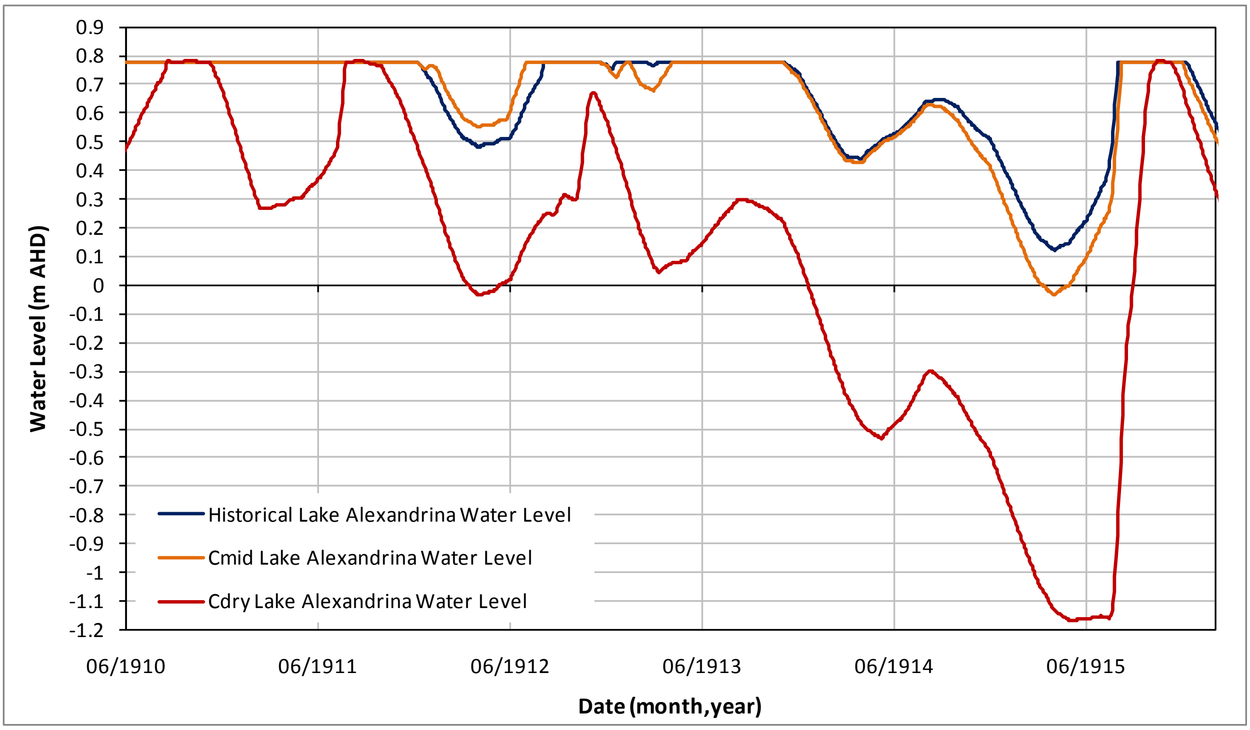



**Figure 93 Water Level under Historical, Cmid and Cdry Conditions (1910/11 to 1915/16)**

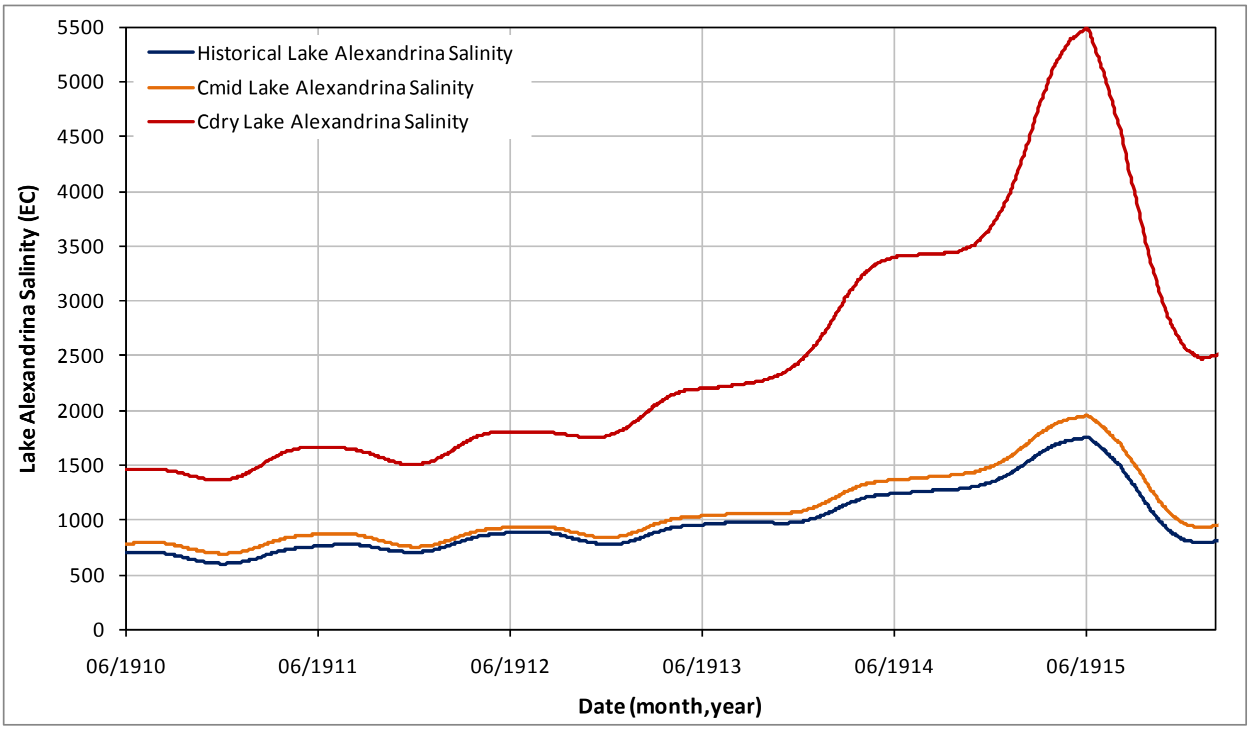



**Figure 94 Lake Alexandrina Salinity under Historical, Cmid and Cdry Conditions (1910/11 to 1915/16)**

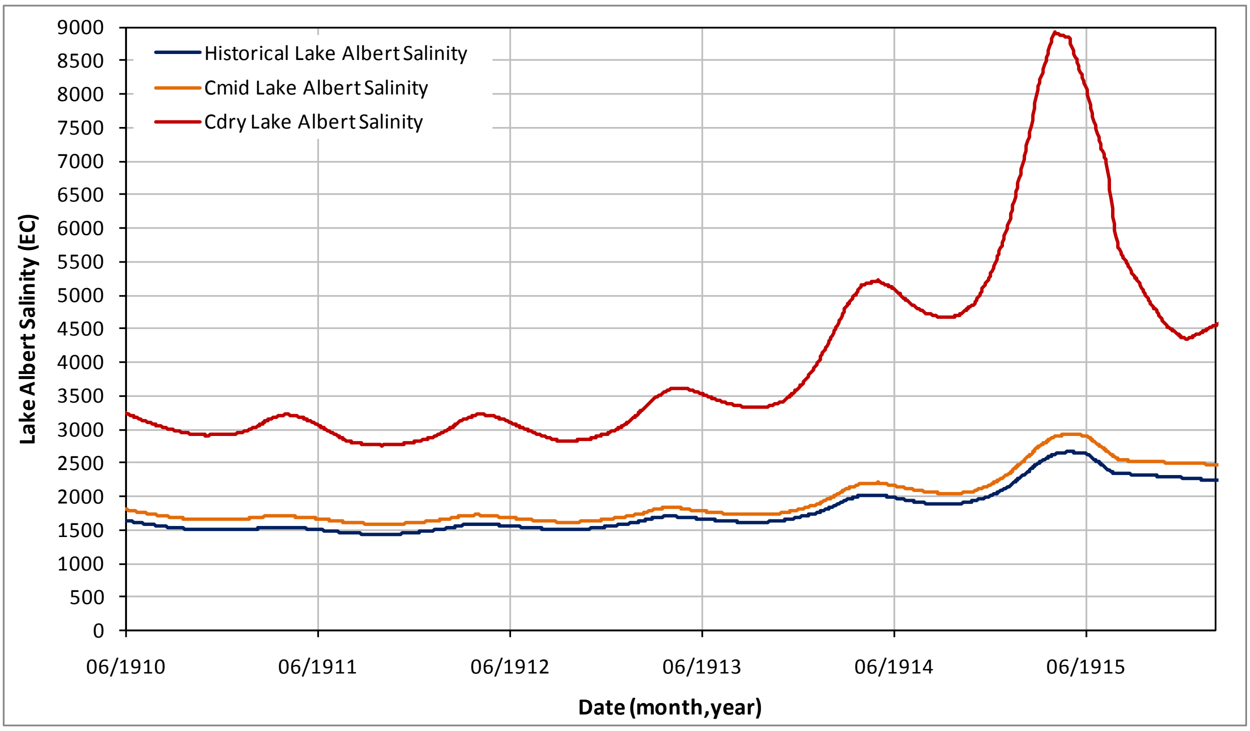



**Figure 95 Lake Albert Salinity under Historical, Cmid and Cdry Conditions (1910/11 to 1915/16)**

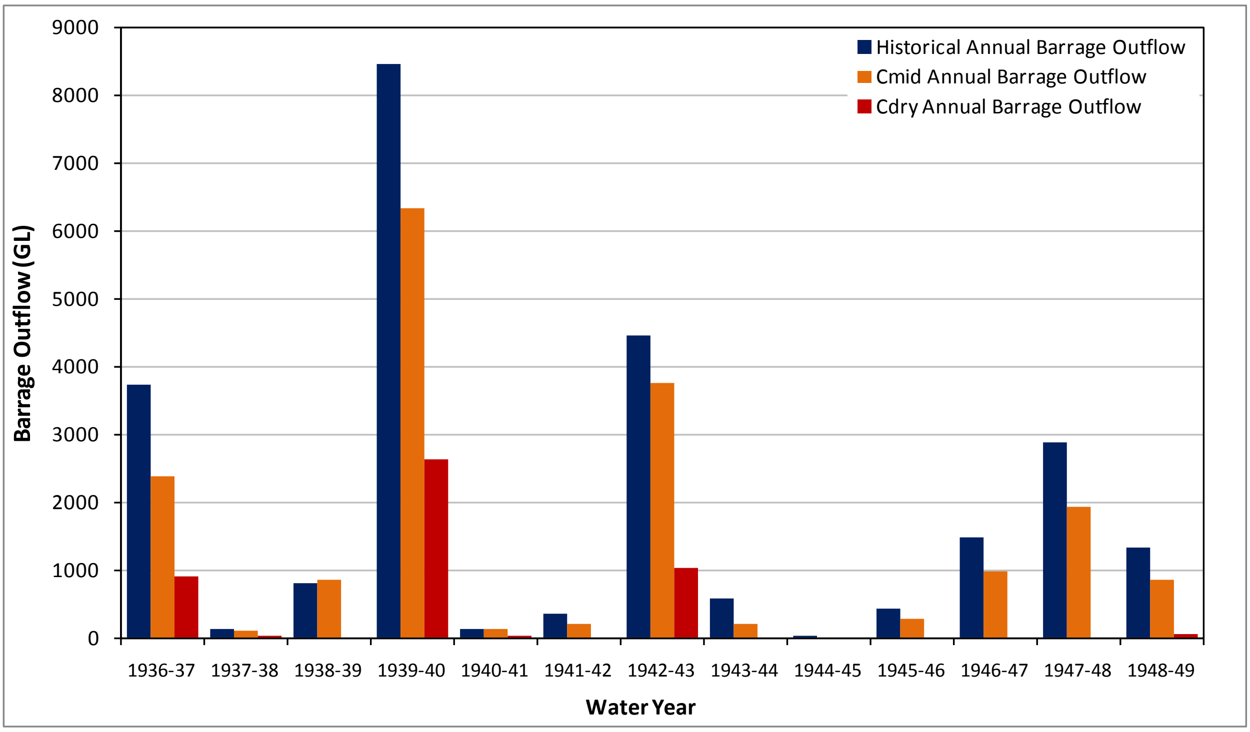



**Figure 96 Barrage Outflows under Historical, Cmid and Cdry Conditions (1936/37 to 1948/49)**

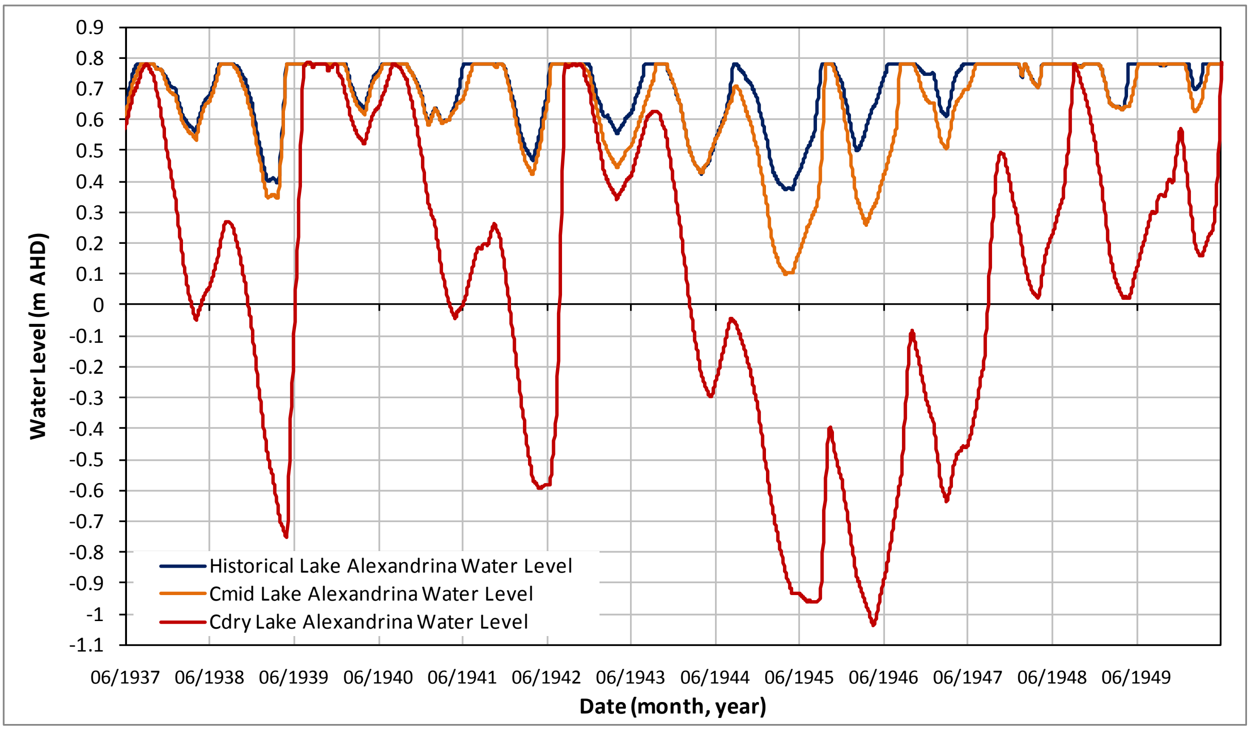



**Figure 97 Water Level under Historical, Cmid and Cdry Conditions (1936/37 to 1948/49)**

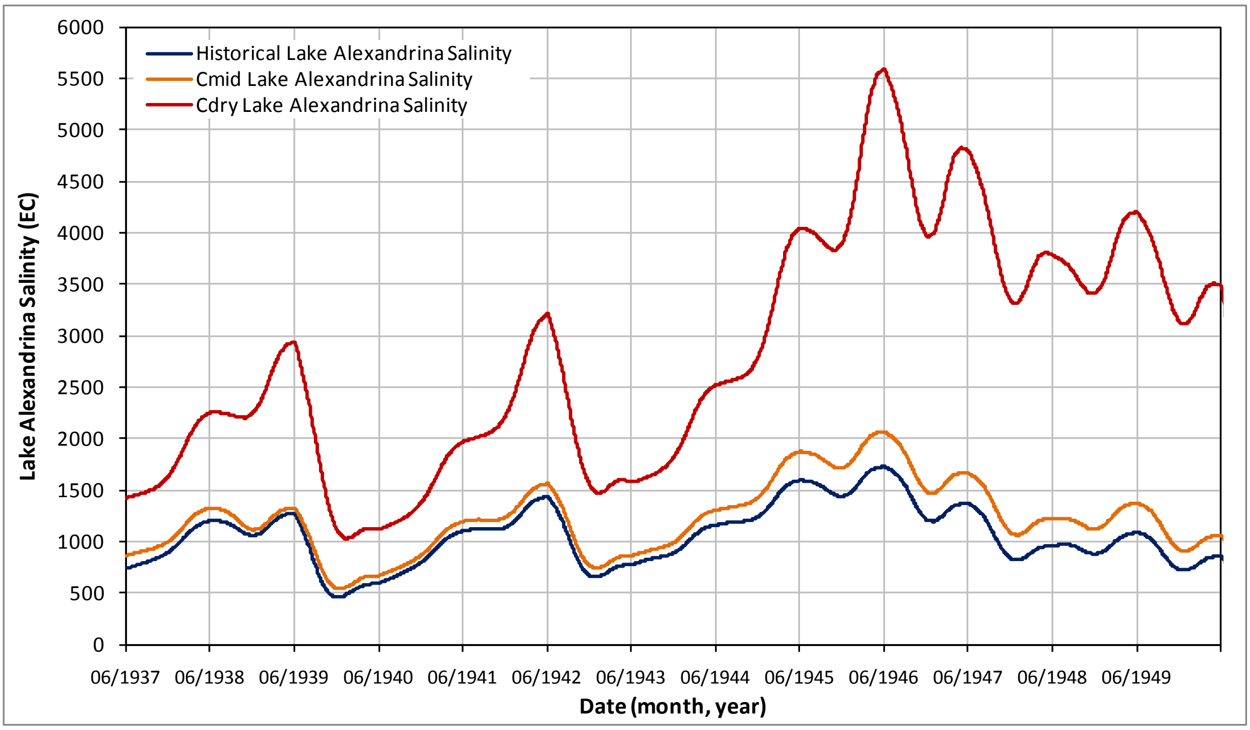



**Figure 98 Lake Alexandrina Salinity under Historical, Cmid and Cdry Conditions (1936/37 to 1948/49)**

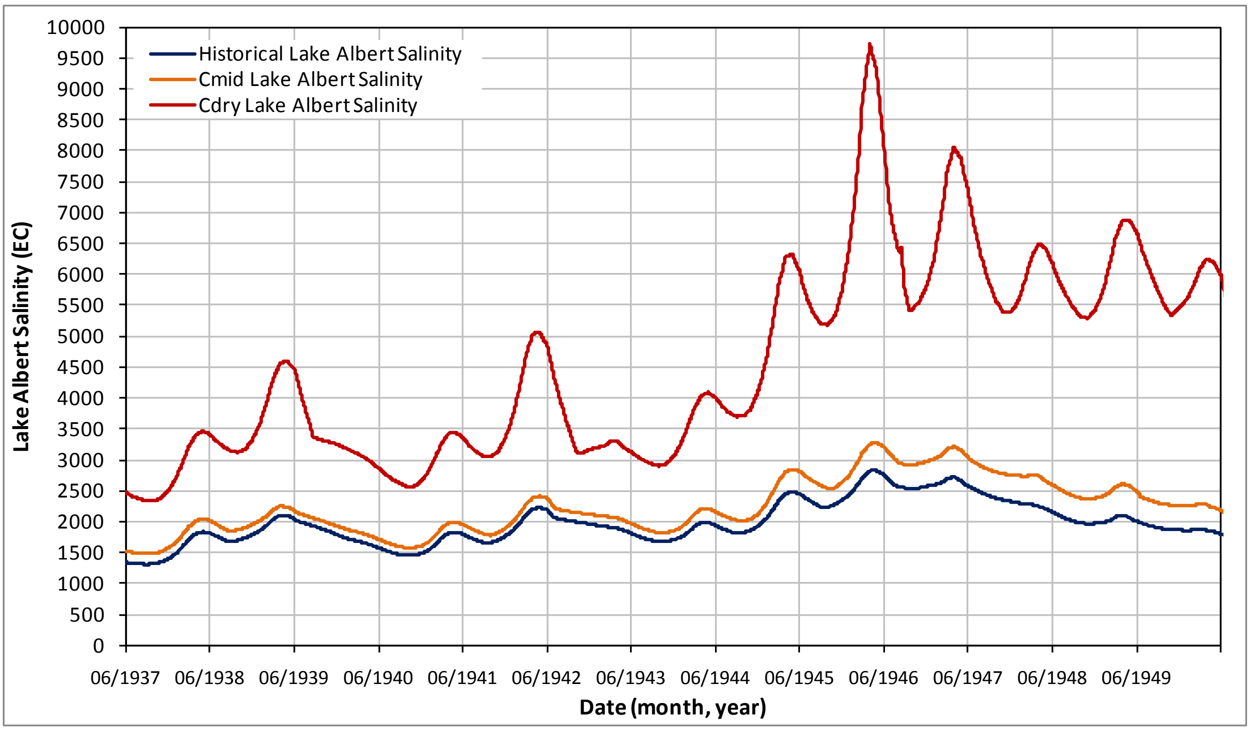



**Figure 99 Lake Albert Salinity under Historical, Cmid and Cdry Conditions (1936/37 to 1948/49)**

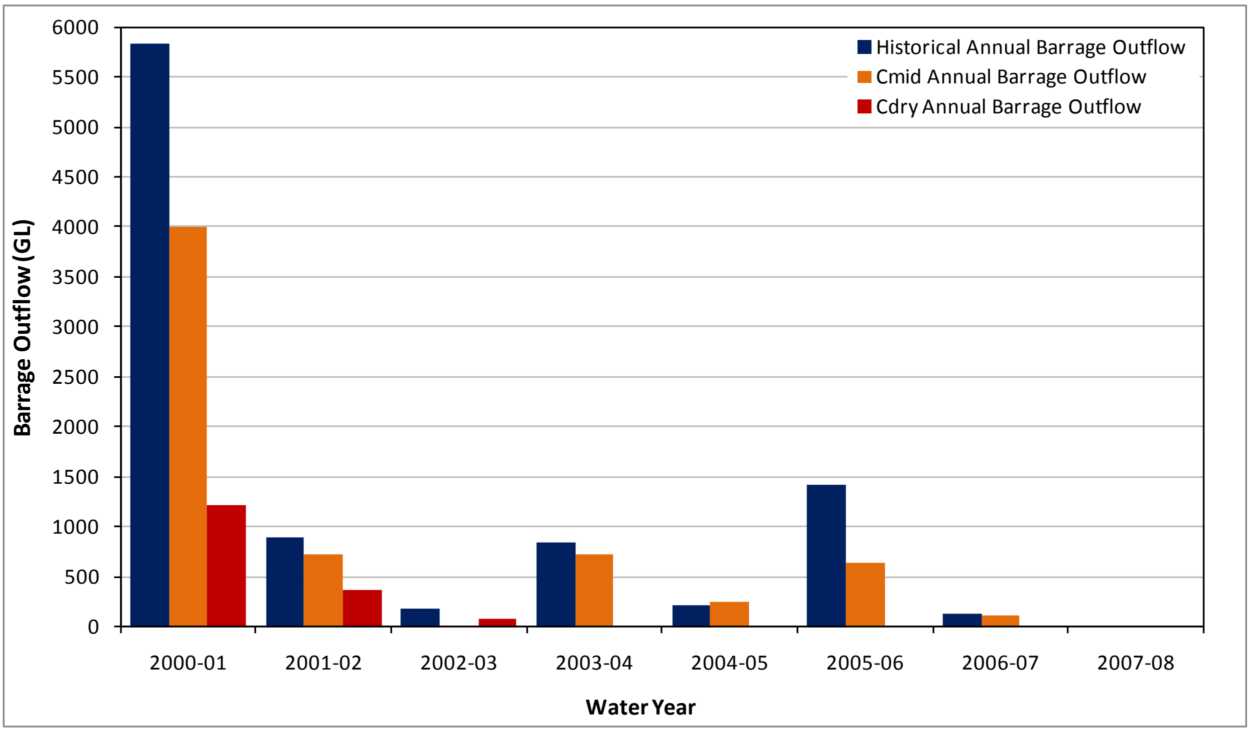



**Figure 100 Barrage Outflows under Historical, Cmid and Cdry Conditions (2000/01 to 2007/08)**

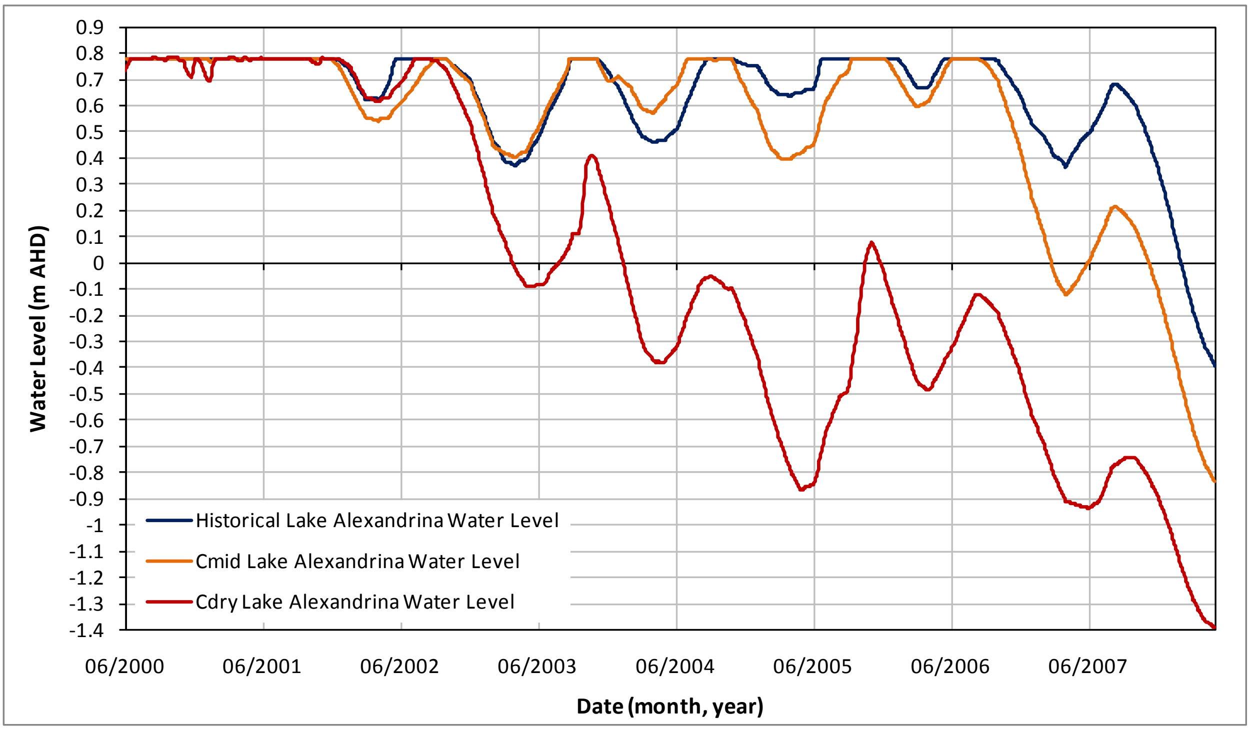



**Figure 101 Water Level under Historical, Cmid and Cdry Conditions (2000/01 to 2007/08)**

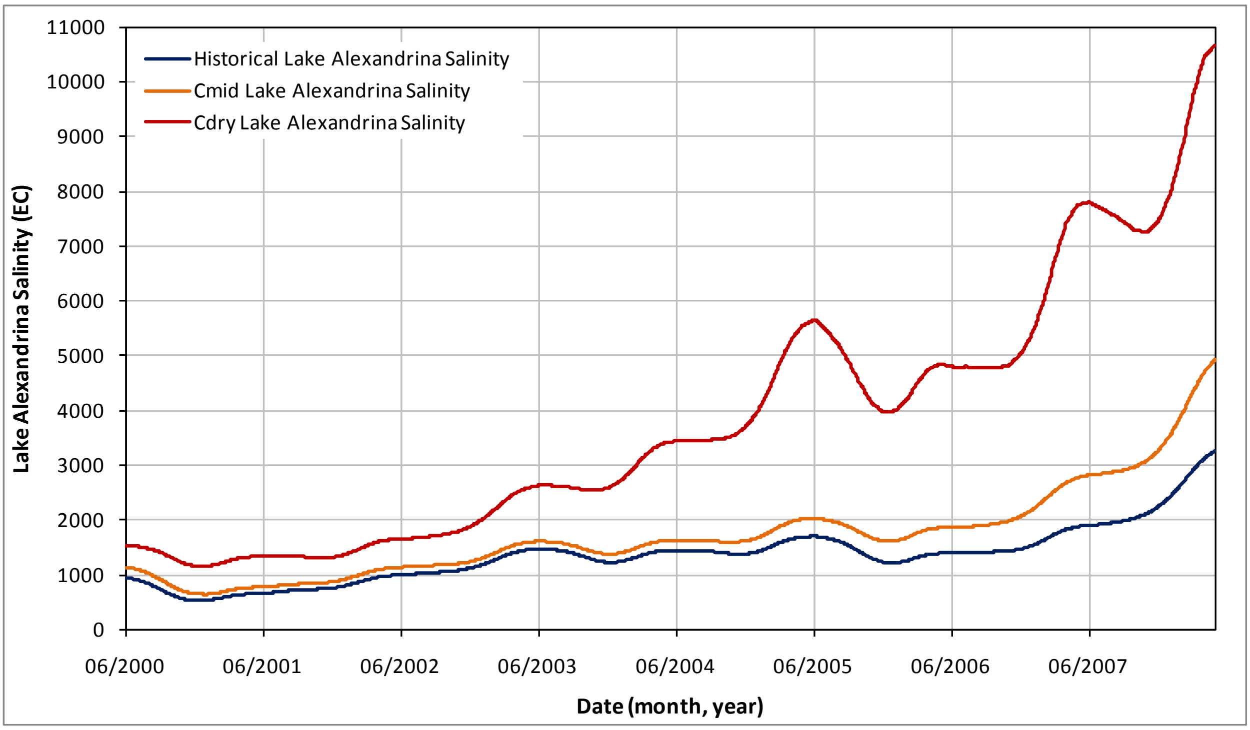



**Figure 102 Lake Alexandrina Salinity under Historical, Cmid and Cdry Conditions (2000/01 to 2007/08)**

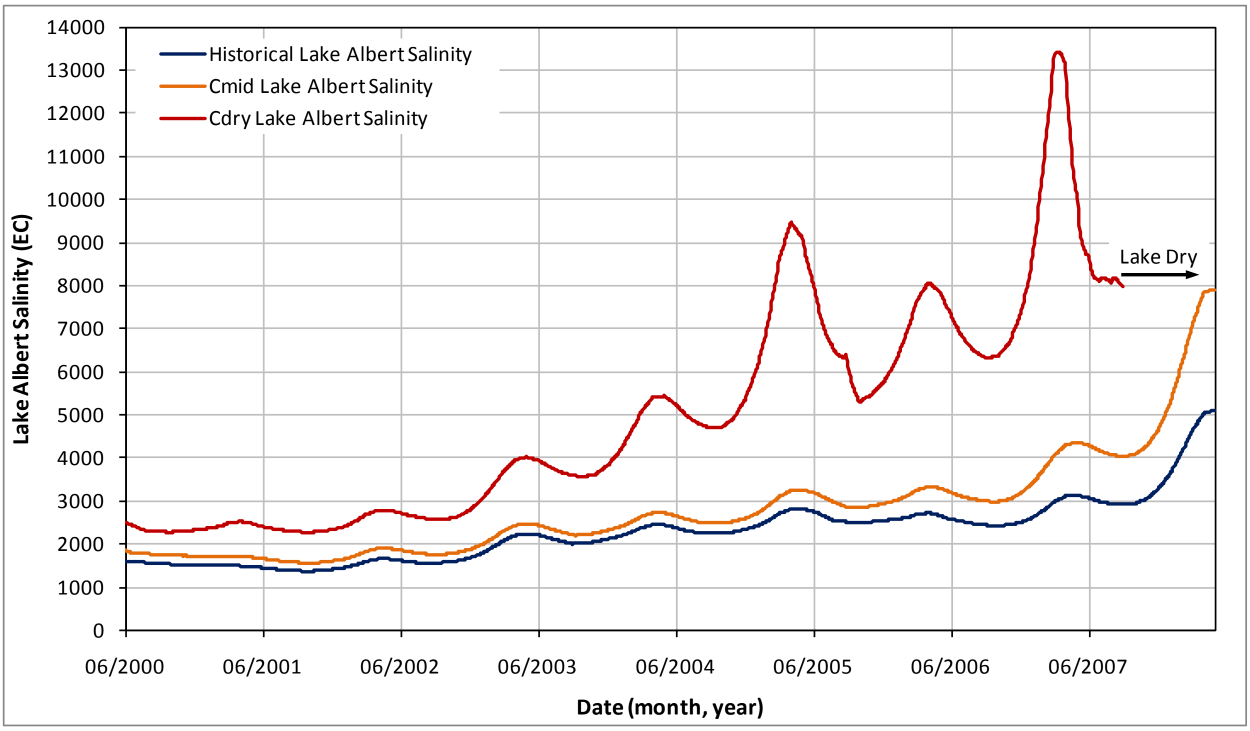



**Figure 103 Lake Albert Salinity under Historical, Cmid and Cdry Conditions (2000/01 to 2007/08)**

## *5.2. APPLICATION OF FLOW REGIMES TO CMID CONDITIONS*

The flow regimes developed for each of the 700, 1000 and 1500 EC thresholds were applied to the Cmid inflows to Lake Alexandrina. Figure 104 shows the Cmid and adjusted inflow sequences, with each year of increased inflow indicated as a departure from the historical sequence. Increases were required in many years under the 700 EC threshold.

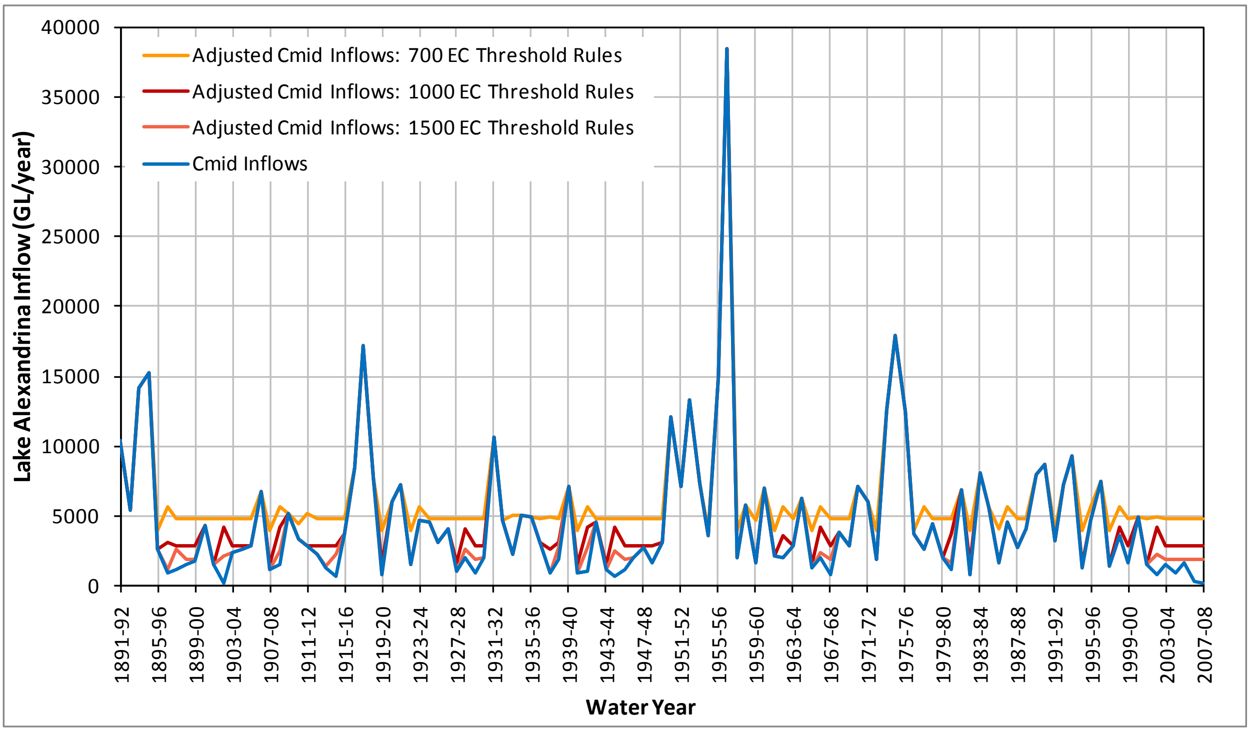



**Figure 104 Adjusted Cmid Inflows using 700, 1000 and 1500 EC Threshold Rules**

A summary of the additional inflows required under each threshold is shown in Table 16. For the 1000 and 1500 EC thresholds, the majority of increased inflows were required within three periods: 1896/97 to 1914/15 (12 and 8 years respectively), 1937/38 to 1948/49 (10 and 4 years) and 1997/98 to 2007/08 (10 and 6 years). Increased flows under the 700 EC threshold was required in over 65% of years. In comparison to the historical inflow conditions, there were between 7 and 13 years additional years for each salinity threshold that required adjustment.

**Table 16 Additional Flows Required for the Cmid Inflow Sequence**

| Statistics | Salinity Threshold | | |
|---|---|---|---|
| | 700 EC | 1000 EC | 1500 EC |
| Length of Record | 117 years | 117 years | 117 years |
| Additional Inflows Required | 78 years | 44 years | 25 years |
| Average Annual Inflow Increase | 2620 GL | 1430 GL | 860 GL |
| Minimum Annual Inflow Increase | 280 GL | 15 GL | 15 GL |
| Maximum Annual Inflow Increase | 4820 GL | 4015 GL | 2015 GL |
| **Additional Volume (GL)** | **Number of Years** | | |
| Min Increase - 500 | 5 | 9 | 10 |
| 500 - 1000 | 5 | 8 | 5 |
| 1000 - 2000 | 14 | 14 | 9 |
| 2000 - 3000 | 20 | 9 | 1 |
| 3000 - 4000 | 24 | 3 | 0 |
| 4000 - Maximum Increase | 10 | 1 | 0 |

The adjusted inflows required for each of the salinity thresholds during the periods 1891/92 to 1916/17 (Figures 105 to 107) and 1978/79 to 2007/08 (Figures 108 to 110) are presented below. For the 1000 and 1500 EC thresholds, these incorporate two of the primary adjustment periods.

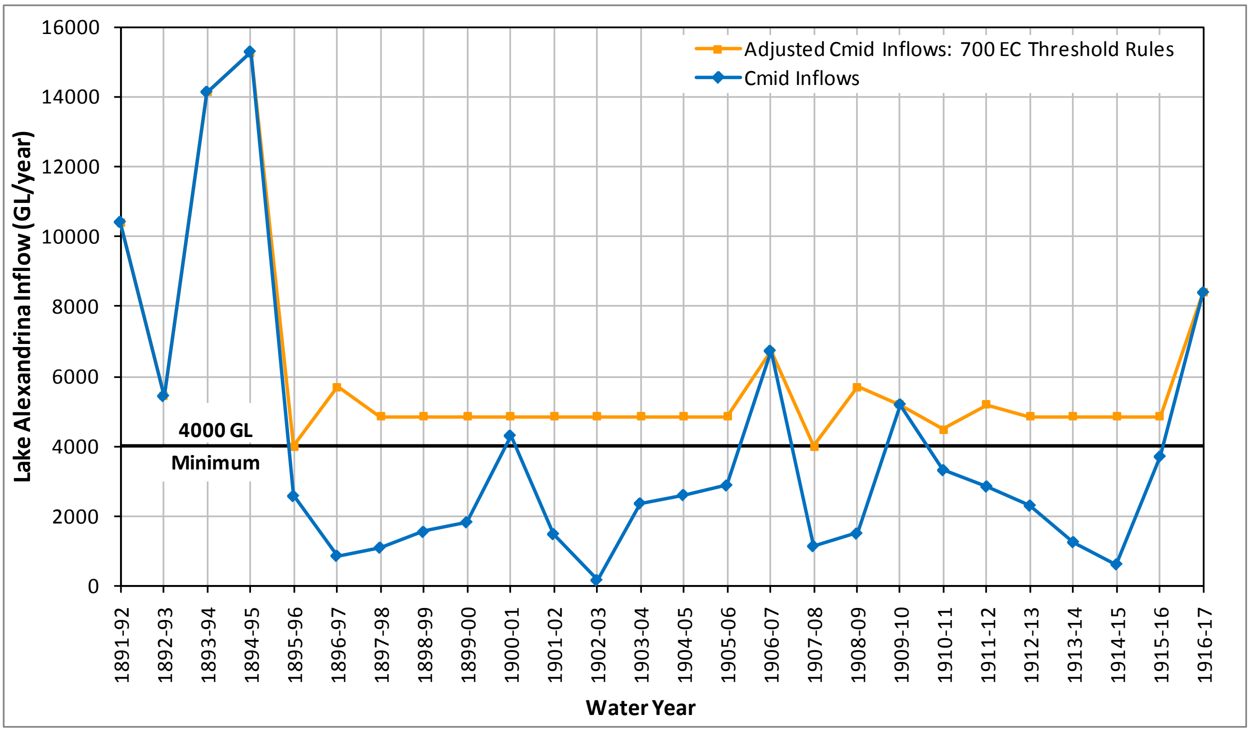



**Figure 105 Adjusted Cmid Inflows: 700 EC Threshold (1891/92 to 1916/17)**

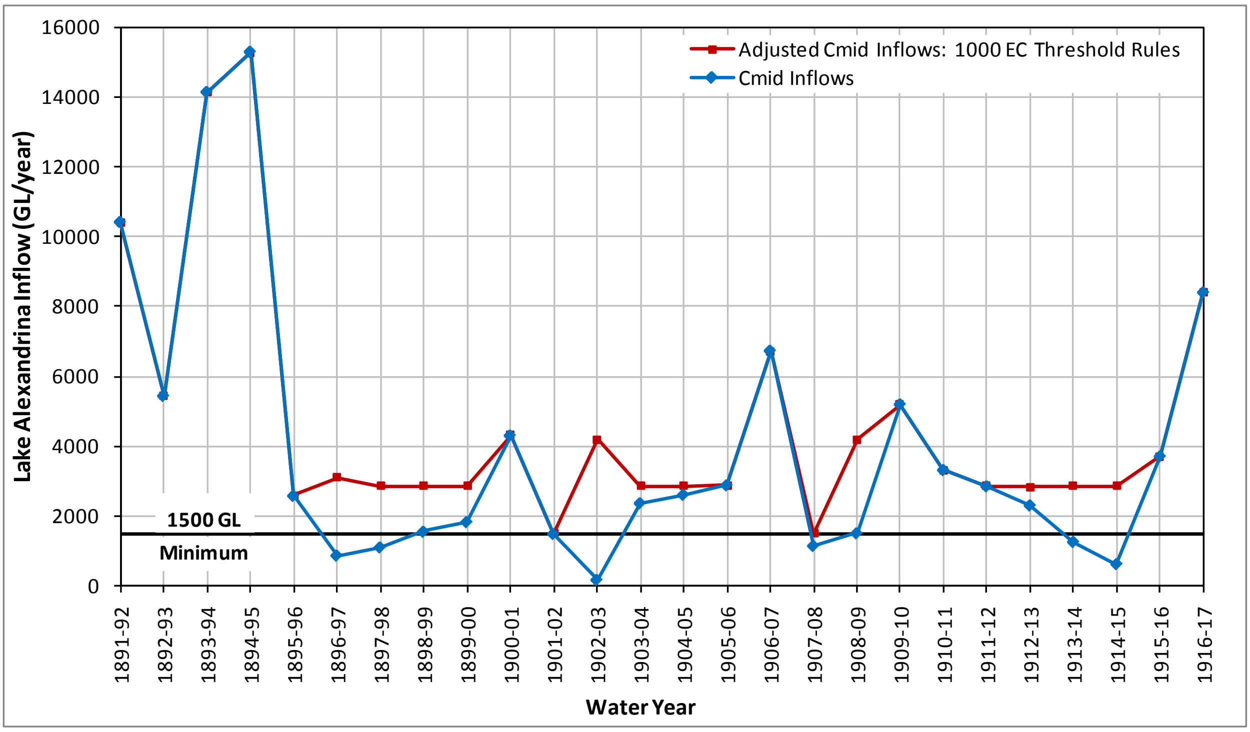



**Figure 106 Adjusted Cmid Inflows: 1000 EC Threshold (1891/92 to 1916/17)**

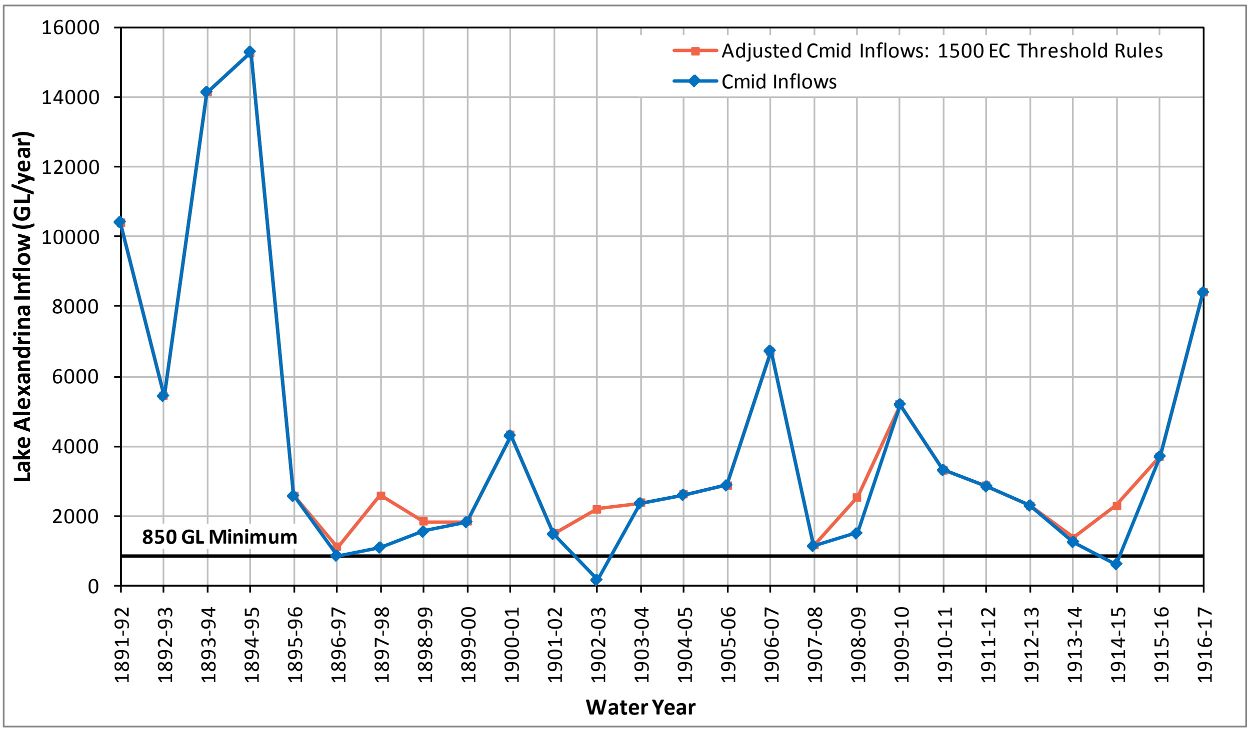



**Figure 107 Adjusted Cmid Inflows: 1500 EC Threshold (1891/92 to 1916/17)**

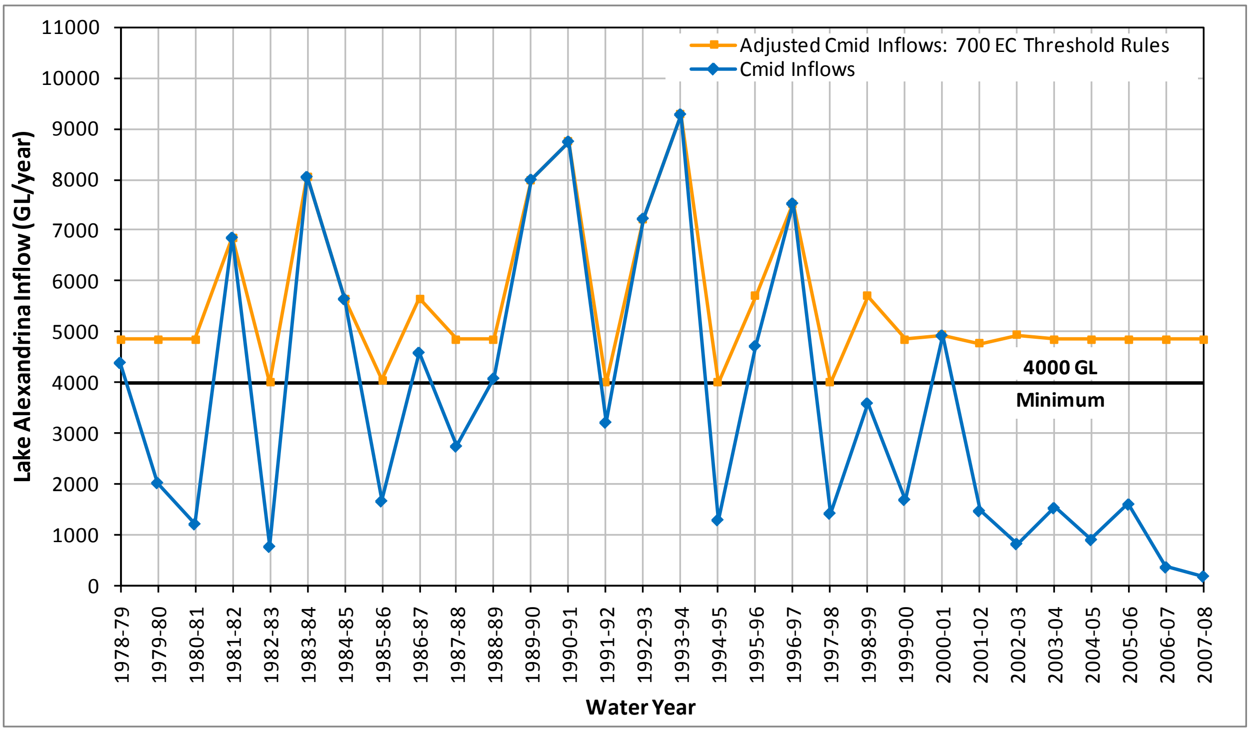



**Figure 108 Adjusted Cmid Inflows: 700 EC Threshold (1978/79 to 2007/08)**

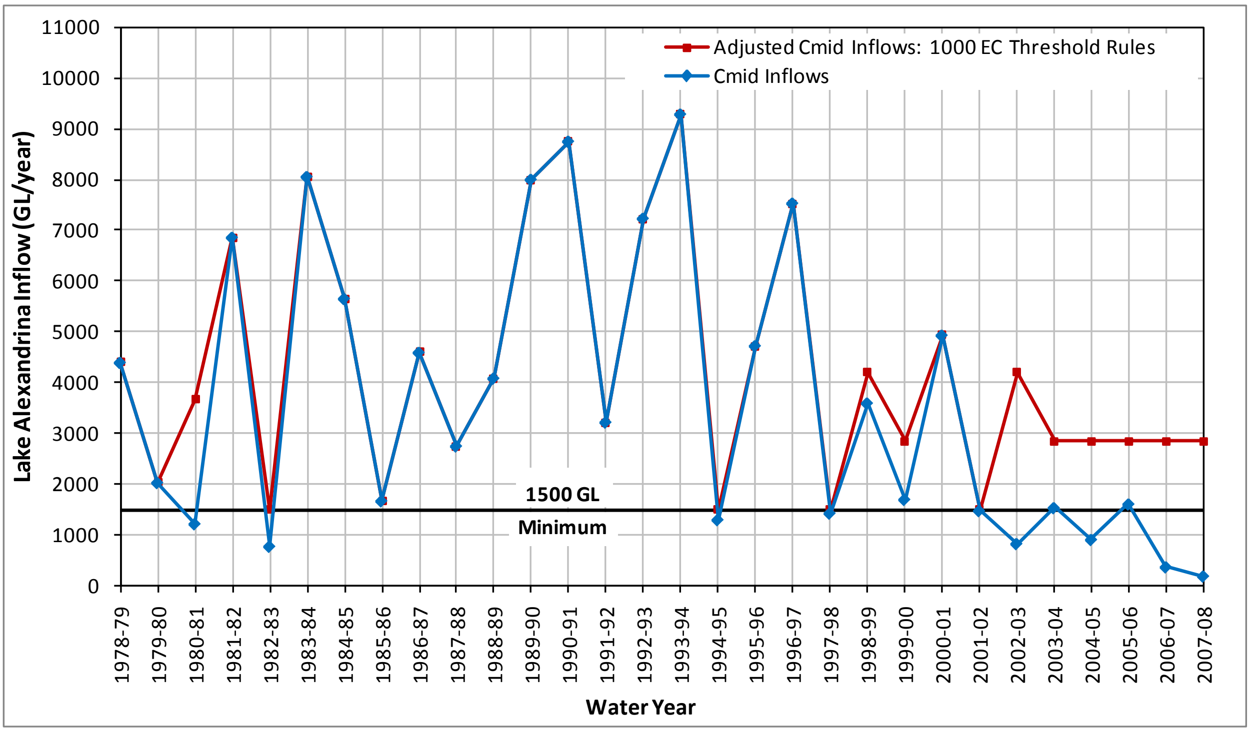



**Figure 109 Adjusted Cmid Inflows: 1000 EC Threshold (1978/79 to 2007/08)**

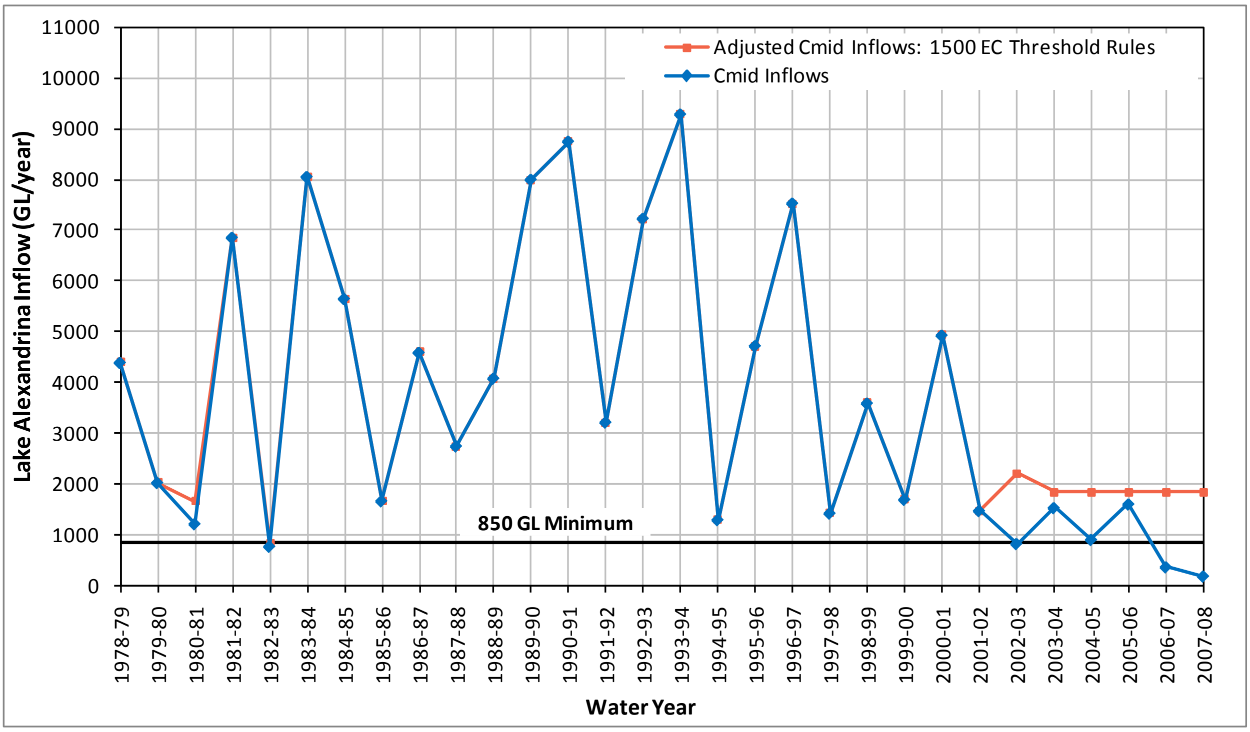



**Figure 110 Adjusted Cmid Inflows: 1500 EC Threshold (1978/79 to 2007/08)**

Table 17 shows the annual barrage outflow statistics under Cmid and adjusted conditions. The mean, median, minimum and 10th percentile outflows have increased significantly under both the 700 and 1000 EC threshold flow regimes. The statistics for the 1500 EC threshold barrage outflows are not significantly different than the Cmid statistics, except for the minimum and 10th percentile outflows.

**Table 17 Cmid and Adjusted (All Thresholds) Barrage Outflow Statistics (1891/92 to 2007/08)**

| Statistics | Annual Barrage Outflow (GL) | | | |
|---|---|---|---|---|
| | Cmid | 700 EC Threshold | 1000 EC Threshold | 1500 EC Threshold |
| Mean | 3760 | 5510 | 4285 | 3945 |
| Median | 2130 | 4005 | 2860 | 2035 |
| Minimum | 0 | 3160 | 800 | 330 |
| Maximum | 37485 | 37400 | 37400 | 37400 |
| 10th Percentile | 170 | 3195 | 920 | 765 |
| 90th Percentile | 8865 | 8895 | 8895 | 8895 |

Figures 111 to 113 show the additional barrage outflows that result from the modified Cmid inflow sequence and to implement the flow regime to maintain salinities in Lake Alexandrina under each of the salinity thresholds.

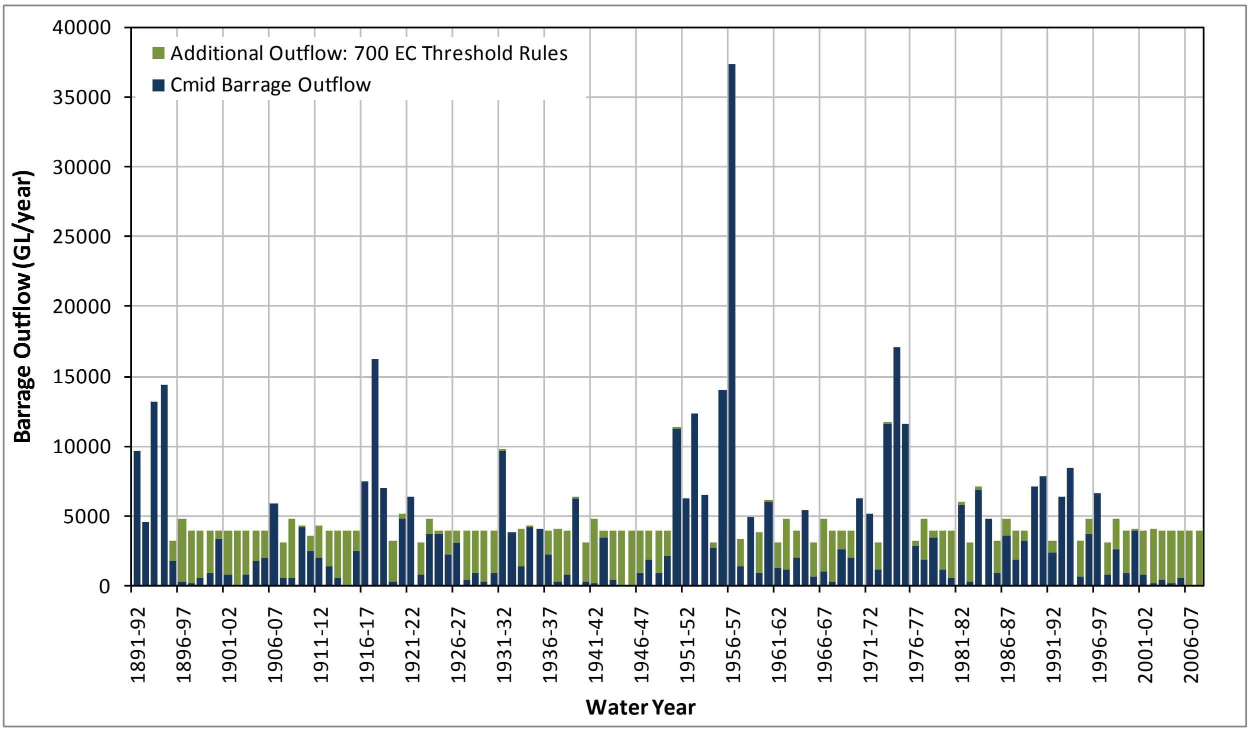



**Figure 111 Additional Barrage Outflows (Cmid): 700 EC Threshold**

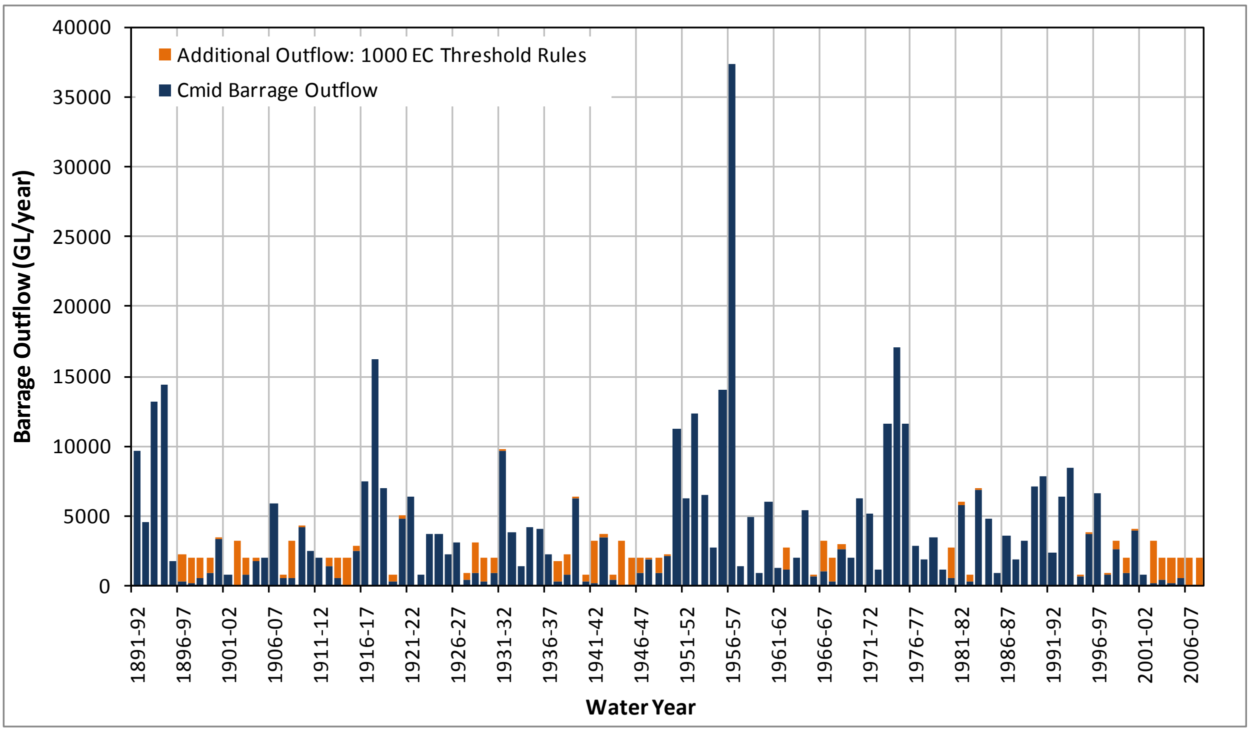



**Figure 112 Additional Barrage Outflows (Cmid): 1000 EC Threshold**

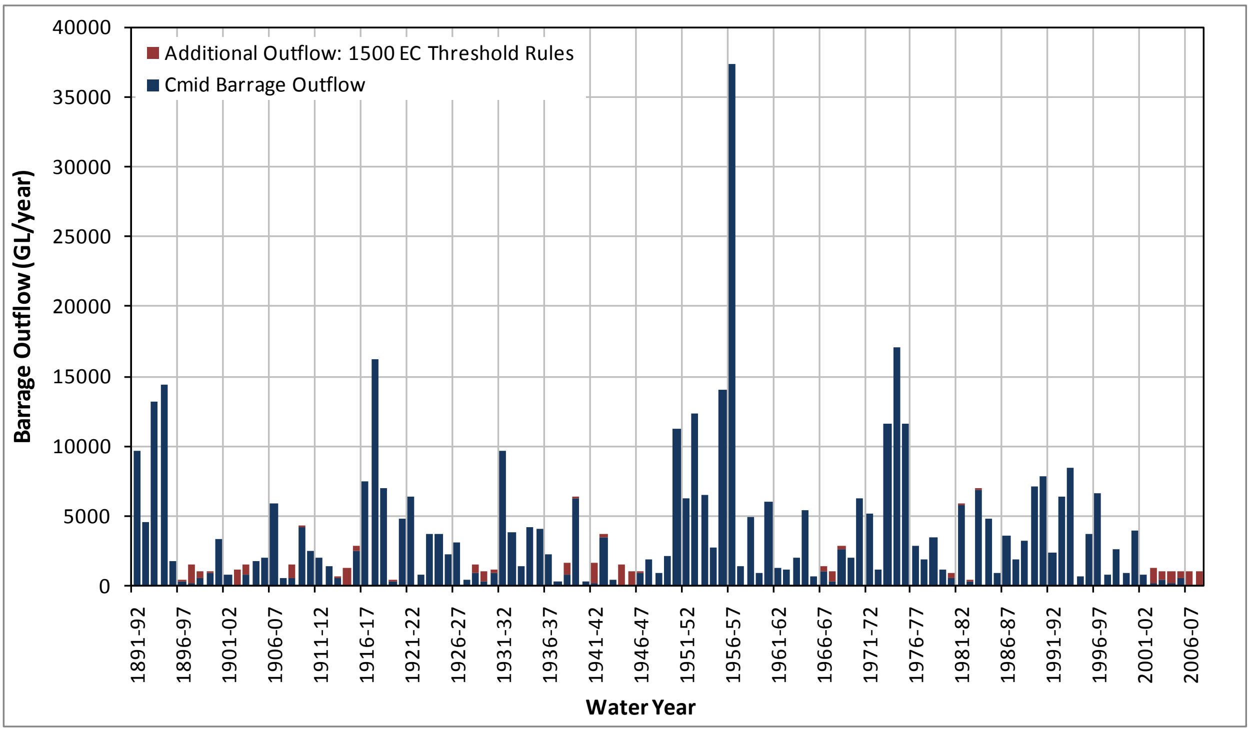



**Figure 113 Additional Barrage Outflows (Cmid): 1500 EC Threshold**

Figure 114 shows that there are significant changes to the Cmid barrage outflow frequency curve for the 700 and 1000 EC salinity thresholds.

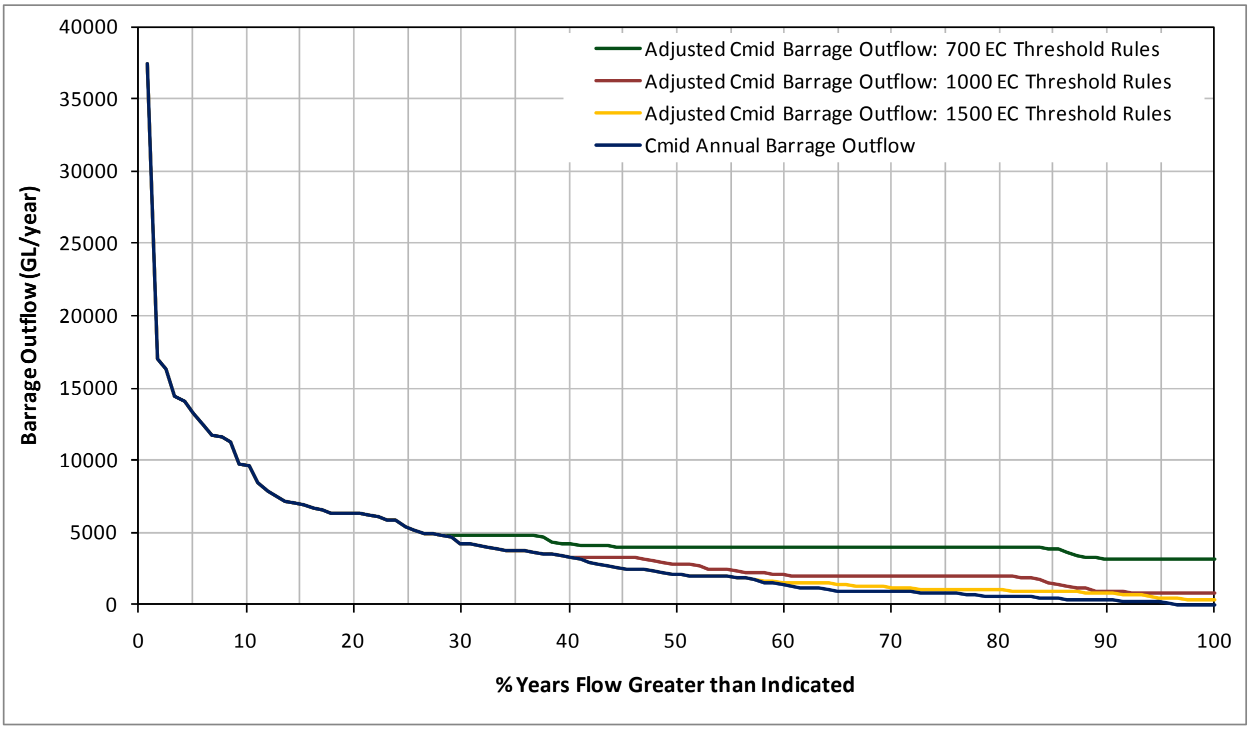



**Figure 114 Cmid and Adjusted Annual Barrage Outflow Frequency Curves: All Thresholds**

Figure 115 shows the adjusted Cmid annual barrage outflows that result from application of each of the salinity threshold regimes for the period from 1891/92 to 1916/17, with Figures 116 and 117 depicting the resultant Lake Alexandrina and Lake Albert salinity time-series responses. Figures 118 to 120 then present the same information for the period 1975/76 to 2007/08.

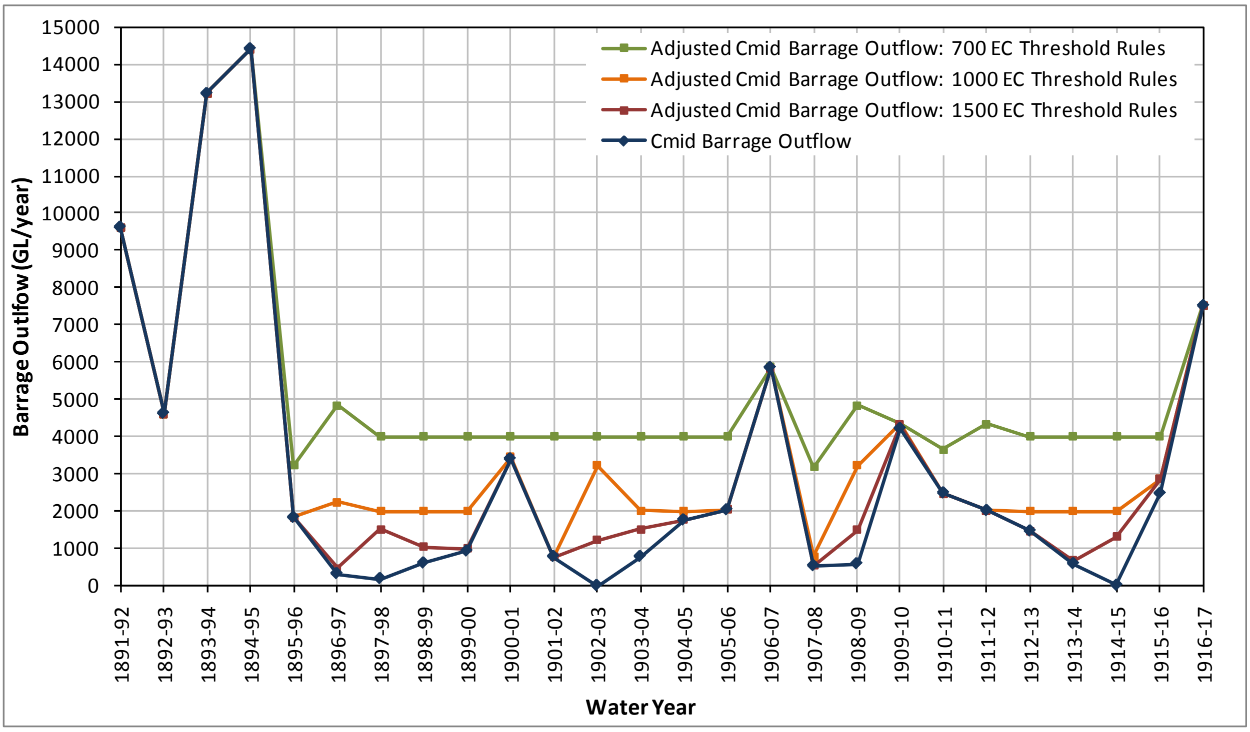



**Figure 115 Adjusted Cmid Annual Barrage Outflows: All Thresholds (1891/92 to 1916/17)**

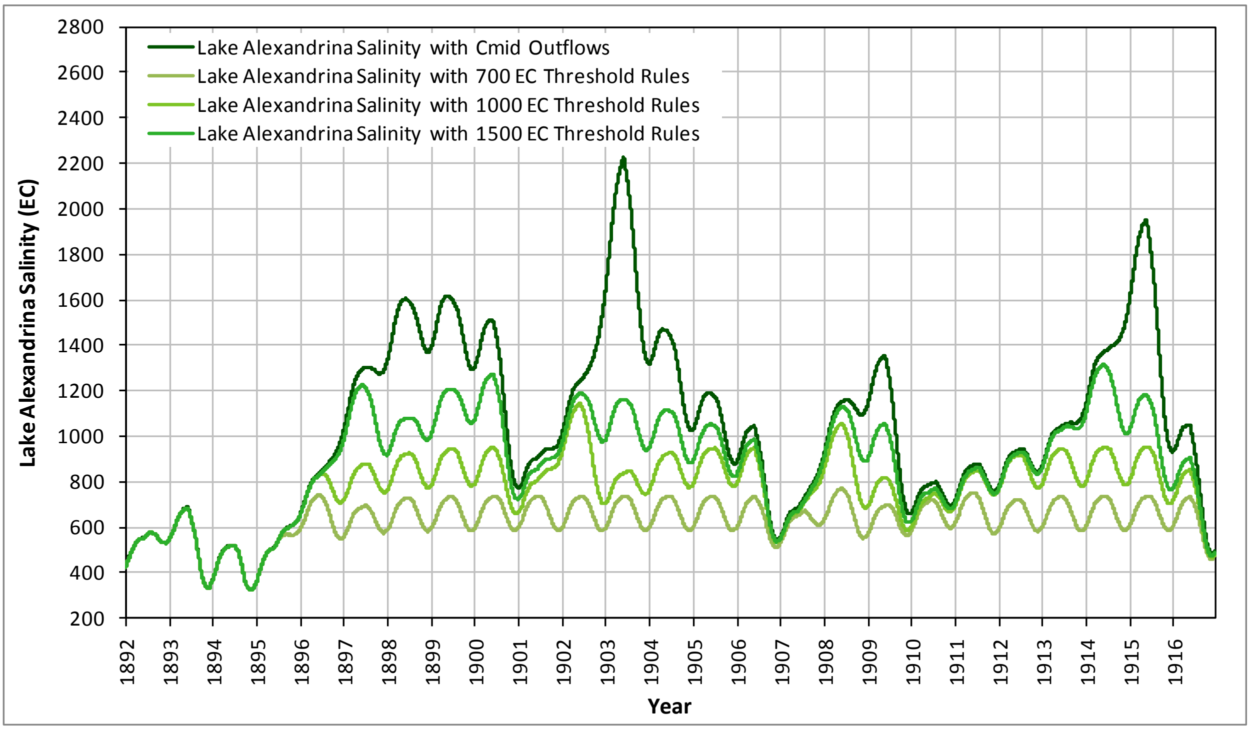



**Figure 116 Lake Alexandrina Salinity with Adjusted (Cmid) Barrage Outflows: All Thresholds (1892 to 1916)**

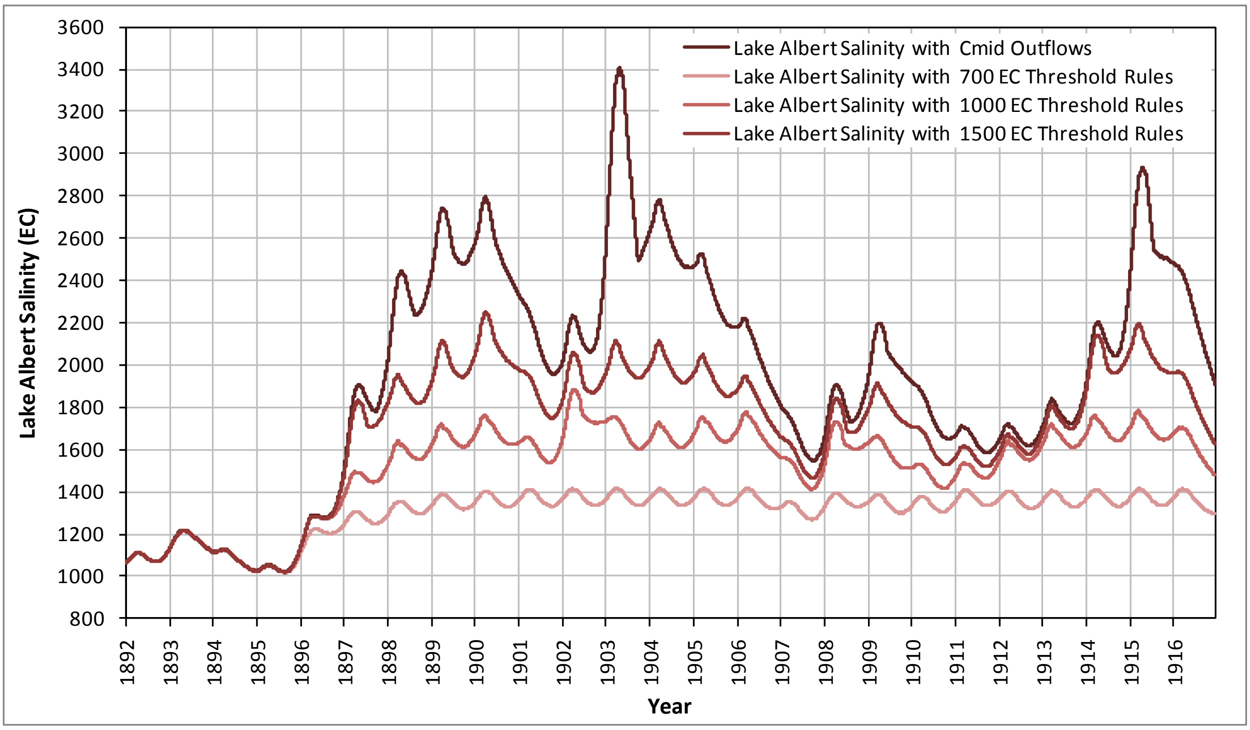



**Figure 117 Lake Albert Salinity with Adjusted (Cmid) Barrage Outflows: All Thresholds (1892 to 1916)**

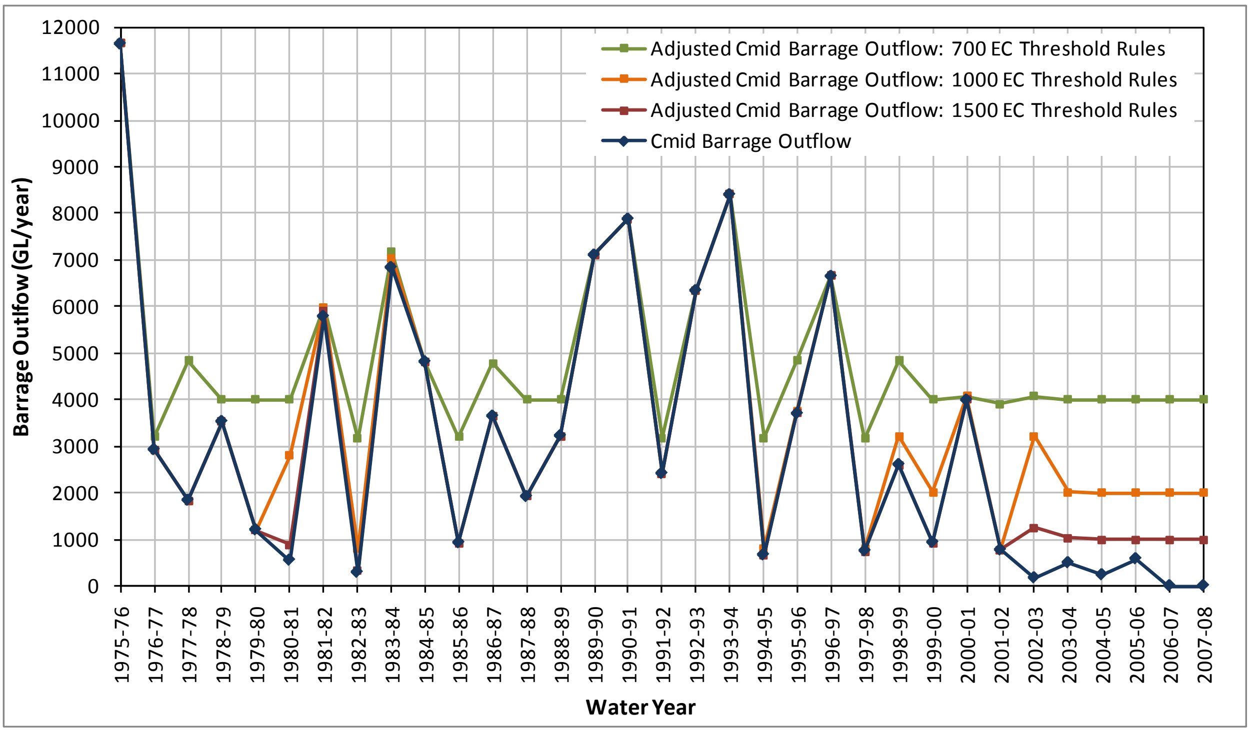



**Figure 118 Adjusted Cmid Annual Barrage Outflows: All Thresholds (1975/76 to 2007/08)**

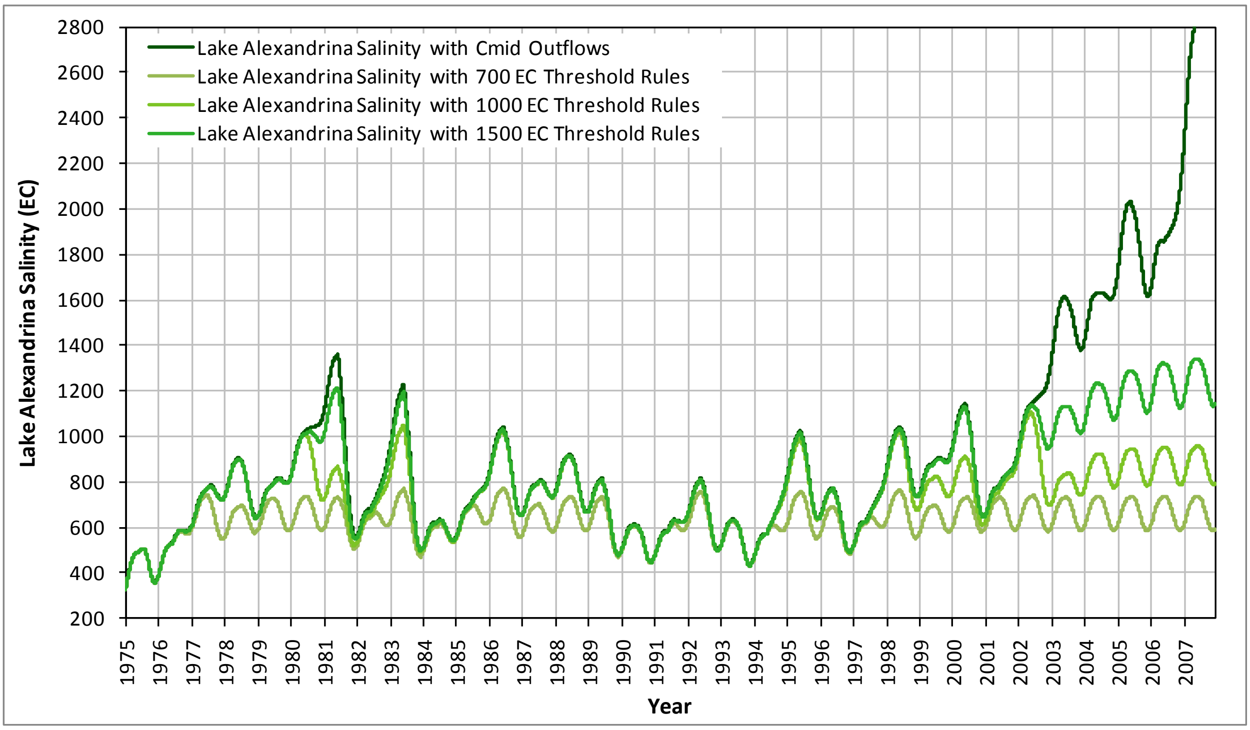



**Figure 119 Lake Alexandrina Salinity with Adjusted (Cmid) Barrage Outflows: All Thresholds (1975 to 2007)**

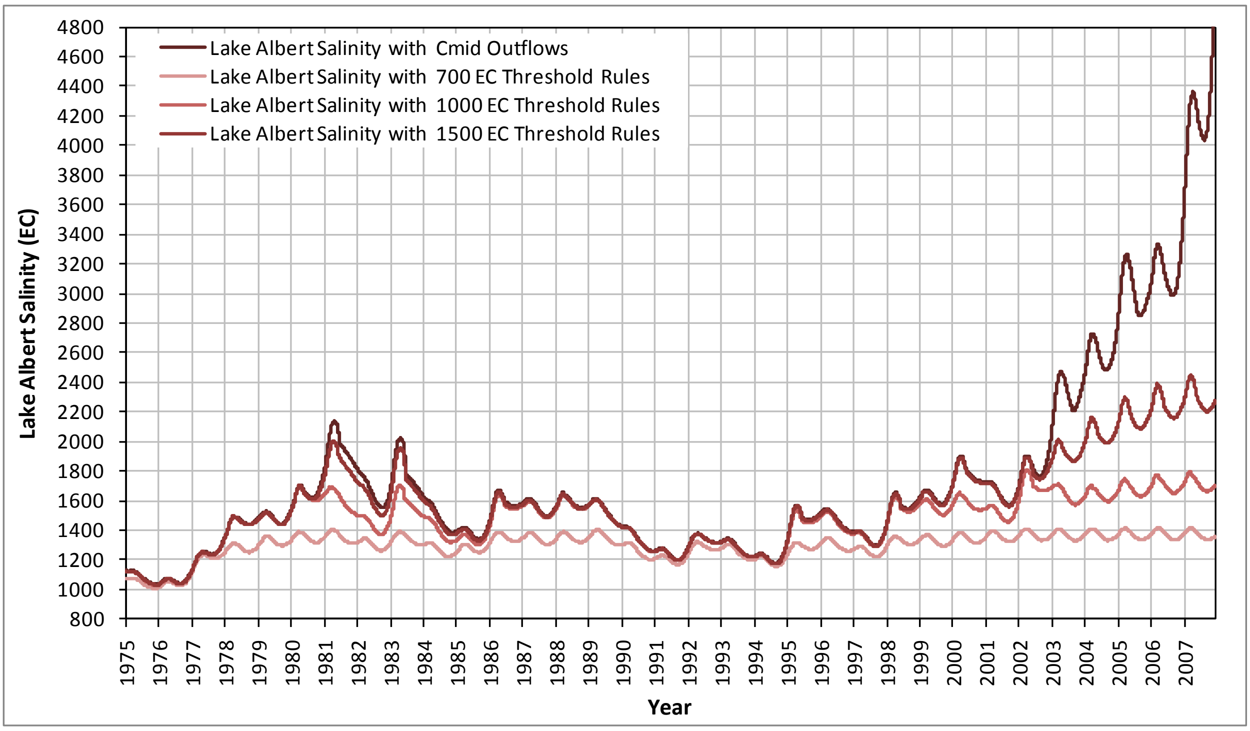



**Figure 120 Lake Albert Salinity with Adjusted (Cmid) Barrage Outflows: All Thresholds (1975 to 2007)**

## 5.3. APPLICATION OF FLOW REGIMES TO CDRY CONDITIONS

The flow regimes developed for each of the 700, 1000 and 1500 EC thresholds were applied to the Cdry inflows to Lake Alexandrina. Figure 104 shows the Cdry and adjusted flow sequences, with each year of increased inflow indicated as a departure from the historical sequence. Significant increases were required in many years under both the 700 and 1000 EC threshold,.

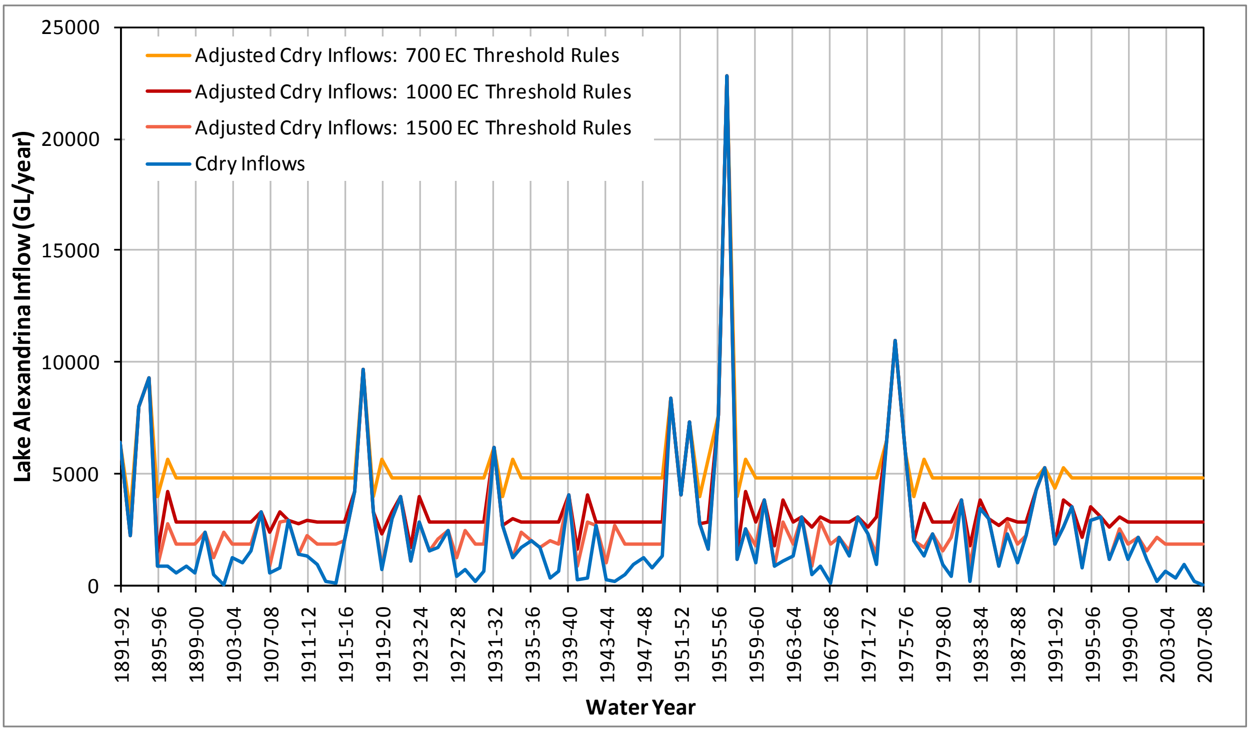



**Figure 121 Adjusted Cdry Inflows using 700, 1000 and 1500 EC Threshold Rules**

A summary of the additional inflows required under each threshold is shown in Table 18. The extremely dry nature of the Cdry sequences led to the requirement for additional inflows in a significant number of years for each salinity threshold. More than half of the increased inflows under the 1500 EC threshold were required within three periods: 1896/97 to 1914/15 (15 years), 1937/38 to 1949/50 (11 years) and 1998/99 to 2007/08 (9 years). Increased flows under the 700 and 1000 EC threshold were required in over 88% and 72% of years respectively.

**Table 18   Additional Flows Required for the Cdry Inflow Sequence**

| Statistics | Salinity Threshold | | |
|---|---|---|---|
| | 700 EC | 1000 EC | 1500 EC |
| Length of Record | 117 years | 117 years | 117 years |
| Additional Inflows Required | 103 years | 84 years | 58 years |
| Average Annual Inflow Increase | 3270 GL | 1685 GL | 1045 GL |
| Minimum Annual Inflow Increase | 555 GL | 165 GL | 30 GL |
| Maximum Annual Inflow Increase | 4945 GL | 3675 GL | 2510 GL |
| **Additional Volume (GL)** | | | |
| Min Increase - 500 | 0 | 7 | 13 |
| 500 - 1000 | 7 | 12 | 20 |
| 1000 - 2000 | 13 | 34 | 21 |
| 2000 - 3000 | 17 | 29 | 4 |
| 3000 - 4000 | 31 | 2 | 0 |
| 4000 - Maximum Increase | 35 | 0 | 0 |

The adjusted inflows required for each of the salinity thresholds during the periods 1891-92 to 1916-17 (Figures 122 to 124) and 1978/79 to 2007/08 (Figures 125 to 127) are presented below. For the 1500 EC threshold, these incorporate two of primary adjustment periods. For the 700 EC threshold, these highlight the need for flow increases in almost every year. This pattern is consistent across the entire record as indicated above.

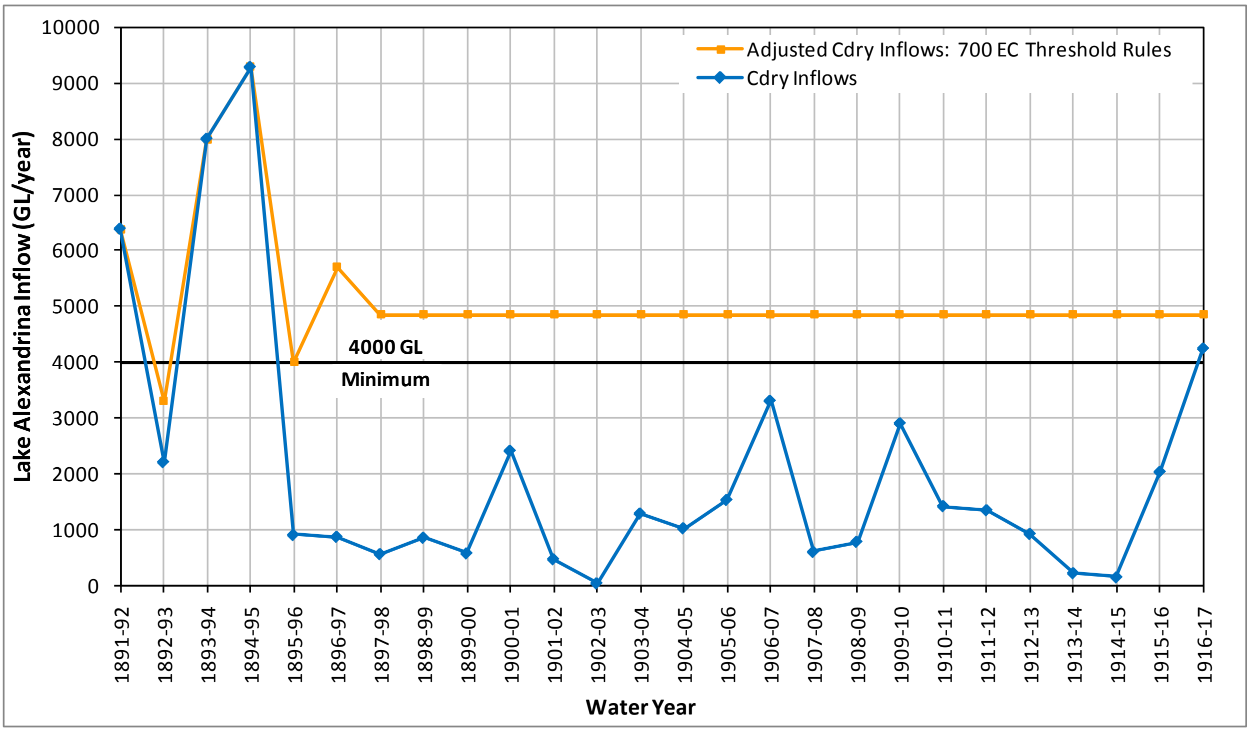



**Figure 122   Adjusted Cdry Inflows: 700 EC Threshold (1891/92 to 1916/17)**

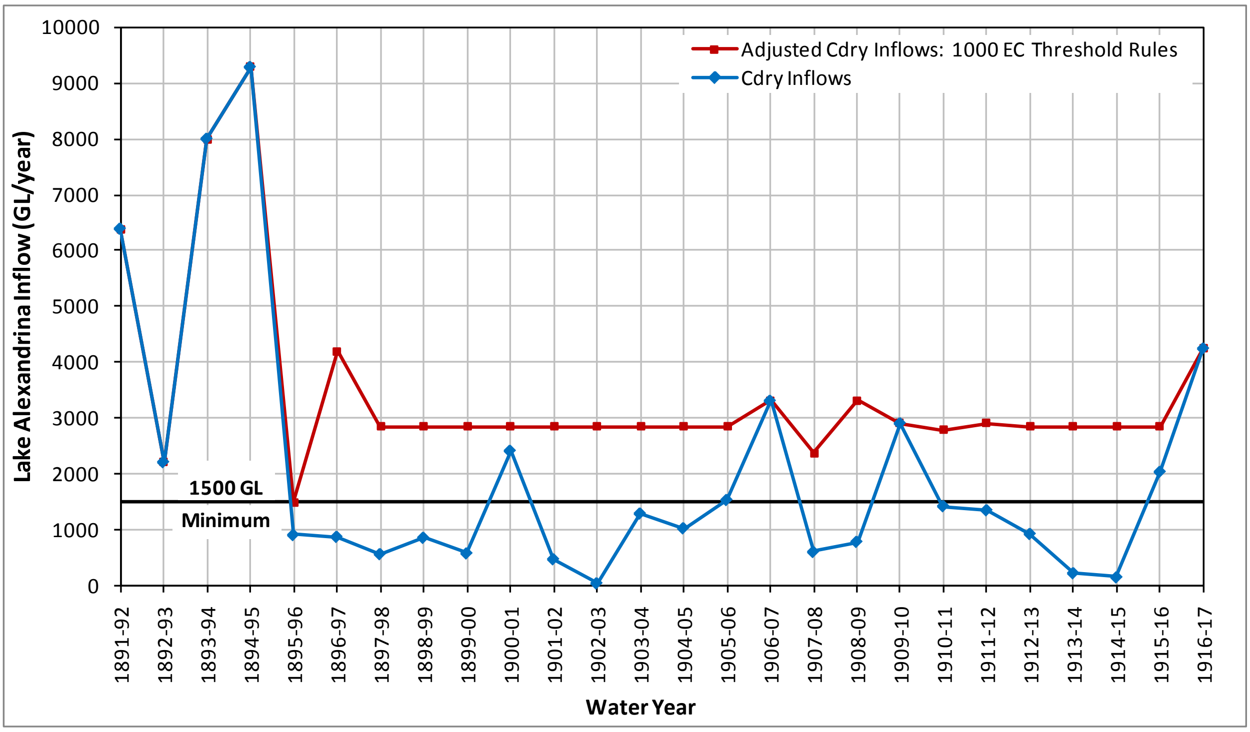



**Figure 123 Adjusted Cdry Inflows: 1000 EC Threshold (1891/92 to 1916/17)**

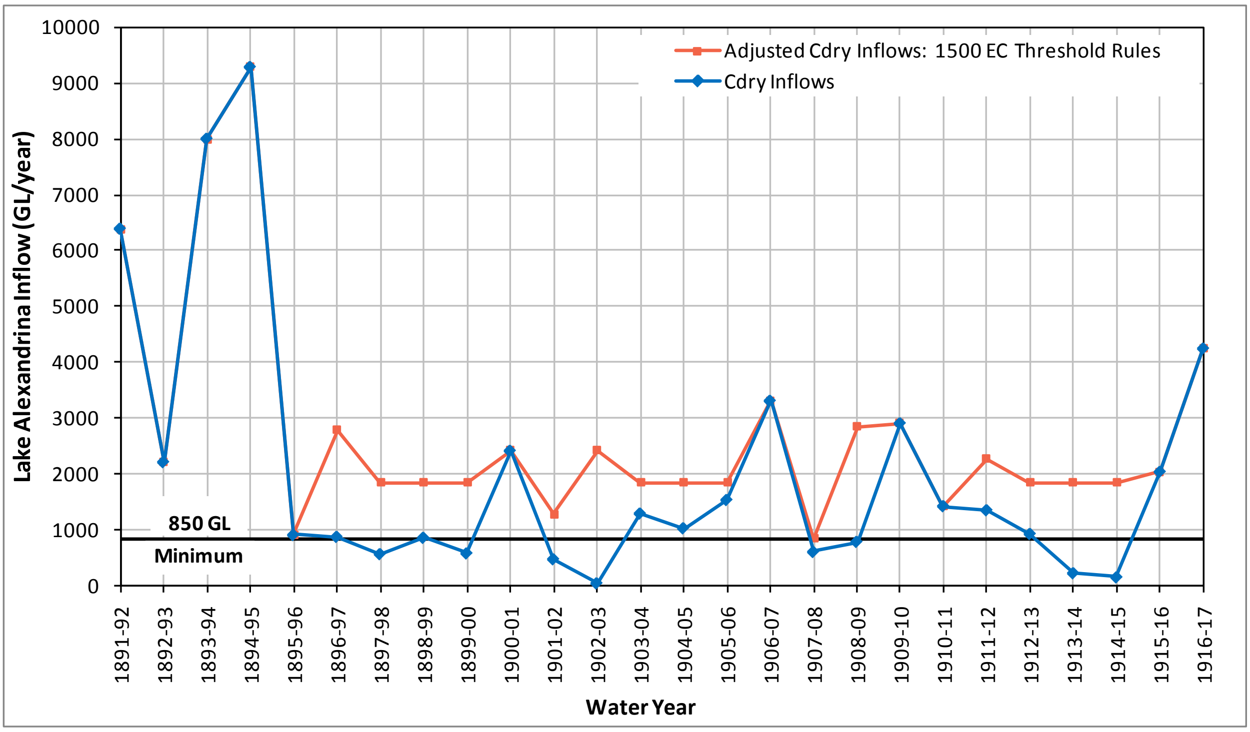



**Figure 124 Adjusted Cdry Inflows: 1500 EC Threshold (1891/92 to 1916/17)**

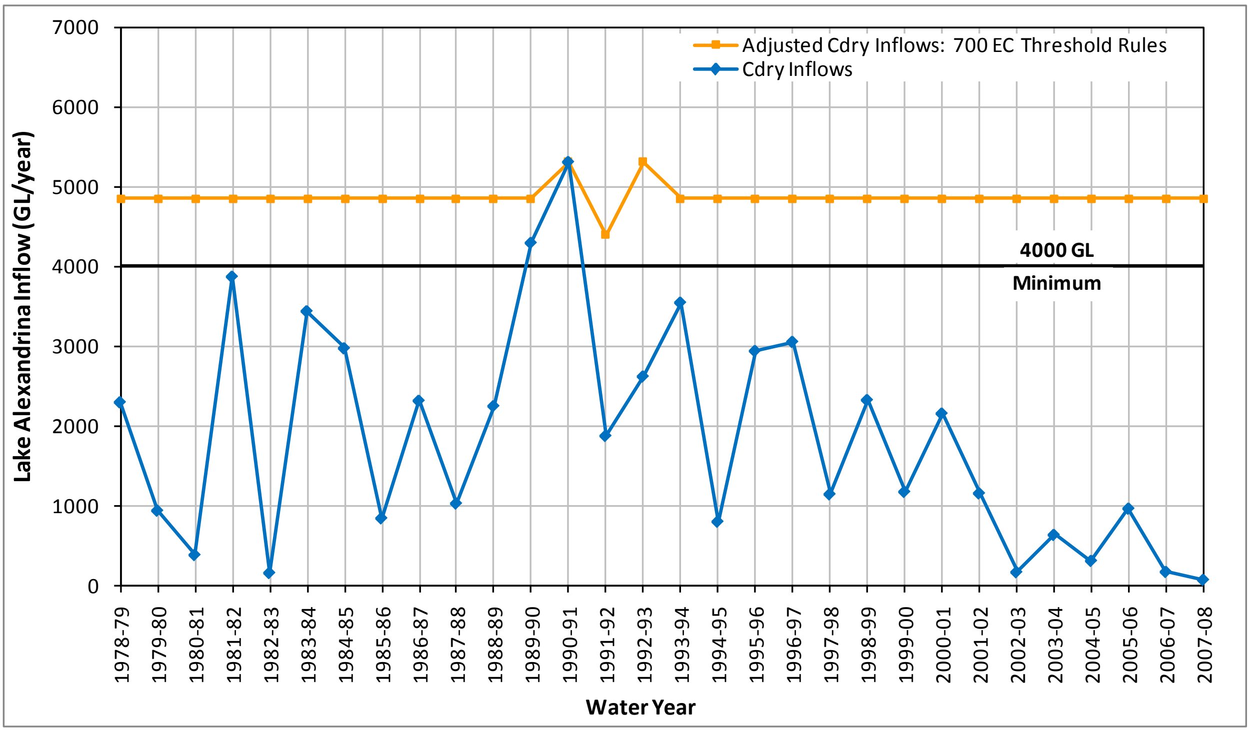



**Figure 125 Adjusted Cdry Inflows: 700 EC Threshold (1978/79 to 2007/08)**

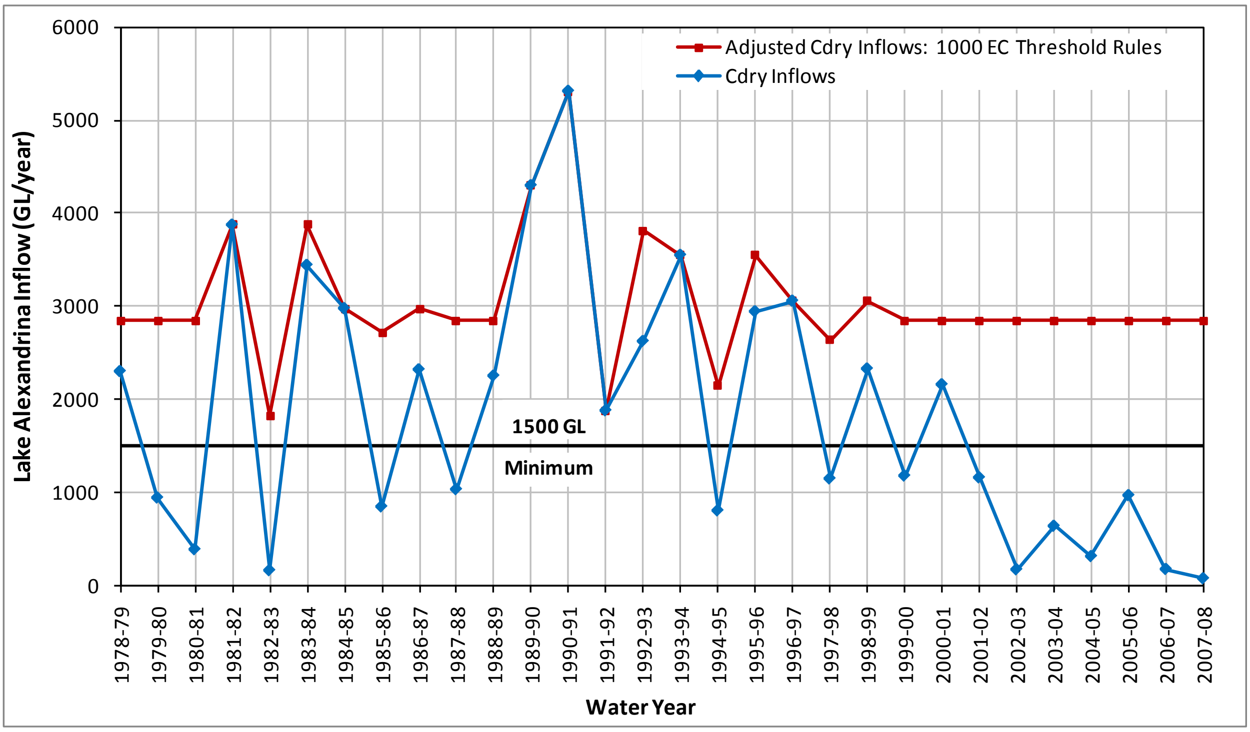



**Figure 126 Adjusted Cdry Inflows: 1000 EC Threshold (1978/79 to 2007/08)**

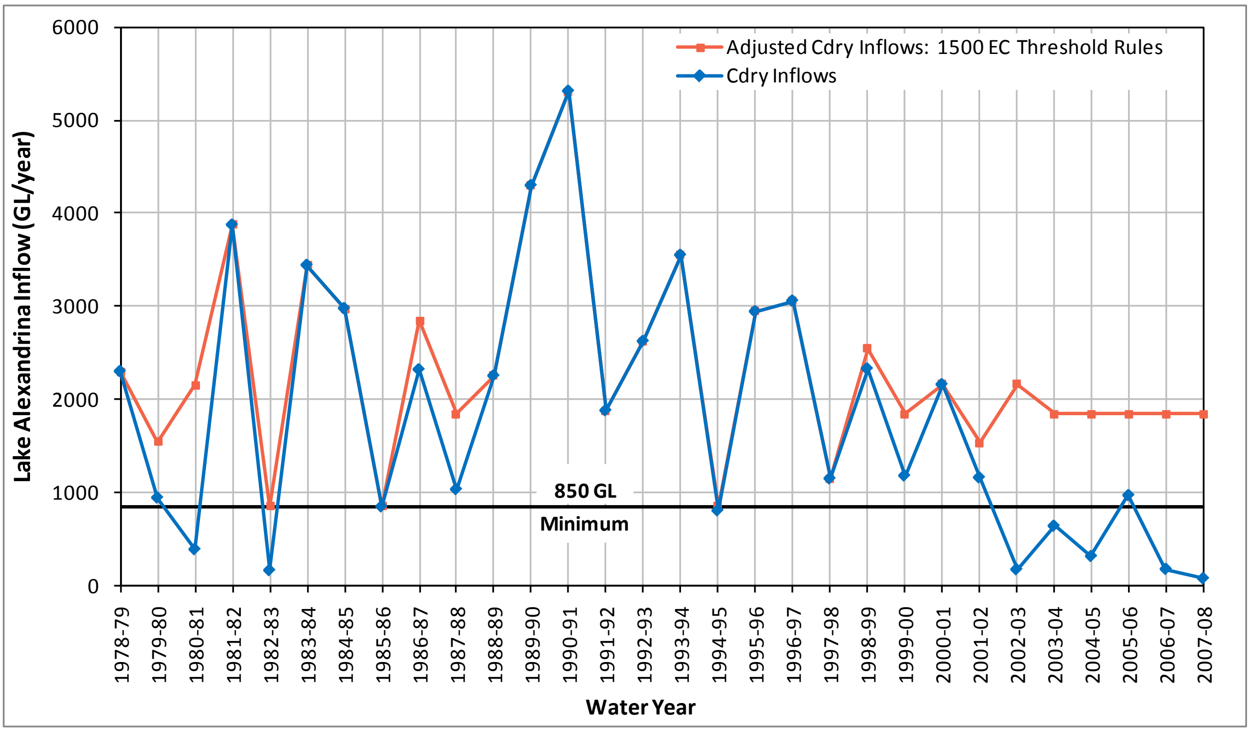



**Figure 127 Adjusted Cdry Inflows: 1500 EC Threshold (1978/79 to 2007/08)**

Table 19 shows the annual barrage outflow statistics under Cdry and adjusted conditions. The mean, median, minimum and 10$^{th}$ percentile outflows have increased significantly under all threshold flow regimes as a result of the very low lake inflows that would occur under this climate scenario and current water sharing rules under the MDB Agreement.

**Table 19 Cdry and Adjusted (All Thresholds) Barrage Outflow Statistics (1891/92 to 2007/08)**

| Statistics | Annual Barrage Outflow (GL) | | | |
|---|---|---|---|---|
| | Cdry | 700 EC Threshold | 1000 EC Threshold | 1500 EC Threshold |
| Mean | 1590 | 4420 | 2750 | 2060 |
| Median | 590 | 4000 | 2000 | 1200 |
| Minimum | 0 | 2480 | 815 | 305 |
| Maximum | 21845 | 21845 | 21845 | 21845 |
| 10$^{th}$ Percentile | 0 | 4000 | 1685 | 540 |
| 90$^{th}$ Percentile | 4335 | 4980 | 4745 | 4745 |

Figures 128 to 130 show the additional barrage outflows that result from the modified Cdry inflow sequence and to implement the flow regime to maintain salinities in Lake Alexandrina under each of the salinity thresholds. Significant additional barrage outflows would be required to maintain 700 or 1000 EC under Cdry conditions.

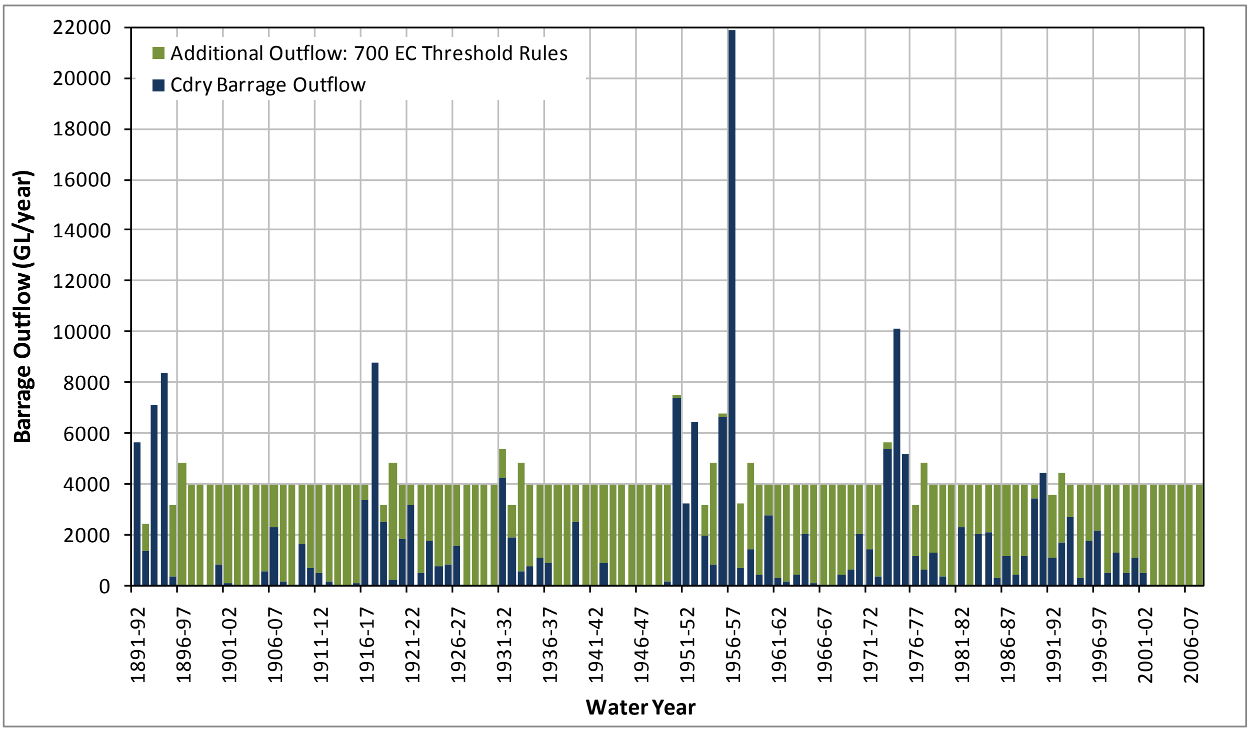



**Figure 128 Additional Barrage Outflows (Cdry): 700 EC Threshold**

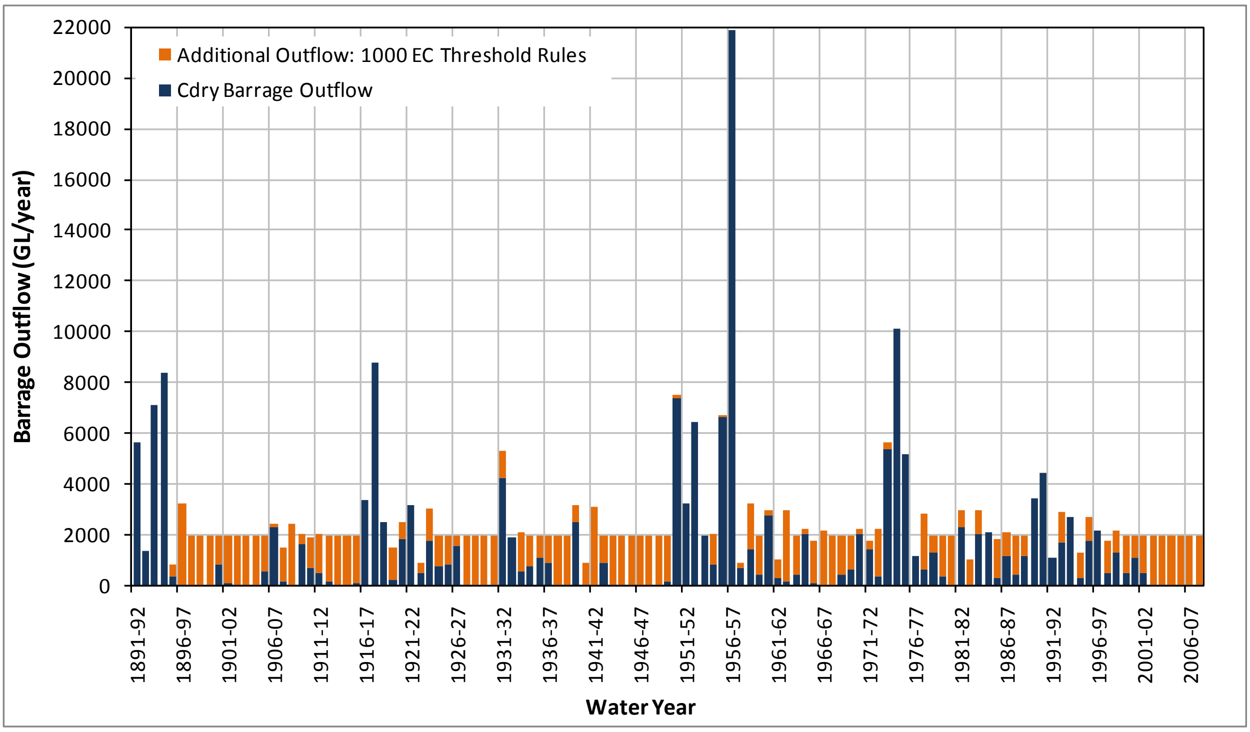



**Figure 129 Additional Barrage Outflows (Cdry): 1000 EC Threshold**

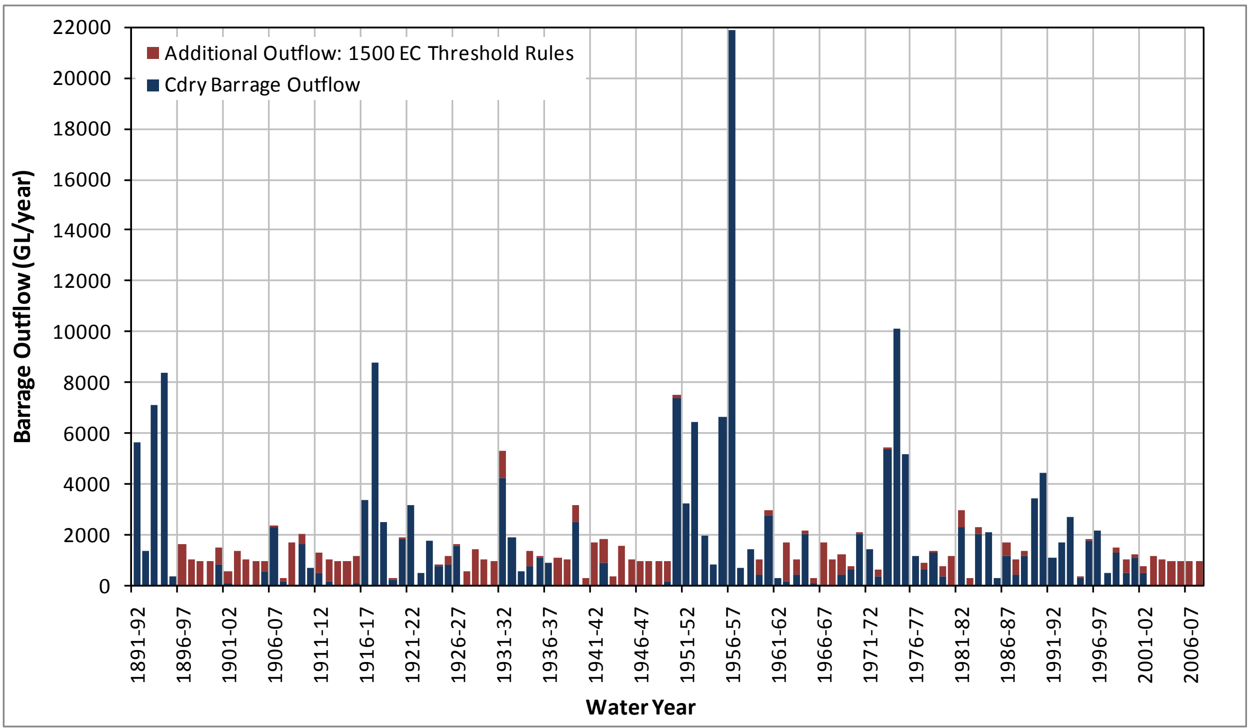



**Figure 130 Additional Barrage Outflows (Cdry): 1500 EC Threshold**

Figure 131 shows that there are significant changes to the Cdry barrage outflow frequency curve for all salinity thresholds. For the 700 and 1000 EC thresholds, the distribution becomes very flat across all 90% of years.

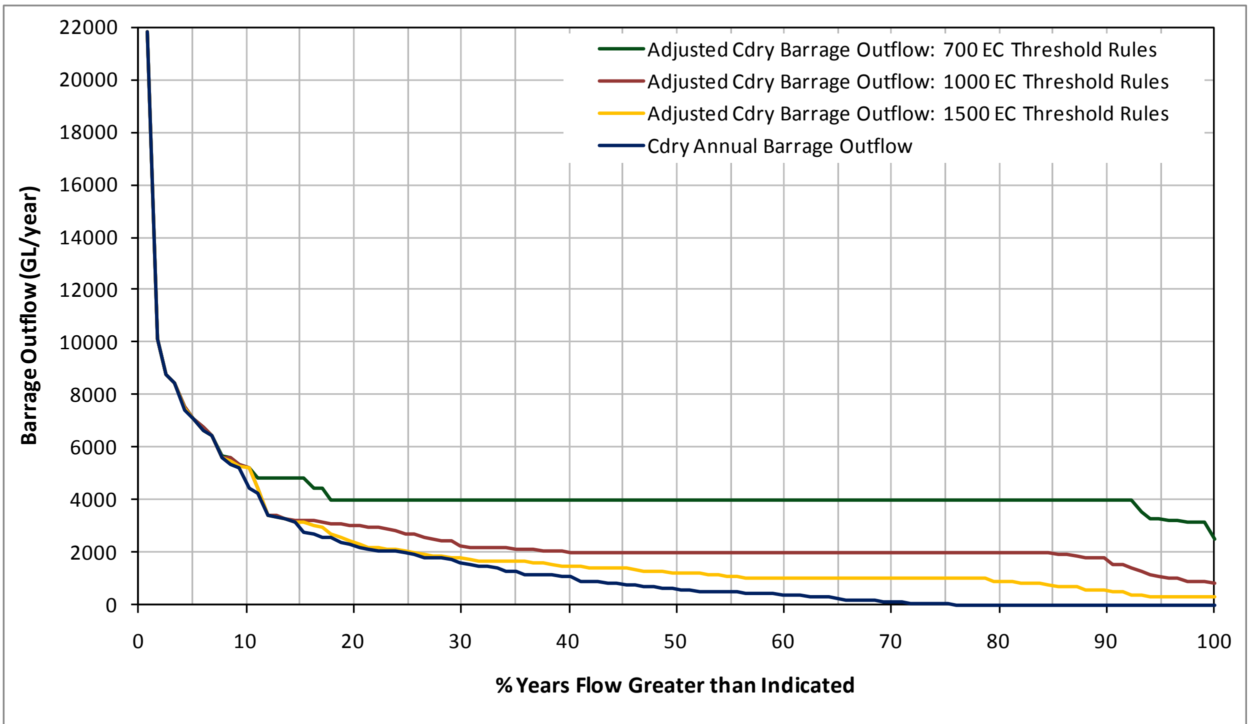



**Figure 131 Cdry and Adjusted Annual Barrage Outflow Frequency Curves: All Thresholds**

Figure 132 shows the adjusted Cdry annual barrage outflows that result from application of each of the salinity threshold regimes for the period from 1891/92 to 1916/17, with Figures 133 and 134 the resultant Lake Alexandrina and Lake Albert salinity time-series responses. Figures 135 to 137 then present the same information for the period 1975/76 to 2007/08.

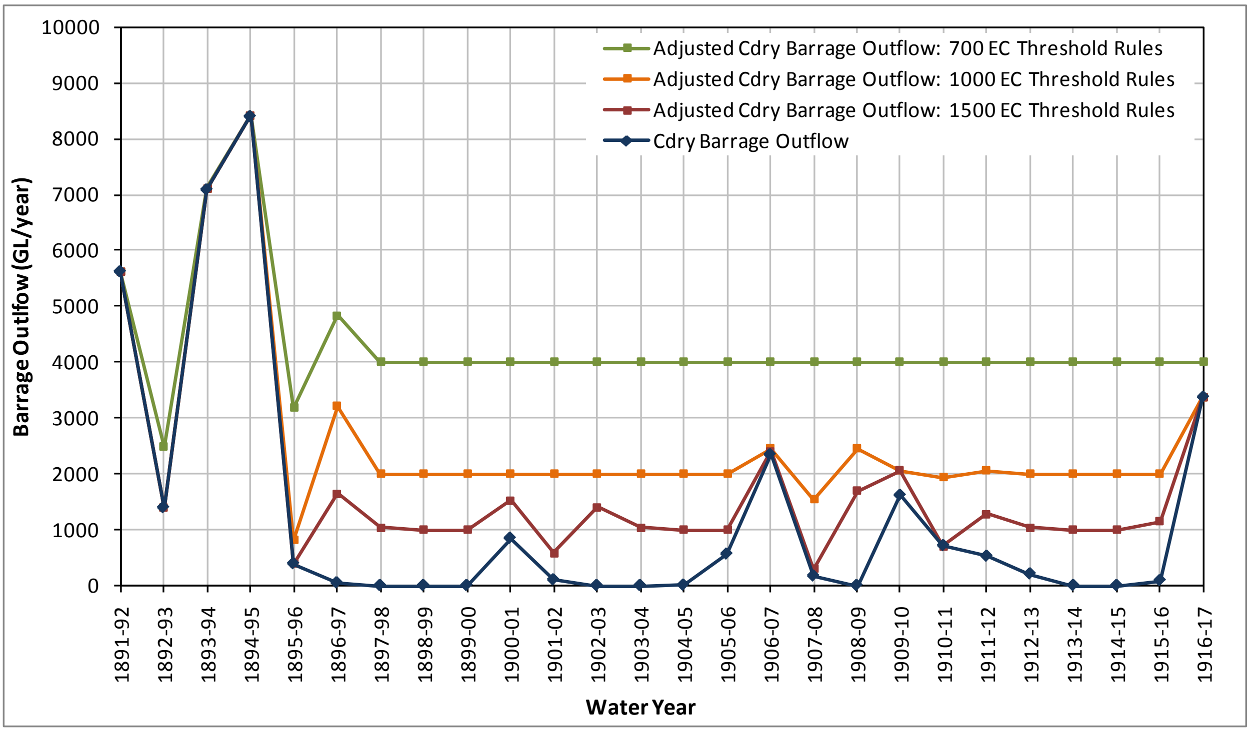



**Figure 132 Adjusted Cdry Annual Barrage Outflows: All Thresholds (1891/92 to 1916/17)**

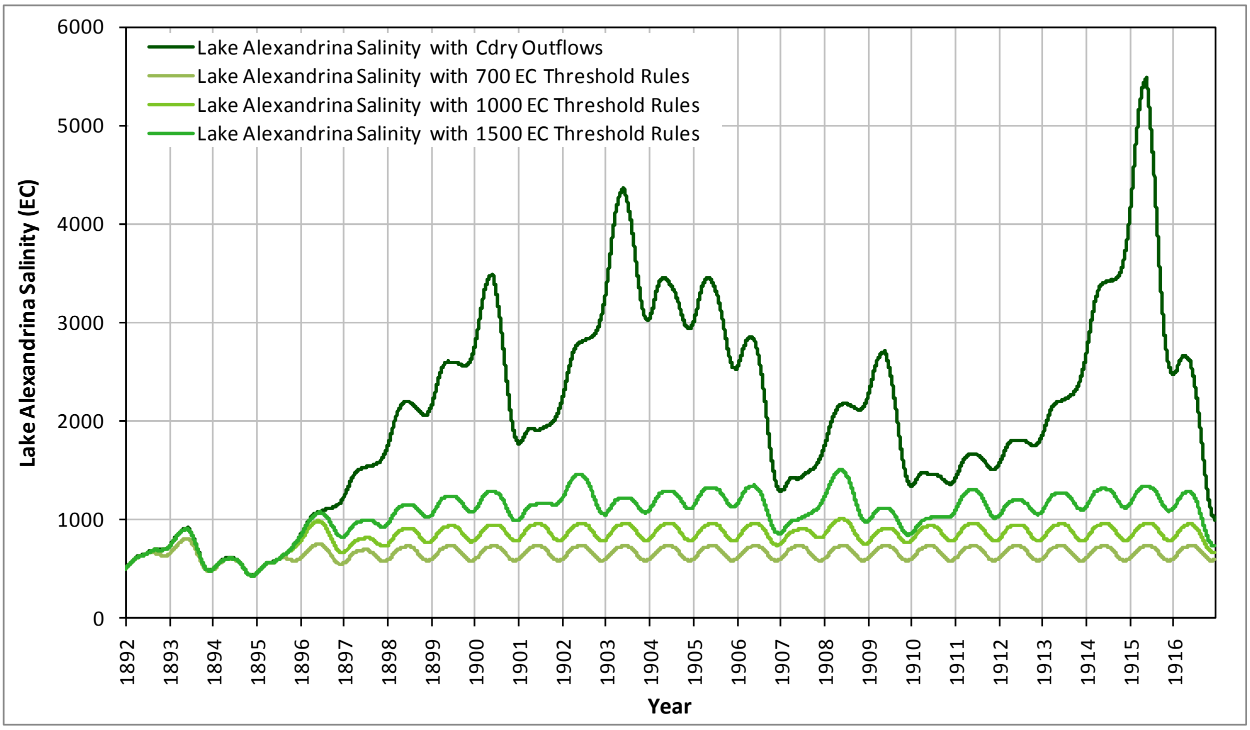



**Figure 133 Lake Alexandrina Salinity with Adjusted (Cdry) Barrage Outflows: All Thresholds (1892 to 1916)**

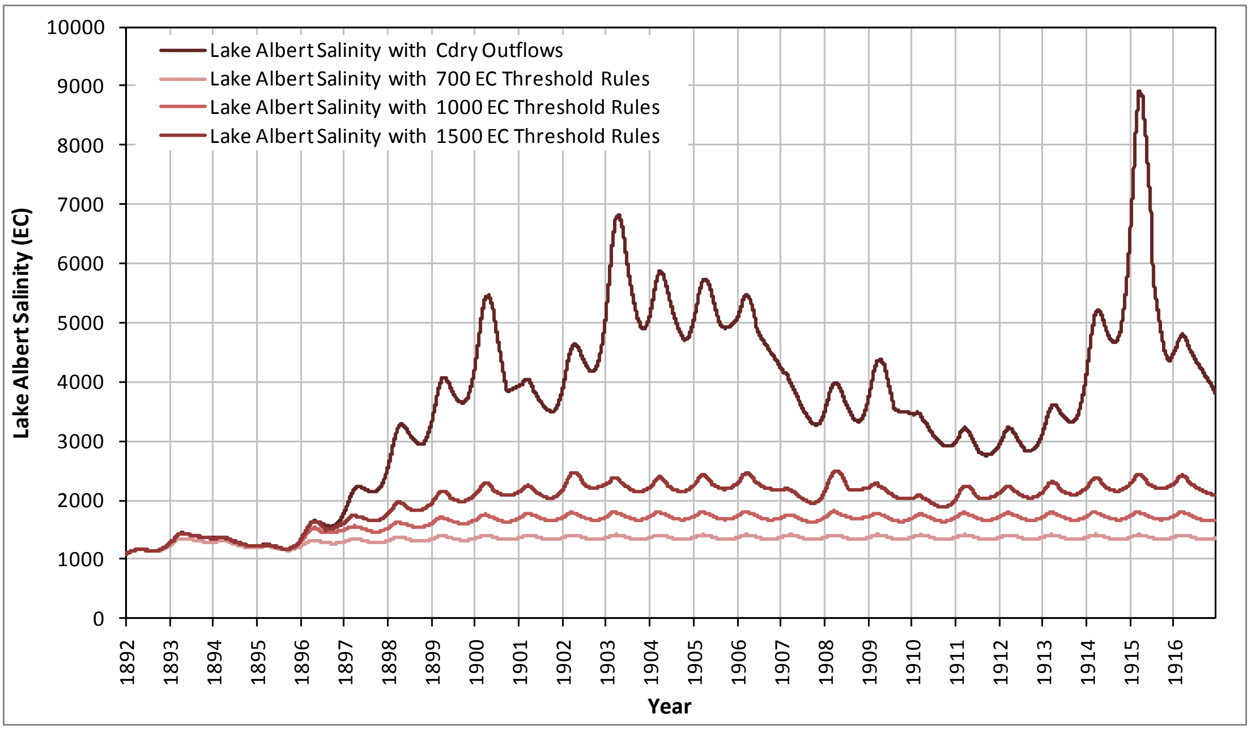



**Figure 134 Lake Albert Salinity with Adjusted (Cdry) Barrage Outflows: All Thresholds (1892 to 1916)**

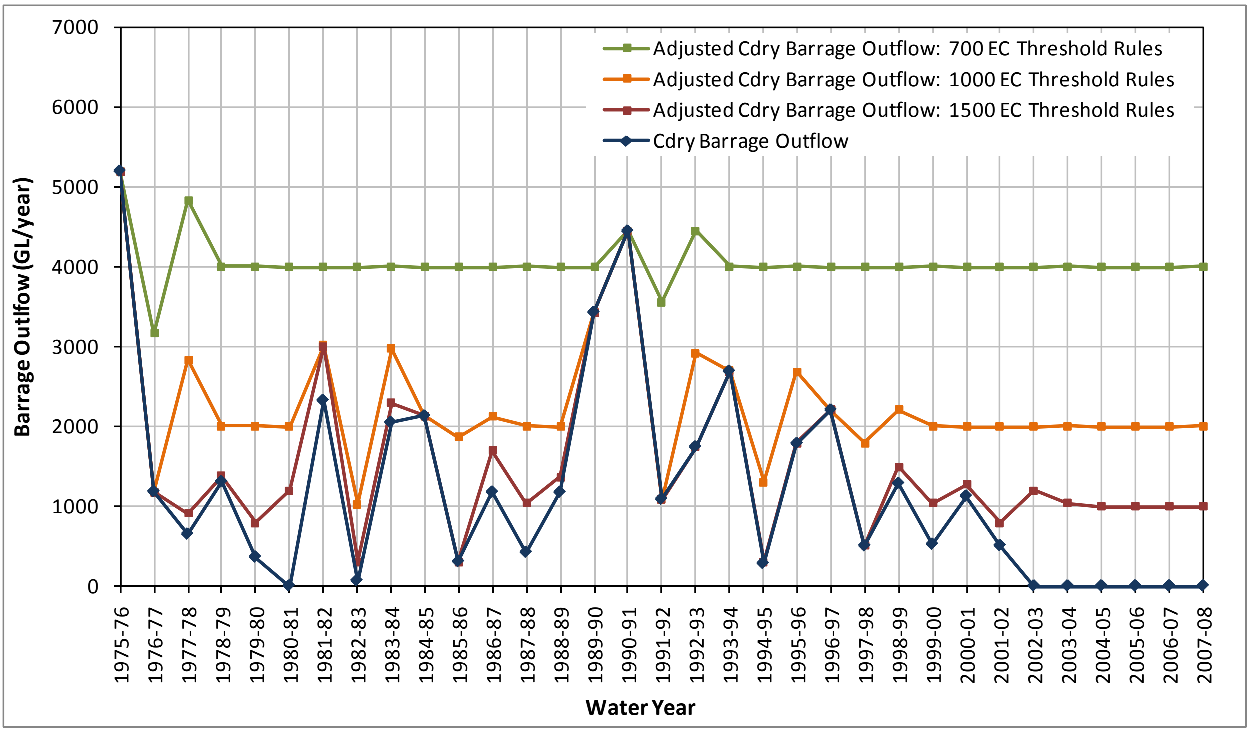



**Figure 135 Adjusted Cdry Annual Barrage Outflows: All Thresholds (1975/76 to 2007/08)**

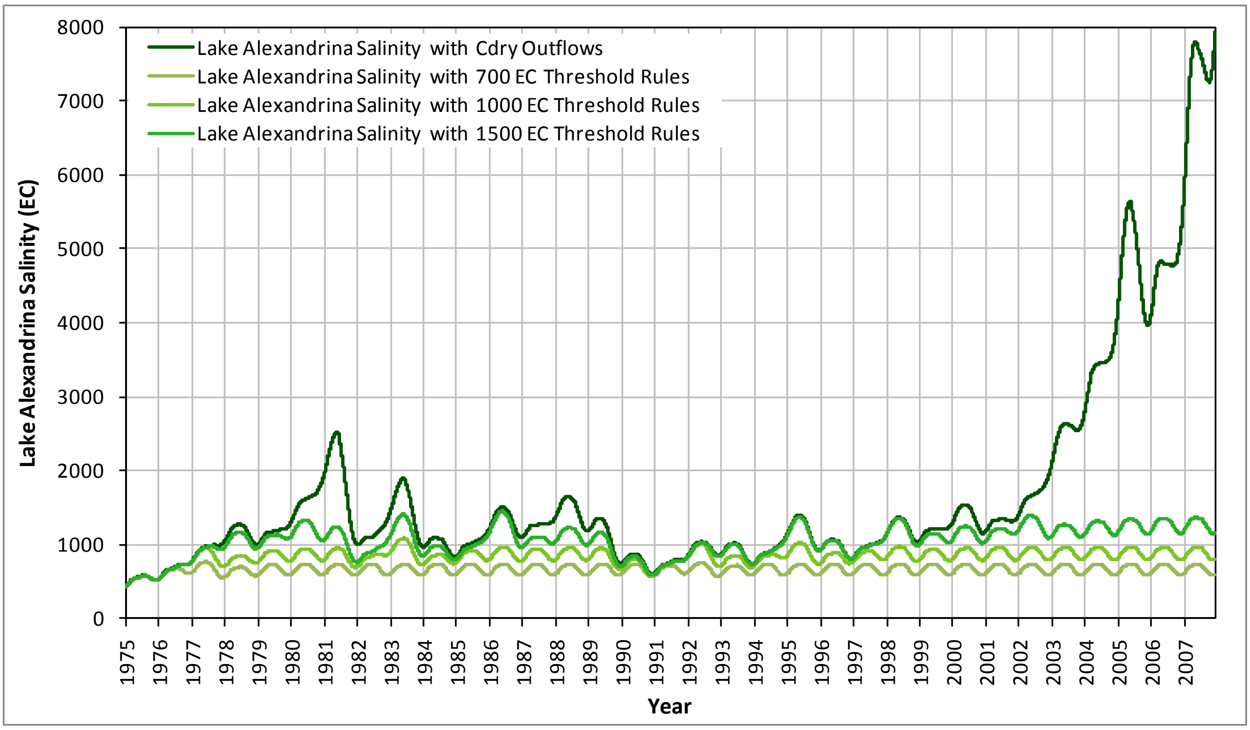



**Figure 136 Lake Alexandrina Salinity with Adjusted (Cdry) Barrage Outflows: All Thresholds (1975 to 2007)**

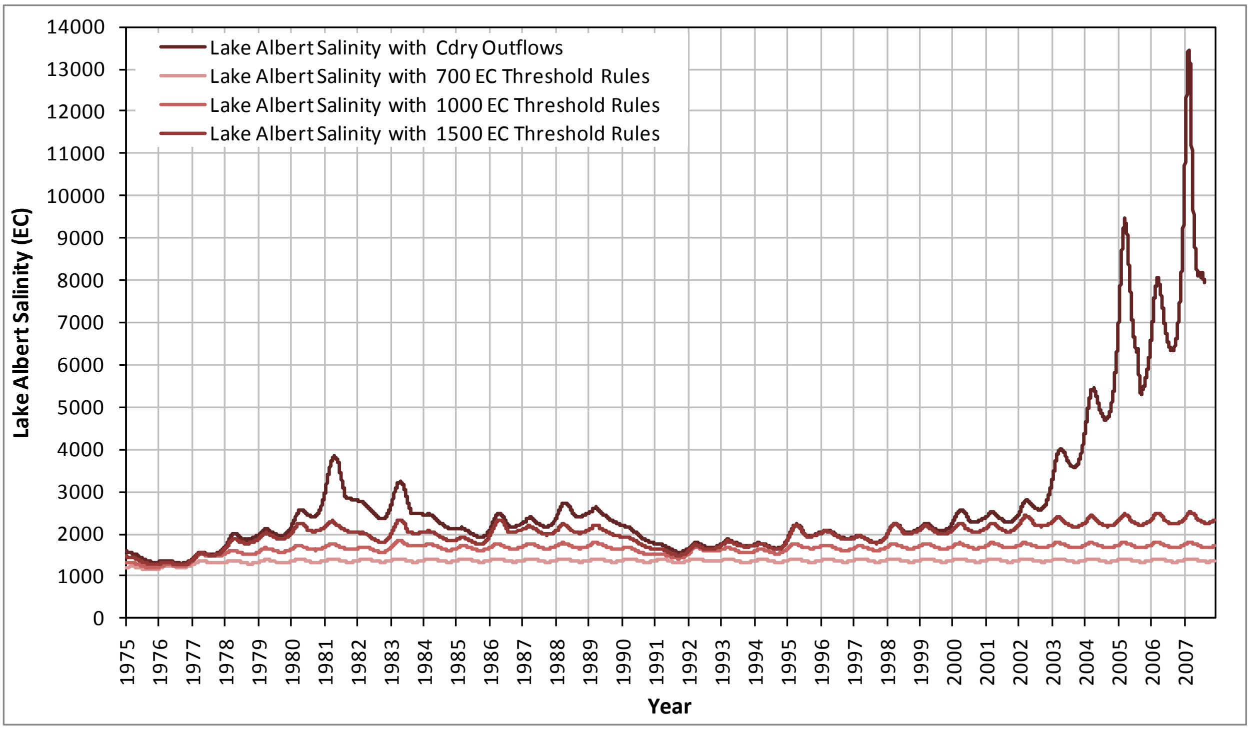



**Figure 137 Lake Albert Salinity with Adjusted (Cdry) Barrage Outflows: All Thresholds (1975 to 2007)**

# 6. WATER AVAILABILITY TO MEET SALINITY MANAGEMENT REQUIREMENTS

This investigation has defined flow regimes to manage salinity within Lake Alexandrina below a series of threshold values. The final stage of this investigation was to consider the ability of the River Murray System to provide for those flow regimes under historical, Cmid and Cdry conditions.

Over the period from 1975 to 2006, average salinity observed in Lake Alexandrina was around 700 to 800 EC with maximum salinities in the range of 1000 to 1500 EC. However, with a repeat of the historical flow regime for this period, in conjunction with the implementation of major salinity management strategies across the MDB, it is expected that maximum salinities would be in the range of 1000 to 1300 EC (refer Figure 4).

Based on an analysis of the salinity tolerances for a number of indicator species (Lester *et al.* 2011a) and the analysis of historical salinity levels and variations undertaken through this investigation, it has been recommended to the Coorong, Lower Lakes and Murray Mouth program (Lester *et al.* 2011b), that a salinity threshold of 1000 EC should be maintained in Lake Alexandrina for the majority of the time, with maximum salinity no higher than 1500 EC. Therefore, in determining the ability of the River Murray System to provide the volumes required to manage salinity in Lake Alexandrina, only the 1000 and 1500 EC thresholds have been evaluated.

The flow requirements to manage salinity at the 1000 and 1500 EC thresholds for the Historical, Cmid and Cdry inflow sequences with current water sharing arrangements under the MDB Agreement (current conditions) have been calculated. In each case the increased flow requirement to manage salinity is the difference between the flow requirements and the flow that would be delivered under current conditions. Therefore, the most appropriate method for undertaking this assessment would be to compare an annual time-series of flow to South Australia with corresponding system water availability. This would have allowed a simple comparison to determine whether the additional flow volumes required could potentially be provided from system resources. However, this data was not made available and an alternative method of assessment is presented in this instance.

As an initial assessment, sequences of flow at the South Australian border under Historical, Cmid and Cdry "natural" (pre-regulation) conditions were used as a substitute for system water availability. There are a number of issues with this approach including:

- The effect of flow "timing" on the volumes available within each water year. Under natural conditions, flow moves through the system to South Australia as it is generated. However, under current conditions flows are held in storage and can be delivered across water years. This results in potentially less water being available within the system for distribution and/or less flow at the South Australian border under natural conditions than under current conditions in a given water year.
- Natural conditions do not include the Snowy Required Annual Release (RAR). The MDBA assume a minimum RAR for planning purposes of 763 GL/year under historical conditions and 373 GL/year for worst case conditions.

The four year period from 2005/06 to 2008/09 has historically the lowest inflow sequence on record. It was considered that if there was sufficient water available to provide for the flow regime over these years, the flow requirements should be able to be satisfied for the full modelled period. Data was provided by the MDBA for Historical, Cmid and Cdry "natural" conditions. From this data, the additional flow that would occur under natural conditions over that of the current conditions flow was calculated and Tables 20 to 22 show the results of the analysis, which is based on the following:

- Additional volume under natural conditions is the difference between the flow at the South Australian border under current and natural conditions for each water year.
- The requirement volume to manage salinity at either the 1000 or 1500 EC threshold, which is dependent on the volumes available and delivered in previous years under current conditions.
- The deficit volume is the shortfall in providing the requirement volume in each water year based on the total water available under natural conditions.

The results for the flow regime to manage salinity at the 1000 EC threshold shows that:

- the additional volumes required are available in the system in all but 2006/07 under historical, Cmid and Cdry conditions.
- there is a deficit in providing the flow requirements in 2006/07. However, this is because the available water did not consider the storing of water that occurs under current conditions from one year to the next. The flow requirement for 2006/07 is based on the flow delivered under current conditions in the previous two years, not the water availability under natural conditions. In the case of Cdry, the flow under natural conditions is less than the flow under current conditions.
- the flow, and therefore water available, in 2005/06 would have been high enough to likely result in volumes stored for use in 2006/07 that would be adequate to provide the volumes required.
- if the flow requirement was completely determined based on the natural conditions time-series, then only 1500 GL would have been required in all cases, which could have been met under Historical and Cmid conditions.

While it is expected that an analysis of system water availability would conclusively show that there would be no deficits in the additional flow requirements, in the absence of this analysis it is still concluded that there is confidence that there would be enough water within the system to meet, if directed, the adjusted flow regimes to manage salinity to the 1000 EC threshold level.

The results for the flow regime to manage salinity at the 1500 EC threshold shows that:

- the additional volumes required are available in the system in all years under historical and Cmid conditions.
- there is a deficit in providing the flow requirements in 2006/07 under Cdry conditions. This is again because the available water did not consider the storing of water from one year to the next and it is again noted that the natural flow is less than the flow under current conditions.
- despite Cdry being an extremely dry climate sequence, water available in 2005/06 is again high enough so that the likely volumes stored for use in 2006/07 would be adequate to provide the volumes required.

Based on this analysis there is confidence that there would be enough water within the system to meet, if directed, the flow regimes to manage salinity to the 1500 EC threshold level.

It is concluded that even during the historically lowest inflow sequence on record there would be sufficient water within the system to provide the required flows to manage salinity in the Lower Lakes at a salinity threshold of 1000 EC in Lake Alexandrina for the majority of the time with a maximum salinity no higher than 1500 EC. However, it is acknowledged that this should be verified once current conditions water-availability data (rather than natural conditions data) can be provided by the MDBA.

**Table 20 Water Availability for 1000 and 1500 EC Threshold Rules under Historical Climate**

| Water Year | Historical | | | | | |
|---|---|---|---|---|---|---|
| | Current Conditions (GL) | Additional Volume Natural Conditions (GL)* | 1000 EC | | 1500 EC | |
| | | | Requirement (GL) | Deficit (GL) | Requirement (GL) | Deficit (GL) |
| 2005/06 | 2634 | 7322 | 2850 | 0 | 2634 | 0 |
| 2006/07 | 1463 | 575 | 2850 | 812 | 1463 | 0 |
| 2007/08 | 860 | 5090 | 2850 | 0 | 2237 | 0 |
| 2008/09 | 506 | 3640 | 2850 | 0 | 1850 | 0 |

* Additional volume available under natural conditions, relative to current conditions

**Table 21 Water Availability for 1000 and 1500 EC Threshold Rules under Cmid Climate**

| Water Year | Cmid | | | | | |
|---|---|---|---|---|---|---|
| | Current Conditions (GL) | Additional Volume Natural Conditions (GL) | 1000 EC | | 1500 EC | |
| | | | Requirement (GL) | Deficit (GL) | Requirement (GL) | Deficit (GL) |
| 2005/06 | 2625 | 6814 | 2850 | 0 | 2625 | 0 |
| 2006/07 | 1390 | 211 | 2850 | 1249 | 1390 | 0 |
| 2007/08 | 760 | 4561 | 2850 | 0 | 2310 | 0 |
| 2008/09 | 485 | 3350 | 2850 | 0 | 1850 | 0 |

**Table 22 Water Availability for 1000 and 1500 EC Threshold Rules under Cdry Climate**

| Water Year | Cdry | | | | | |
|---|---|---|---|---|---|---|
| | Current Conditions (GL) | Additional Volume Natural Conditions (GL) | 1000 EC | | 1500 EC | |
| | | | Requirement (GL) | Deficit (GL) | Requirement (GL) | Deficit (GL) |
| 2005/06 | 2035 | 5610 | 2850 | 0 | 2035 | 0 |
| 2006/07 | 818 | -304 | 2850 | 2336 | 1665 | 1151 |
| 2007/08 | 388 | 3836 | 2850 | 0 | 2035 | 0 |
| 2008/09 | 416 | 2430 | 2850 | 4 | 1850 | 0 |

# 7. CONCLUSIONS

The purpose of this report was to present the results of an investigation into the development of the inflow and outflow regimes required for the Lower Lakes for the purposes of maintaining a desired ecological character, which was described using threshold water quality (defined in terms of salinity) and water level targets.

It was shown that barrage outflows are the key driver for managing salinity levels in Lake Alexandrina because they are the only mechanism for the export of salt from the system. The initial analysis of historical barrage outflows and the salinity variation in Lake Alexandrina showed that there is a marked increase in salinity as annual barrage outflows fall below 2000 GL and three-year cumulative outflows fall below 4000 GL.

However, as barrage outflows are the result of lake inflows and losses and diversions across the lakes, it was necessary to first determine a lake inflow regime to manage salinity for 700, 1000 and 1500 EC thresholds. These regimes applied criteria to calculate the required inflow in each year, based on an absolute minimum inflow and the inflow from the previous two years. Through the assumption of constant annual losses it was then possible to determine a corresponding barrage outflow regime. In practice, inflows may need to be adjusted based on actual losses and diversions each year, as well as the source and salinity of available water, to achieve the barrage outflow requirements for salinity management.

The criteria developed accommodated lower system water availability in a given year by factoring in a minimum inflow and outflow, which is less than the average annual inflow and outflow. However, in the following year Lake Alexandrina requires a higher inflow and outflow to meet the minimum requirements, thereby ensuring that salinities remain below the threshold.

The flow regimes developed for each salinity threshold were validated using an historical inflow sequence as well as two climate sequences with reduced water availability (climate change scenarios Cmid and Cdry from the Murray-Darling Basin Sustainable Yields project). Each adjusted flow regime using the criteria developed was found to appropriately manage salinity within the corresponding threshold.

Finally, water availability within the River Murray System was examined to check that the flow regimes required to manage salinity in the Lower Lakes could be provided. The most appropriate method for undertaking this assessment would be to compare an annual time-series of flow to South Australia with corresponding system water availability. This would have allowed a simple comparison to determine whether the additional flow volumes required could potentially be provided from system resources. However, this data was not made available and an alternative method of assessment was used as a preliminary analysis. The analysis undertaken used flow to South Australia under "natural" conditions as a substitute for water availability and it was concluded that even during the historically lowest inflow sequence on record (Cdry) there would be sufficient water within the system to provide the required flows to manage salinity in the Lower Lakes.

# 8. REFERENCES

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Murray-Darling Basin Commission (2001), Basin Salinity Management Strategy: 2001-2015. Report published by the Murray-Darling Basin Ministerial Council.

Murray-Darling Basin Commission (2002), Setting up of *MSM-BIGMOD* Modelling Suite for the River Murray System. Technical Report 2002/5, Murray-Darling Basin Commission, Canberra, Australia.

*Water Act 2007* (Cth) Schedule 1 - The Murray-Darling Basin Agreement.

# REFERENCES

# UNITS OF MEASUREMENT

## Units of measurement commonly used (SI and non-SI Australian legal)

| Name of unit | Symbol |
|---|---|
| day | d |
| gigalitre | GL |
| hectare | ha |
| kilolitre | kL |
| kilometre | km |
| litre | L |
| megalitre | ML |
| metre | m |
| millimetre | mm |
| second | s |
| year | yr |

# GLOSSARY

**Anabranch** — A branch of a river that leaves the main channel

**Aquatic ecosystem** — The stream channel, lake or estuary bed, water, and/or biotic communities, and the habitat features that occur therein

**Aquatic habitat** — Environments characterised by the presence of standing or flowing water

**Barrage** — Specifically any of the five low weirs at the mouth of the River Murray constructed to exclude seawater from the Lower Lakes

**Baseflow** — The water in a stream that results from groundwater discharge to the stream; often maintains flows during seasonal dry periods and has important ecological functions

**Basin** — The area drained by a major river and its tributaries

**Benchmark condition** — Points of reference from which change can be measured

**BoM** — Bureau of Meteorology, Australia

**Catchment** — That area of land determined by topographic features within which rainfall will contribute to run-off at a particular point

**CSIRO** — Commonwealth Scientific and Industrial Research Organisation

**DEH** — Department for Environment and Heritage (Government of South Australia)

**DENR** — Department of Environment and Natural Resources (Government of South Australia)

**DFW** — Department for Water (Government of South Australia)

**DWLBC** — Department of Water, Land and Biodiversity Conservation (Government of South Australia)

**EC** — Electrical conductivity; 1 EC unit = 1 micro-Siemen per centimetre (µS/cm) measured at 25°C; commonly used as a measure of water salinity as it is quicker and easier than measurement by TDS

**Ecological indicators** — Plant or animal species, communities, or special habitats with a narrow range of ecological tolerance; for example, in forest areas, such indicators may be selected for emphasis and monitored during forest plan implementation because their presence and abundance serve as a barometer of ecological conditions within a management unit

**Ecological processes** — All biological, physical or chemical processes that maintain an ecosystem

**Ecological values** — The habitats, natural ecological processes and biodiversity of ecosystems

**Ecology** — The study of the relationships between living organisms and their environment

**Ecosystem** — Any system in which there is an interdependence upon, and interaction between, living organisms and their immediate physical, chemical and biological environment

**Electrical Conductivity (EC)** – Electrical conductivity is a measure of the water's ability to conduct an electrical current. Electrical conductivity (measured at 25$^{o}$C in units of mS cm$^{-1}$ or µS cm$^{-1}$) can be used to estimate salinity because a relationship exists between the levels of dissolved salts in a water body and its conductivity.

**EMLR** — Eastern Mount Lofty Ranges

**Entitlement flow** — Maximum monthly River Murray flow to South Australia agreed in to the Murray-Darling Basin Agreement 2008

**Environmental values** — The uses of the environment that are recognised as being of value to the community. This concept is used in setting water quality objectives under the Environment Protection (Water Quality) Policy, which recognises five environmental values — protection of aquatic ecosystems, recreational water use and aesthetics, potable (drinking water) use, agricultural and aquaculture use, and industrial use. It is not the same as ecological values, which are about the elements and functions of ecosystems.

**Environmental water provisions** — That part of environmental water requirements that can be met; what can be provided at a particular time after consideration of existing users' rights, and social and economic impacts

**Environmental water requirements** — The water regimes needed to sustain the ecological values of aquatic ecosystems, including their processes and biological diversity, at a low level of risk

**Ephemeral streams or wetlands** — Those streams or wetlands that usually contain water only on an occasional basis after rainfall events. Many arid zone streams and wetlands are ephemeral.

**Estuaries** — Semi-enclosed water bodies at the lower end of a freshwater stream that are subject to marine, freshwater and terrestrial influences, and experience periodic fluctuations and gradients in salinity

**Estuarine habitat** — Tidal habitats and adjacent tidal wetlands that are usually semi-enclosed by land but have open, partly obstructed, or sporadic access to the open ocean, and in which ocean water is at least occasionally diluted by freshwater run-off from the land

**Evapotranspiration** — The total loss of water as a result of transpiration from plants and evaporation from land, and surface water bodies

**Fishway** — A generic term describing all mechanisms that allow the passage of fish along a waterway. Specific structures include fish ladders (gentle sloping channels with baffles that reduce the velocity of water and provide resting places for fish as they 'climb' over a weir) and fishlifts (chambers, rather like lift-wells, that are flooded and emptied to enable fish to move across a barrier).

**Floodplain** — Of a watercourse means: (1) floodplain (if any) of the watercourse identified in a catchment water management plan or a local water management plan; adopted under the Act; or (2) where (1) does not apply — the floodplain (if any) of the watercourse identified in a development plan under the *Development (SA) Act 1993*; or (3) where neither (1) nor (2) applies — the land adjoining the watercourse that is periodically subject to flooding from the watercourse

**Flow bands** — Flows of different frequency, volume and duration

**Flow regime** — The character of the timing and amount of flow in a stream

**Greenhouse effect** — The balance of incoming and outgoing solar radiation which regulates our climate. Changes to the composition of the atmosphere, such as the addition of carbon dioxide through human activities, have the potential to alter the radiation balance and to effect changes to the climate. Scientists suggest that changes would include global warming, a rise in sea level and shifts in rainfall patterns.

**Groundwater** — Water occurring naturally below ground level or water pumped, diverted and released into a well for storage underground; see also 'underground water'

**Infrastructure** — Artificial lakes; dams or reservoirs; embankments, walls, channels or other works; buildings or structures; or pipes, machinery or other equipment

**Irrigation** — Watering land by any means for the purpose of growing plants

**Irrigation season** — The period in which major irrigation diversions occur, usually starting in August–September and ending in April–May

**Lake** — A natural lake, pond, lagoon, wetland or spring (whether modified or not) that includes part of a lake and a body of water declared by regulation to be a lake. A reference to a lake is a reference to either the bed, banks and shores of the lake or the water for the time being held by the bed, banks and shores of the lake, or both, depending on the context.

**Land** — Whether under water or not, and includes an interest in land and any building or structure fixed to the land

**Licence** — A licence to take water in accordance with the Act; see also 'water licence'

**Licensee** — A person who holds a water licence

**m AHD** — Defines elevation in metres (m) according to the Australian Height Datum (AHD)

**MDBA** — Murray–Darling Basin Authority

**MDBC** — Murray–Darling Basin Commission

**Model** — A conceptual or mathematical means of understanding elements of the real world that allows for predictions of outcomes given certain conditions. Examples include estimating storm run-off, assessing the impacts of dams or predicting ecological response to environmental change

**Monitoring** — (1) The repeated measurement of parameters to assess the current status and changes over time of the parameters measured (2) Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, animals, and other living things

**Percentile** — A way of describing sets of data by ranking the dataset and establishing the value for each percentage of the total number of data records. The 90th percentile of the distribution is the value such that 90% of the observations fall at or below it.

**Ramsar Convention** — This is an international treaty on wetlands titled *The Convention on Wetlands of International Importance Especially as Waterfowl Habitat*. It is administered by the International Union for Conservation of Nature and Natural Resources. It was signed in the town of Ramsar, Iran in 1971, hence its common name. The convention includes a list of wetlands of international importance and protocols regarding the management of these wetlands. Australia became a signatory in 1974.

**SA Water** — South Australian Water Corporation (Government of South Australia)

**Stock use** — The taking of water to provide drinking water for stock other than stock subject to intensive farming (as defined by the Act)

**Sub-catchment** — The area of land determined by topographical features within which rainfall will contribute to run-off at a particular point

**Surface water** — (a) water flowing over land (except in a watercourse), (i) after having fallen as rain or hail or having precipitated in any another manner, (ii) or after rising to the surface naturally from underground; (b) water of the kind referred to in paragraph (a) that has been collected in a dam or reservoir

**Threshold** – a point at which a change in conditions (e.g. change in a quality, property or phenomenon) produces a response/shift. For an example, a decline in water level to a point where a shift in the ecological community is observed.

**To take water** — From a water resource includes (a) to take water by pumping or siphoning the water; (b) to stop, impede or divert the flow of water over land (whether in a watercourse or not) for the purpose of collecting the water; (c) to divert the flow of water from the watercourse; (d) to release water from a lake; (e) to permit water to flow under natural pressure from a well; (f) to permit stock to drink from a watercourse, a natural or artificial lake, a dam or reservoir

**Tributary** — A river or creek that flows into a larger river

**Water allocation** — (1) In respect of a water licence means the quantity of water that the licensee is entitled to take and use pursuant to the licence. (2) In respect of water taken pursuant to an authorisation under s.11 means the maximum quantity of water that can be taken and used pursuant to the authorisation

**Water body** — Includes watercourses, riparian zones, floodplains, wetlands, estuaries, lakes and groundwater aquifers

**Watercourse** — A river, creek or other natural watercourse (whether modified or not) and includes: a dam or reservoir that collects water flowing in a watercourse; a lake through which water flows; a channel (but not a channel declared by regulation to be excluded from the this definition) into which the water of a watercourse has been diverted; and part of a watercourse

**Water-dependent ecosystems** — Those parts of the environment, the species composition and natural ecological processes, that are determined by the permanent or temporary presence of flowing or standing water, above or below ground; the in-stream areas of rivers, riparian vegetation, springs, wetlands, floodplains, estuaries and lakes are all water-dependent ecosystems

**Water-use year: South Australia** — The period between 1 July in any given calendar year and 30 June the following calendar year; also called a licensing year

**Water-use year: Murray-Darling Basin Authority** — The period between 1 June in any given calendar year and 31 May the following calendar year

**Wetlands** — Defined by the Act as a swamp or marsh and includes any land that is seasonally inundated with water. This definition encompasses a number of concepts that are more specifically described in the definition used in the Ramsar Convention on Wetlands of International Importance. This describes wetlands as areas of permanent or periodic to intermittent inundation, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tides does not exceed six metres.