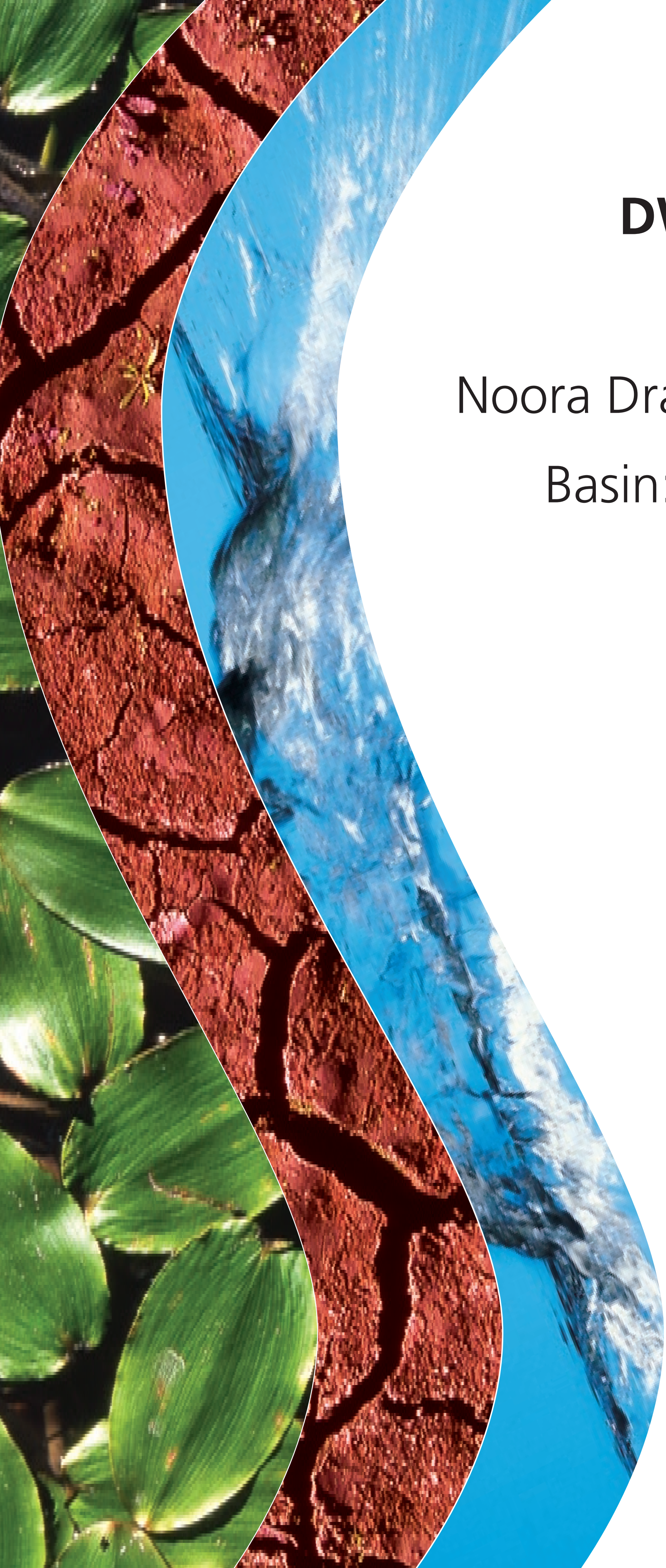

DWLBC REPORT

Noora Drainage Disposal Basin: Surface Water Investigation

2007/17

Government of South Australia
Department of Water, Land and Biodiversity Conservation

Noora Drainage Disposal Basin: Surface Water Investigation

Dr Theresa M. Heneker

Knowledge and Information Division
Department of Water, Land and Biodiversity Conservation

July 2007

Report DWLBC 2007/17

Government of South Australia
Department of Water, Land and Biodiversity Conservation

Knowledge & Information

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FOREWORD

South Australia's unique and precious natural resources are fundamental to the economic and social wellbeing of the State. It is critical that these resources are managed in a sustainable manner to safeguard them both for current users and for future generations.

The Department of Water, Land and Biodiversity Conservation (DWLBC) strives to ensure that our natural resources are managed so that they are available for all users, including the environment.

In order for us to best manage these natural resources it is imperative that we have a sound knowledge of their condition and how they are likely to respond to management changes. DWLBC scientific and technical staff continue to improve this knowledge through undertaking investigations, technical reviews and resource modelling.

Rob Freeman
CHIEF EXECUTIVE
DEPARTMENT OF WATER, LAND AND BIODIVERSITY CONSERVATION

EXECUTIVE SUMMARY

Salt Interception Schemes (SIS) along the River Murray intercept highly saline groundwater before it discharges into the river. A crucial component to the development of new schemes at Bookpurnong, Loxton, Murtho and Pike was the identification of a site with enough capacity to store and evaporate this intercepted groundwater. Noora Basin currently receives discharges from the Bookpurnong SIS and the Renmark and Berri irrigation areas but is under-utilised and hence has excess capacity available. It has therefore been proposed to use this area to store the additional intercepted water from the Loxton SIS currently under construction, the proposed Murtho SIS and potentially from a future Pike SIS.

The extent of Noora Basin covers around 16,000 Ha, but topography encloses a primary disposal area of approximately 3,300 Ha, which is primarily Government owned. This area is enclosed at a height of 19.7 mAHD. The objective of this investigation was to assess the ability of this primary disposal area to accept the planned SIS increases in pumping volumes and salinities over the next 100 years and to determine the long-term disposal capacity rate, assuming a maximum operating level of 19.0 mAHD. To enable this assessment, a monthly salt-water balance model was developed. This allowed the continuous accounting of water and salt moving into and out of the basin, as well as permitting the easy evaluation of changing input parameters such as pumping rates.

Three scenarios were evaluated:

- Scenario 1: Drainage, and Loxton, Bookpurnong and Murtho SIS disposal.
- Scenario 2: Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS disposal.
- Scenario 3: Variation in pumping rates to achieve targeted operational levels.

The modelling showed that there is sufficient capacity within Noora Basin to accept the proposed drainage and Bookpurnong, Loxton, Murtho and Pike SIS pumping rates.

A sensitivity analysis showed that even with negating factors such as reduced evaporation or infiltration or increased SIS salt concentrations, the resulting water levels were still below the maximum operating level of 19.0 mAHD over 100 years.

Maximum long-term average SIS pumping rates, coupled with drainage discharges of 40 L/s, have been determined in order to achieve a range of maximum operating levels within the basin.

Monitoring should be an important component to the ongoing basin operation and management. Initially, surface water monitoring need only focus on the Western Basin and include routine measurement of the volume and quality of water discharged into it as well as the installation of continuous water level and salinity recorders at strategic locations. Ultimately, the level of monitoring adopted will be driven by the need to reconcile actual and predicted disposal capacity and for reconciling groundwater impact modelling. The Infrastructure and Business Division of DWLBC, with the assistance of other DWLBC Divisions, Rural Solutions SA, SA Water and Resource and Environmental Management (REM), is currently preparing a comprehensive Noora Basin Monitoring Framework and Monitoring Plan that will address the environmental and technical management and monitoring issues associated with expanded operation of the Noora Basin.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1 BACKGROUND

The Noora Drainage Disposal Basin is located approximately 20 km east of Loxton and 19 km south east of the River Murray. It was originally identified as a suitable disposal location due to its low elevation and because groundwater naturally discharges into the area. Commissioned in 1982 as a site for the disposal of excess irrigation water from the Renmark and Berri irrigation areas, increasing irrigation efficiency has reduced the amount of excess water in recent years. Volumes pumped from temporary basins within the irrigation areas to Noora have decreased from a peak discharge of 6,000 ML/year in 1982-83 to generally less than 2,000 ML/year since 2000-01. The salinities of the discharged water have ranged from 3,000 to 37,000 mg/L. Recently, the lower volumes of drainage water pumped have been of higher salinities due to increased evapo-concentration within the temporary basins before pumping. However, due to the lower volumes pumped, the overall salt loads pumped to the basin have been lower.

Noora Basin also receives water from the recently completed Bookpurnong Salt Interception Scheme (SIS), which intercepts highly saline groundwater before it discharges into the River Murray. A crucial component to the development of more schemes at Loxton (under construction), Murtho and Pike (planned) is the need for a disposal basin(s) with enough capacity to store and evaporate this intercepted groundwater. Noora Basin is currently under-utilised and hence has excess capacity available. It has therefore been proposed to use this area to store the additional intercepted water. This option would involve the discharge of increasing volumes of water with salinities over 25,000 mg/L.

This report presents an evaluation of the disposal capacity of Noora Basin, which has been mainly driven by the need to:

- Support the Murtho SIS approval submission currently before the Murray-Darling Basin Commission (MDBC). The model results will provide SA and the other MDBC-partner governments with a technical confidence assessment of the basin capacity to form a viable and sustainable part of the Murtho SIS.
- Help refine the South Australian Regional Disposal Strategy (RDS) by predicting the long-term capacity of the basin and its potential to receive water from future possible SIS schemes such as Pike.
- Provide predictive estimates of basin inundation and water levels that will enable groundwater modelling to proceed to predict groundwater level changes within aquifers beneath and surrounding Noora Basin. These groundwater predictions in turn will be used by SA to undertake risk assessments of the potential impacts from the expanded Noora Basin operation on surrounding vegetation and land use.

1.2 OBJECTIVES AND METHODOLOGY

The extent of Noora Basin is shown in Figure 1. Of the 16,000 Ha extent, topography encloses a main disposal area of approximately 3,300 Ha, which is primarily Government owned. Shown in Figure 2, this area is enclosed at an elevation of 19.7 mAHD. Hence, water would need to be ponded above this elevation before flow into adjacent areas occurred (refer Section 2.1).

The primary objective of this investigation was to assess the ability of the primary disposal area to accept the planned increases in pumping volumes and salinities over the next 100 years. To enable this assessment, it was proposed to develop a monthly salt-water balance model. Such a model allows the continuous accounting of water and salt moving into and out of the basin, as well as permitting the easy evaluation of changing input parameters such as pumping rates or the development of alternative management strategies.

Assuming a 100-year operational life, the objectives can be defined as follows:

- Determine the ability of the primary disposal area to accept the accumulated volumes of water and salt as each new SIS becomes operational.
- Quantify the changing inundation areas, volumes of water stored and water levels over the period 2005 to 2106 for the proposed discharge rates.
- Quantify the salt discharged and stored as well as any impact on basin operations.
- Determine the long-term average disposal rates for a range of maximum operational elevations and if required, assess potential management strategies to extend the operational life of the basin.
- Determine any risks to adjacent low-lying properties.
- Provide basin model outputs (inundated area, water levels and salinity) as inputs to numerical groundwater modelling (Hodgkin *et al*., 2007) of potential impacts of expanded basin operation on surrounding aquifer systems.

The methodology developed for this investigation to achieve these objectives is outlined as follows:

1. Develop a model structure through an analysis of topography and connectivity within the basin.
2. Develop volume, depth and surface area relationships.
3. Develop a monthly water balance model for the basin that replicates the hydrological characteristics, the hydraulic filling properties and minimises any risks to adjacent low-lying properties.
4. Calibrate the model using existing climate and water level data.
5. Run the model over the period 2005 to 2106 using averaged climate data, proposed pumping rates and a design maximum operating level to:
    - determine the capability of the basin to store the intercepted volumes.
    - quantify the changing inundation areas, volumes and ponded water levels.
    - quantify the salt discharged and stored as well as any impact on basin operations.
6. Assess the sensitivity of model parameters in terms of changing inundation areas, volumes and ponded water levels.
7. Calculate long-term average disposal rates to achieve a range of maximum operating levels.

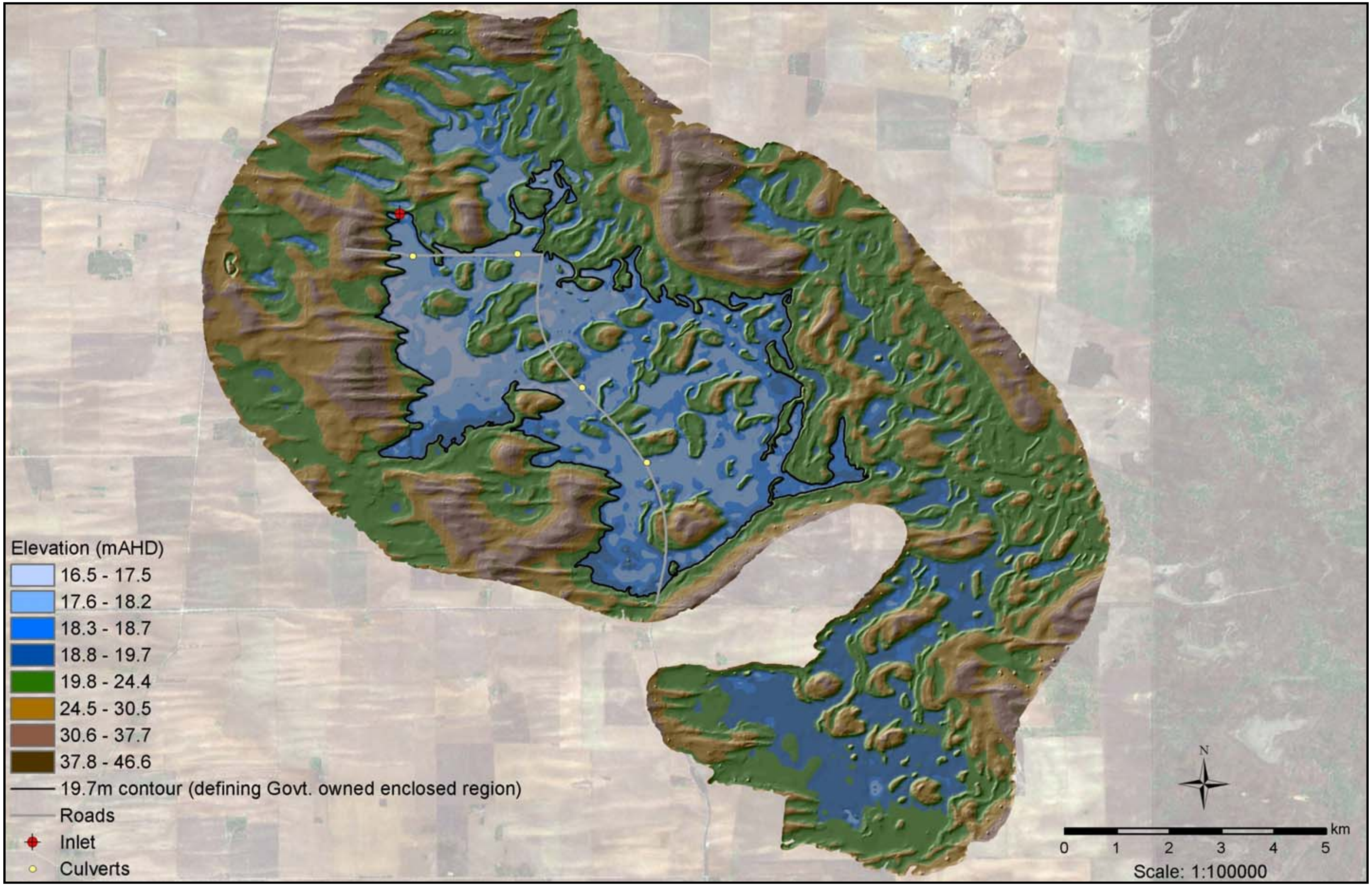


Figure 1 Noora Basin: Main Disposal Area and Other Low-Lying Areas.

Figure 2 Noora Basin: Government Owned Main Disposal Area

2. MODEL DEVELOPMENT

2.1 MODEL STRUCTURE

2.1.1 Topographic Analysis

A raster Digital Terrain Model (DTM) of the Noora Basin with a spatial resolution of five metres was constructed by Sinclair Knight Merz (SKM) using spot heights and one metre contours (both provided to SKM by DWLBC) during a previous investigation (SKM, 2005). Elevations within the DTM area range from 16.5 to 46.6 mAHD. Contours at 0.1 metre vertical spacing were then generated from the DTM using standard ArcGIS Spatial Analyst Contours functions.

This investigation focused on a Government-owned area within the basin that has been used previously to dispose of drainage water from the Renmark and Berri irrigation areas (refer Figure 2). It is intended that this area can continue to receive drainage water in addition to water pumped from new salt interception schemes. The generated contours were used to assess the volumetric capacity of this area and the maximum level to which water could be ponded before flow into adjacent areas occurs. A low-lying area to the north (Allotment 53) was identified and is shown in Figure 3. This area is not Government owned and, although a depression is present within the allotment area (17 mAHD elevation), it is disconnected from the main basin up to 19.7 mAHD. To maximise the storage capacity and reduce the need for additional management of water and salt once it enters the basin, in particular, preventing impacts on areas external to the Government owned area, this value has been assumed as the design maximum operating level.

Figure 3 Characteristics of Allotment 53 and Relationship to Main Basin.

The area within this 19.7 mAHD contour was then extracted from the DTM using a 10 m buffer. This raster surface, together with the 0.1 m contours and standard ArcGIS 3D Analyst Area and Volume functions, was used to calculate depth, volume and surface area relationships for the basin. This provided volume to height and surface area to height relationships to be used in the model. Linear interpolation was used to calculate surface areas and volumes at inundation levels between these increments. At full supply, the estimated total capacity is 35,240 ML, inundating an area of 2,400 Ha. The remaining area outside of the 19.7 mAHD contour was excluded from this investigation.

Figure 2 shows roads crossing the basin, one running north-south and the other east-west, which are at an elevation of 20 mAHD. Therefore, engineering works are likely to be required to prevent erosion and ensure stability of these roads and associated infrastructure if or when the water level is raised above 19.0 mAHD. Figure 4 shows the relationship between capacity and elevation. Almost half of the total basin capacity is located between 19.0 and 19.7 mAHD. Therefore, limiting the operational height to 19.0 mAHD would severely limit the operational capacity of the basin.

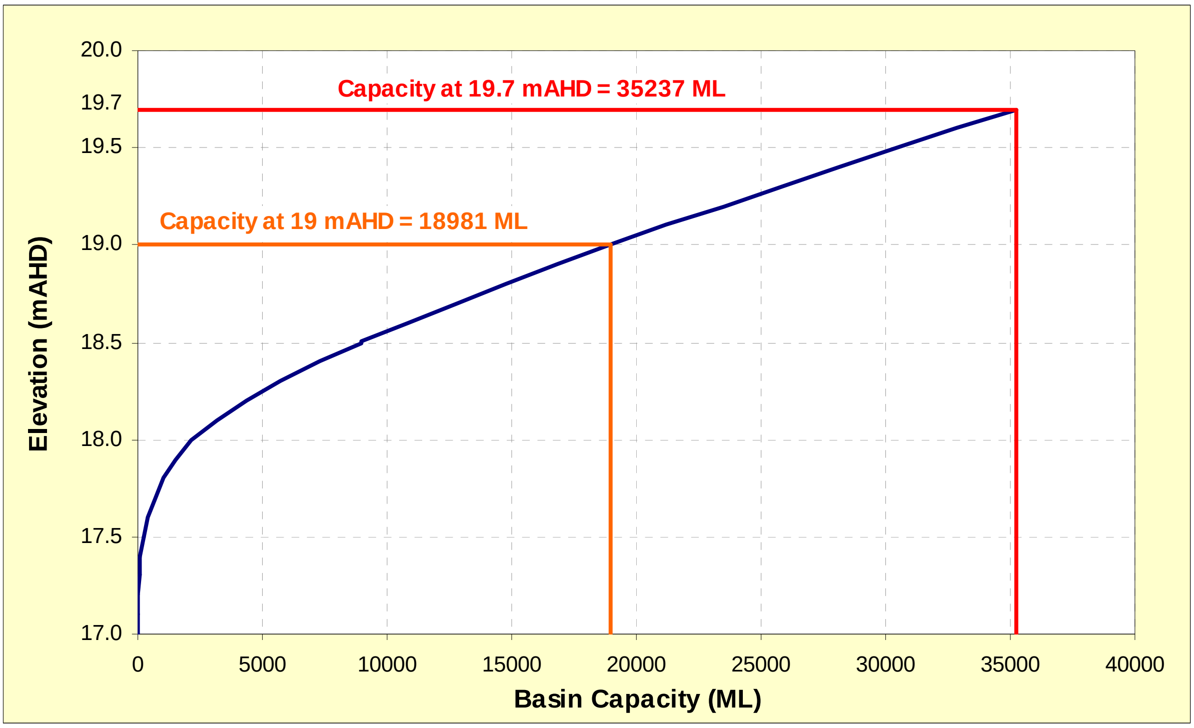


Figure 4 Variation of Basin Capacity with Elevation.

2.1.2 Intra-Basin Connectivity

The Government-owned land within the Noora Basin can be divided into four discrete sub-basins, separated by the two roads running north-south and other east-west, as shown in Figure 5. These sub-basins are linked by four culverts, flow through which can be blocked using stop-logs. The discharge point of water pumped to the basin is located at the north western corner in sub-basin 1. Historically, the volumes of disposal water have only been sufficient to fill sub-basin 1 and partially fill sub-basin 3 to a level of approximately 18.6 mAHD). The capacities of each sub-basin, to the maximum operating level of 19.7 mAHD, was evaluated and are shown in Table 1. These values indicated that the capacities of sub-basins 1 and 2 are low in comparison to the overall basin capacity.

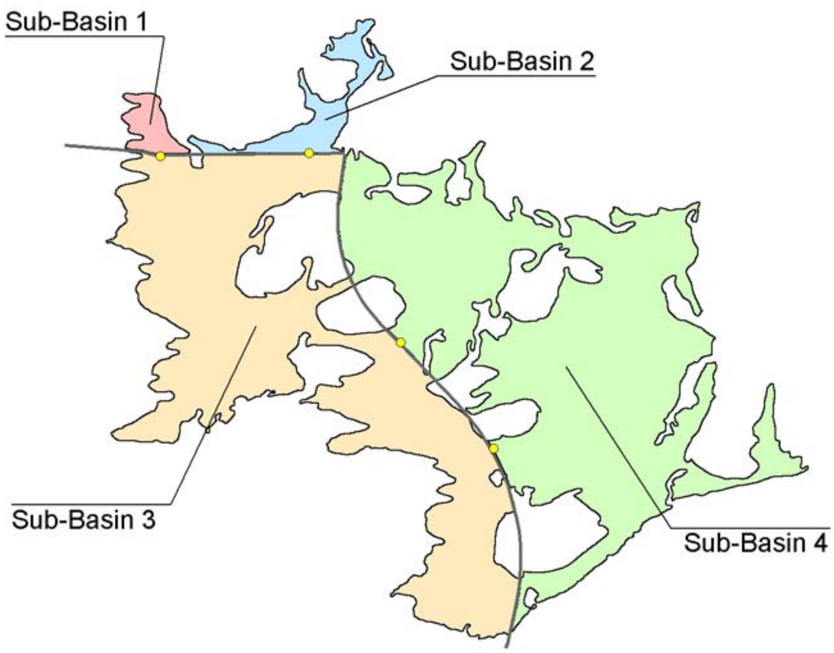


Figure 5 Noora Sub-Basins.

Table 1 Noora Sub-Basins: Capacity and Maximum Inundation Areas (19.7 mAHD).

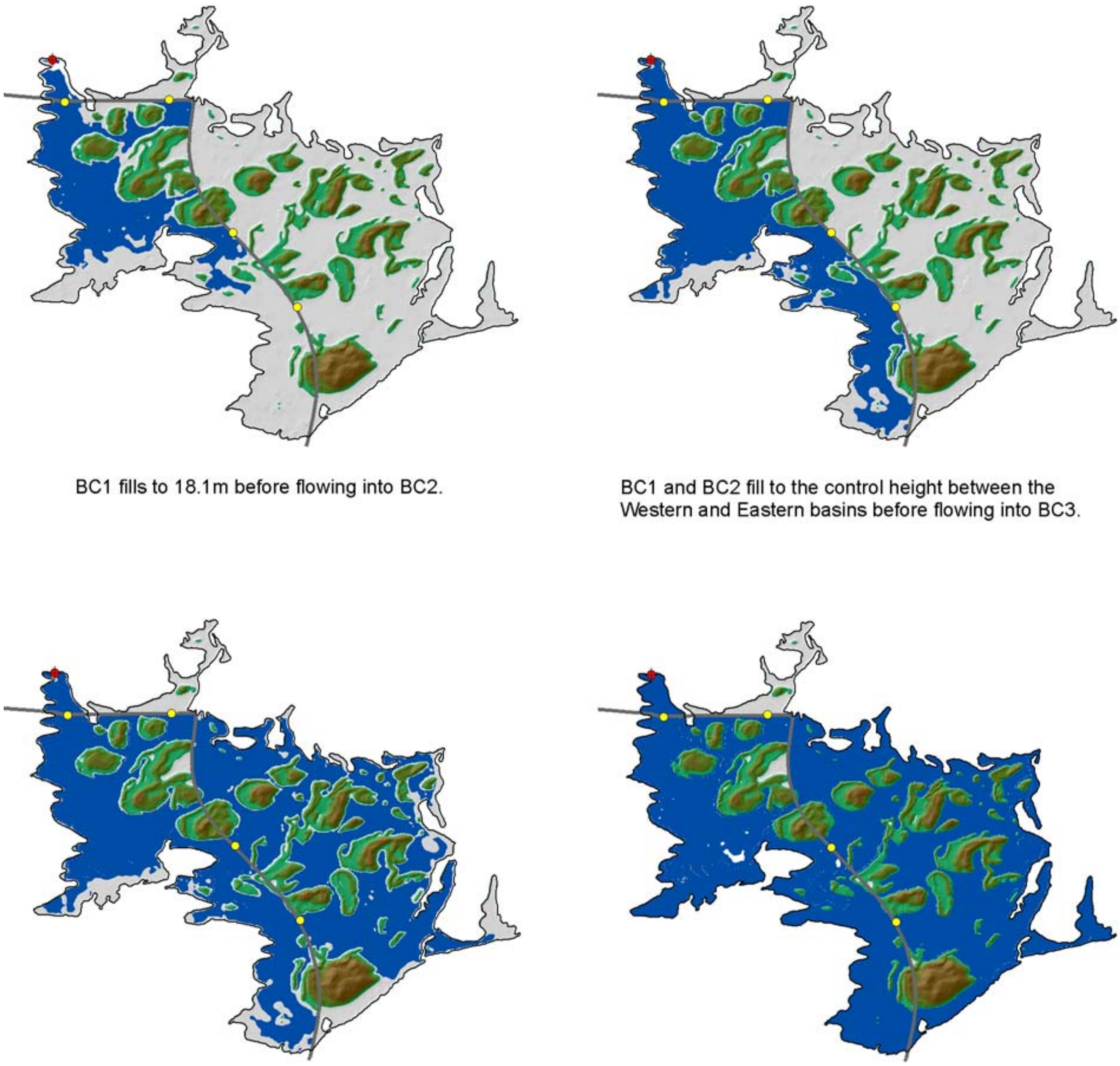
Sub-Basin	Capacity (ML)	Inundation Area (Ha)
1	600	40
2	1252	89
3	16588	1080
4	16797	1202
Total	35237	2411

The proposed pumping volumes during the first year of basin operation (refer Section 3.1) are six times that required to fill sub-basin 1 to 19.7 mAHD. Therefore, without a specific purpose for maintaining a water level variation between sub-basins 1 and 3, there is little benefit in using stop-logs to control water interchange between the two. Hence, sub-basins 1 and 3 were combined and evaluated as one area.

Sub-basin 2 is adjacent to the low-lying land described in Section 2.1.1. Because of its low capacity, there is little advantage to the basin management strategy by storing water or any real disadvantage by not storing water in this sub-basin. Recent photos of the culvert separating sub-basin 2 and 3 indicated that the pipe is blocked by a steel plate. Therefore, it is recommended that this remains in place, and the model developed here has excluded sub-basin 2. Not storing water here may also lessen the impact of groundwater level rises in the adjacent northern low-lying area.

2.1.3 Modelled Basin Representation

Topography and the roads and culverts within the basin combine to define where discharges are stored and the extent of inundation. The areas within sub-basins 1, 3 and 4 were represented as a series of four storages that sequentially fill as shown in Figure 6. These storages have been defined as Basin Combination 1 to 4 (BC1 to BC4). A natural contour at 18.1 mAHD defines the extent of BC1 and the north-south road the extent of BC2. The maximum water level within BC2 before flow into BC3 occurs is defined by a control height. This control height is defined by the stop-logs in front of the culverts, which in Figure 6 has been set at 18.6 mAHD. Once flow into BC3 occurs, the extent of inundation is restricted by the natural contour at 18.7 mAHD. BC4 is constrained at 19.7 mAHD.



BC1 fills to 18.1m before flowing into BC2.

BC1 and BC2 fill to the control height between the Western and Eastern basins before flowing into BC3.

BC1 and BC2 fill to the control height between the Western and Eastern basins and BC3 fills to 18.7m before flowing into BC4.

BC1 to BC4 filled to capacity at 19.7m.

Figure 6 Increasing Inundated Area as Basin Area Combinations Sequentially Fill.

In order to model the sequential filling and spilling of BC1 to BC4, these four storages were represented conceptually as shown in Figure 7, with a control height of 18.6 mAHD. Representation in this way allowed the straightforward calculation of infiltration, rainfall and evaporation volumes, and hence an accurate conservation of water and salt, within a relatively simple monthly water balance model as described in Section 2.2.

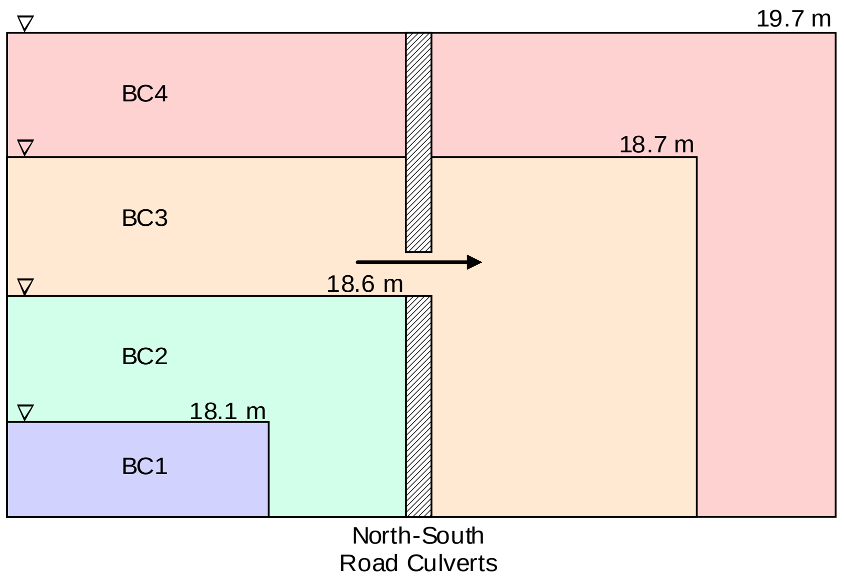


Figure 7 Model Conceptualisation of Noora Basin Storage.

2.2 MODEL DEFINITION

A monthly salt-water balance model was developed with the water budget described using the following:

$$V_{(t)} = V_{(t-1)} + Q_{(t)} + P_{(t)} - E_{(t)} - I_{(t)} \quad (1)$$

$$S_{(t)} = S_{(t-1)} + S_{Q(t)} - S_{I(t)} \quad (2)$$

where:

$V_{(t)}$	=	Volume of entire basin at the end of the month
$V_{(t-1)}$	=	Volume at the end of the previous month
$Q_{(t)}$	=	Discharge into basin for the month
$P_{(t)}$	=	Mean monthly rainfall
$E_{(t)}$	=	Mean monthly evaporation
$I_{(t)}$	=	Infiltration or seepage occurring at the water-soil interface
$S_{(t)}$	=	Salt in basin at the end of the month
$S_{(t-1)}$	=	Salt in basin at the end of the previous month
$S_{Q(t)}$	=	Salt contained in discharged volume
$S_{I(t)}$	=	Salt contained in infiltration volume

To calculate the change in volume due to rainfall, evaporation and leakage, the change in water level ($P_{(t)}$ - $E_{(t)}$ - $I_{(t)}$) was determined first. As described above, Noora Basin is not an idealised, single basin but rather a series of inter-connected sub-basins that are being modelled as sequentially filling storages. Therefore, an increase in water level from one month to the next may push water into a subsequent storage or a decrease in water level may result in the disconnection of the Western and Eastern basins, which required evaluation.

The resulting water level change on each basin combination was evaluated individually, and the volume to height relationship (refer Section 2.1.1) was then used to determine the change in volume. This was important to ensure that the amounts of evaporation, infiltration and rainfall were correctly calculated; the definition of these parameters and their application is described further in the following sections.

2.2.1 Pumping Volumes

A pumping schedule was supplied for each of the operational and proposed Salt Interception Schemes, which was converted to input volumes. It was assumed that the pumping rates remain constant within a month and there are no seasonal variations. The pumping schedule is detailed in Section 3.1.

For model calibration and validation (Section 2.3), volumes pumped at irregular intervals were supplied, which were redistributed to give monthly totals. A constant pumping rate was assumed between pump readings.

2.2.2 Climatological Data

Rainfall data from the Taldra (Renmark) Bureau of Meteorology station (M024017) was used in this investigation. Monthly averages for the period 1982 to 2004 are given in Table 1. Rainfall is only assumed to contribute to the water balance if it falls on the wetted surface of the basin itself. Rain falling on bare soil is assumed to be lost to either evaporation or infiltration. This was considered a reasonable approximation, particularly given the low annual rainfall at the basin.

Evaporation data from the station location at Lake Victoria (A4260904) was used and the monthly averages for the period 1982 to 2004 are also given in Table 2. An evaporation pan factor of 0.65 was used to adjust the recorded data. The evaporation rate was also adjusted based on the salinity of the evaporating water (refer Section 2.2.4)

Table 2 Climate Averages for Noora Basin (1982-2004).

Month	Rainfall (mm)	Evaporation (mm)
Jan	15	307
Feb	17	259
Mar	14	219
Apr	18	131
May	26	76
Jun	28	53
Jul	26	56
Aug	27	83
Sept	28	123
Oct	29	188
Nov	20	238
Dec	18	284
Annual	**266**	**2018**

2.2.3 Infiltration

Previous modelling studies by SKM (2005) and AWE (2003) as part of the Stage 3 Regional Disposal Strategy calculated estimates of basin seepage rates from a minimum of 0.1 mm/day to a maximum of 0.4 mm/day. Brief summaries of these studies are provided in Hodgkin *et al*. (2007). Hodgkin *et al*. (2007) also includes calibration of the groundwater model to observed groundwater level changes in surrounding monitoring wells and has determined a typical infiltration rate of about 0.2 mm/day. Basin leakage was therefore modelled using 0.2 mm/day and the model sensitivity to this leakage parameter was also assessed. The model assumes that the seepage rate remains constant over time.

2.2.4 Salt

Significant volumes of salt will enter the basin with both the drainage and SIS discharges. Sodium chloride was assumed to be the primary constituent for calculating saturation concentration. It is likely that a salinity gradient will form across the basin, with lower salinities at the discharge point in the north-west corner increasing to saturation concentrations to the south and east. Such a system is difficult to model, particularly with limited data. Therefore, a simplified system has been modelled, where the water and salt have effectively been modelled separately. The density of the saline water has not been adjusted for the salt content, but at the end of each month the total volume stored is equal to the sum of the volume of water and the volume of precipitated salt.

The model conceptualises the basin as a series of four storages that sequentially fill. For the purpose of salt accounting only two storages are considered, the Western and Eastern Basins. The Western Basin was assumed to fill to the level of the stop-logs controlling flow

(18.6 mAHD) from the western to the eastern side before flow into the Eastern Basin begins. Once this occurs, the less saline incoming water was assumed to 'push' more saline water through the culverts on the north-south road into the Eastern Basin. As such, the Eastern Basin will likely develop much higher salinities than the Western Basin.

Sodium chloride has a saturation concentration of about 260,000 mg/L. It has been assumed that any excess salt will be precipitated such that the maximum concentration of the water will be 260,000 mg/L. To take into account the salinity gradient, Equation 2 was applied to the Western and Eastern Basins individually, accounting for the total volume of water and tonnes of salt stored in each basin at a particular time. From this, the excess salt not retained in solution was estimated.

SKM (2005) assumed the specific gravity of precipitated salt to be 1.25 gcm^{-3} but there is no reference to the source of this value. Sources including Lide *et al*. (2004) show the specific gravity of precipitated sodium chloride to be 2.165 gcm^{-3} and this value has been assumed here. In order to determine the total volumes of water and salt stored, the 'equivalent volume' of tonnes of salt stored is calculated using this specific gravity. This means that a volume of 1,000 ML will store 2.165 million tonnes of precipitated salt and hence 2.165 million tonnes of precipitated salt has an equivalent volume of 1,000 ML.

Evaporation rates decline with increasing water salinity. Figure 8 shows the relationship used by SKM (2005). The model has assumed that the discharges contain only sodium chloride. Therefore, the relationship shown in Figure 8 was only applied up to a salinity of 260,000 mg/L and the corresponding evaporation factor of 0.7. This evaporation factor was applied after the evaporation pan factor.

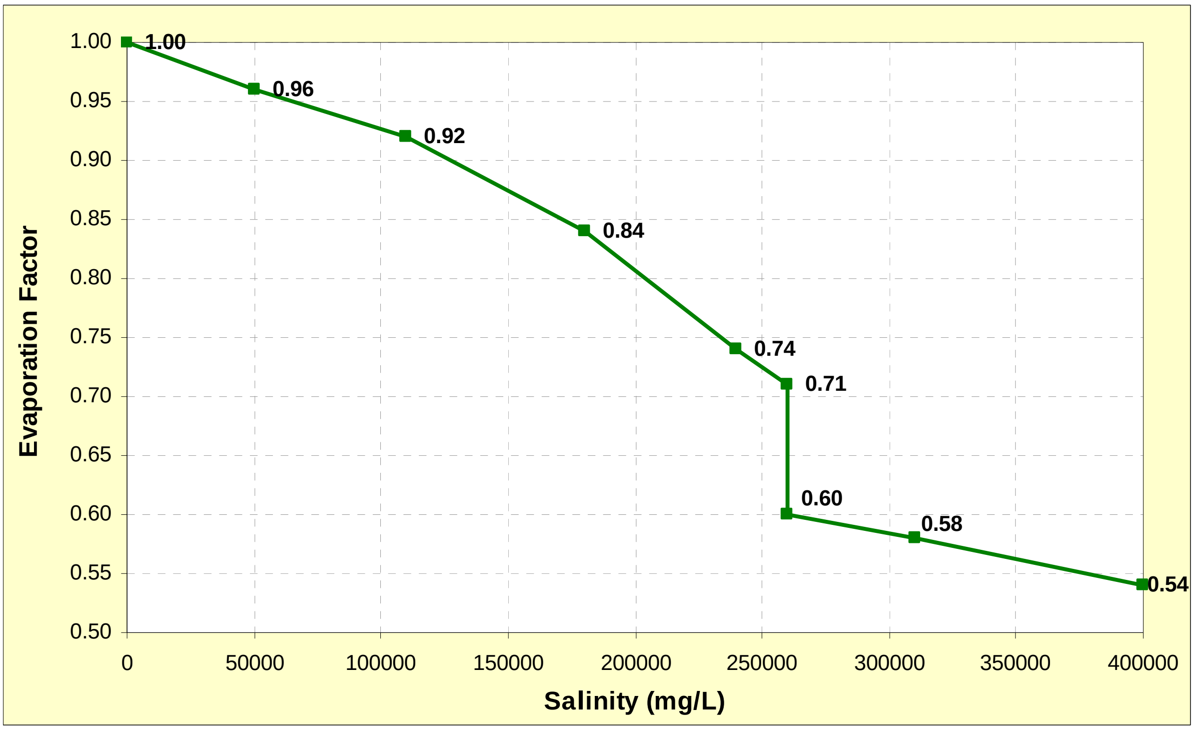


Figure 8 Relationship Between Salinity and Evaporation (from SKM, 2005).

2.3 MODEL CALIBRATION AND VALIDATION

Calibration of the evaporation pan factor and general model validation was undertaken by comparing recorded water level data for Noora and the volumes of drainage water pumped from the Disher Creek and Berri pump stations (provided by Ross Stockdale, DWLBC, Berri).

As described in Section 2.1.2, discharges historically occurred into sub-basin 1, which then flowed into sub-basin 3. A culvert with stop-logs maintained higher water levels in sub-basin 1 and the height of these stop-logs varied. Sub-basin 1 is relatively small and the resolution of the DTM precluded modelling this explicitly. Therefore, the historical sub-basins 1 and 3 were combined and the model run assuming a single basin. Calibration was made by comparing the modelled water levels to the observed data from sub-basin 3.

While there was 20 years of water level data, it was not continuous and limited information was available as to the height of the stop-logs between the basins at any particular time. The volumes pumped were estimated from the records of pump operating hours and then the total volume was corrected depending on the number of pumps operating during that time. The estimated volumes were available at irregular intervals and were redistributed to give monthly totals. Only annual pumping data were available prior to 1992. The nature and quality of the available data made the calibration and validation process difficult. Using observed evaporation and rainfall data for the period 1994 to 2002, an evaporation pan factor value of 0.65 was found to give the best results. Figure 9 shows the calibration and validation results. Increasing or decreasing the pan factor increases and decreases the modelled curve. Considering the assumptions made in the basin model and the quality of the data, the results were considered reasonable.

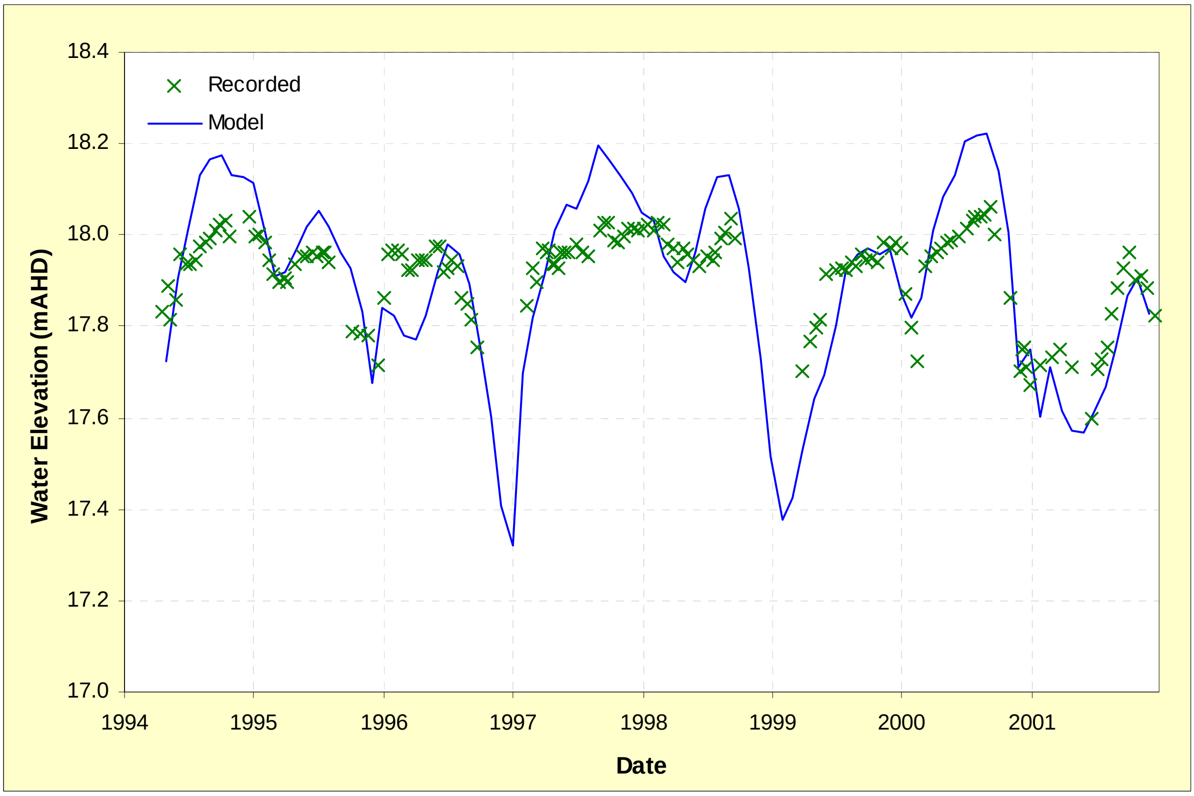


Figure 9 Model Validation Results (1994 to 2001).

3. MODEL SCENARIO EVALUATION

The primary objective of this investigation is to assess the capability of Noora Basin to accept increased discharge volumes and salinities over the next 100 years (2006 to 2106). In the following sections, the potential volumes and salinities of drainage and SIS water are provided and then the scenarios are evaluated, in particular:

- Scenario 1: Drainage, and Loxton, Bookpurnong and Murtho SIS disposal.
- Scenario 2: Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS disposal.
- Scenario 3: Variation in pumping rates to achieve targeted operational levels.

The projected maximum inundated areas and the influence that salt precipitation is likely to have in terms of total area inundated were determined and mapped for a number of discrete time periods within each scenario, allowing a visual assessment of inundation extent during the initial, middle and latter stages of the 100-year basin operation. In the absence of engineering works, the maximum operating level is assumed to be 19.0 mAHD (refer Section 2.1). A sensitivity analysis of the results to model parameters has also been undertaken with realistic bounds placed on these parameters.

3.1 VOLUMES AND SALINITIES OF DRAINAGE AND SIS WATER

Disposal of drainage water from the Renmark and Berri irrigation areas has occurred since 1982, although increasing irrigation efficiency has reduced the amount of excess water discharged in recent years. Volumes pumped to the basin have decreased from a peak discharge of 6,000 ML/year in 1982-83 to generally less than 2,000 ML/year since 2000-01. Figure 10 shows the total volumes pumped to Noora Basin since 1982-83.

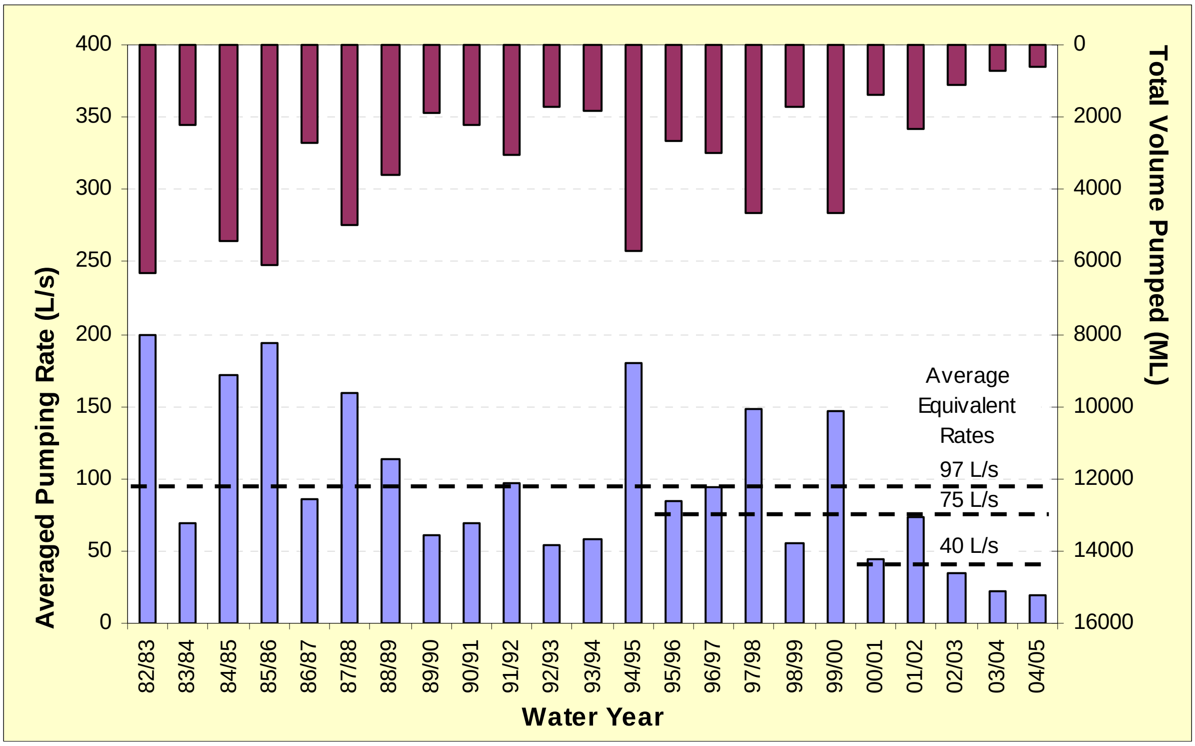


Figure 10 Noora Basin Historical Drainage Pumping Rates and Volumes.

The non-uniform nature of the drainage volumes pumped has necessitated an estimation of an equivalent continuous volume or average equivalent pumping rate. This equivalent average pumping rate was determined, equating to these volumes pumped continuously over each year. Hence, rates for short periods may be greater than those shown.

The average equivalent pumping rate from 1982 to 2005 was 97 L/s. However, the decrease in volumes pumped is clearly shown in Figure 10 and, if this trend continues, the total volumes stored in the basin and hence the maximum ponded water levels may be significantly less than those estimated if this average value is used. Such overestimates may lead to increased engineering works to ensure the stability of roads and associated infrastructure than would otherwise be needed. Therefore, more recent volumes pumped to the basin were evaluated to determine alternative values that are representative of current pumping rates.

The average equivalent pumping rate since 1995-96 has been 75 L/s, and since 2000-01 has reduced further to 40 L/s. This 40 L/s rate is considered the more realistic, maximum future rate for the combined pumping of drainage water from Disher Creek (Renmark irrigation water) and Berri. Some suggestion as to the ability of Noora to accept water from the Katarapko Island Evaporation Basin was initially considered but future pumping from this basin is considered unlikely (A. Searle, DWLBC, *pers. comm.*, 2006). Therefore, during the evaluation of the operational capacity of Noora Basin, the 40 L/s equivalent pumping rate has been defined as the future drainage pumping rate. It is again emphasised that this rate will be applied continuously over the period of basin operation. In reality, higher rates may be applied over shorter periods but the total volumes pumped are equivalent.

Water is stored in the Disher Creek and Berri Evaporation Basins before being pumped to Noora. The salinities of the water pumped from these basins have ranged from 3,000 to 37,000 mg/L. Recently, the lower volumes of drainage water pumped have been of higher salinities due to increased evapo-concentration within the basins before pumping. However, due to the lower volumes pumped, the overall salt loads pumped to the basin have been lower. The total salt pumped to Noora Basin since 2000-01 has been estimated at around 150,000 tonnes. To pump this salt load at the average equivalent rate of 40 L/s requires an average equivalent salinity of 19,000 mg/L. This value was assumed as the future drainage salinity during the evaluation of the operational capacity of Noora Basin.

At 40 L/s, the total volume of drainage pumped between 2006 and 2106 would be 127 GL with a salt load of 2.42 million tonnes.

Table 3 presents the proposed sequence of pumping rates over the period 2006 to 2106. It has been assumed that the pumping rates proposed will remain constant within each month and that there are no seasonal variations. The SIS pumping rates required have been determined from detailed groundwater modelling and these rates need to be maintained for the schemes to be successful. For example, the Bookpurnong scheme should pump at a constant rate 86 L/s during 2006 and 2007, 47 L/s from 2008 to 2010, 39 L/s from 2010 to 2012 and so on. The ability of the basin to meet the demands of all inflow sources is crucial to the long-term viability of proposed SIS disposals.

The salinity of discharge from each SIS has been assumed to be at a constant level of 26,000 mg/L. This average was assigned after considering the flow-rate weighted salinities provided in the various SIS groundwater models, which typically range between 24,000 and 29,000 mg/L for individual schemes. For the associated pumping rate, Table 4 shows the total salt pumped to Noora during each year.

Table 3 Proposed Maximum Future Drainage and SIS Pumping Rates.

Year	Drainage (L/s)[1]	Salt Interception Schemes				Total Inflow (L/s)	Total Inflow (ML/yr)
		Bookpurnong[2] (L/s)	Loxton[2] (L/s)	Murtho[3] (L/s)	Pike[3] (L/s)		
2006	40	86	-	-	-	126	3974
2008	40	47	123	-	-	210	6623
2010	40	39	79	50	-	208	6559
2012	40	36	68	48	61	253	7979
2014	40	39	64	48	56	247	7789
2020	40	48	59	50	56	253	7979
2030	40	54	57	58	63	272	8578
2040	40	57	57	69	60	283	8925
2050	40	59	58	75	70	302	9524
2060	40	60	59	81	79	319	10060
2070	40	61	60	92	84	337	10628
2080	40	61	61	107	88	357	11258
2090	40	61	62	116	91	370	11668
2100	40	62	63	125	93	383	12078
2106	40	62	63	128	94	387	12204

1 Drainage water comprises Disher Creek and Berri

2 Loxton and Bookpurnong Groundwater Model (Yan *et al.*, 2005)

3 Pike and Murtho Groundwater Model (Yan *et al.*, 2006)

Table 4 Total Salt Pumped Annually to Noora for Proposed Drainage and SIS Pumping Rates.

Year	Total Inflow (L/s)	Total Inflow (ML/yr)	Total Salt Inflow (tonnes/yr)
2006	126	3974	94482
2008	210	6623	163356
2010	208	6559	161717
2012	253	7979	198614
2014	247	7789	193694
2020	253	7979	198614
2030	272	8578	214193
2040	283	8925	223212
2050	302	9524	238791
2060	319	10060	252730
2070	337	10628	267488
2080	357	11258	283887
2090	370	11668	294546
2100	383	12078	305205
2106	387	12204	308485

3.2 SCENARIO 1: DRAINAGE, AND LOXTON, BOOKPURNONG AND MURTHO SIS PUMPING

Scenario 1 consists of the combined drainage and Loxton, Bookpurnong and Murtho SIS pumping option. A sensitivity analysis then considers variations to three key model parameters:

- Evaporation Coefficient: This has been varied by around ±15% and is considered to effectively include variations in rainfall.
- Infiltration Rate: Lower bound of 0.1 mm/day and upper bound of 0.4 mm/day, adapted from previous model studies. Although the infiltration rate represents another loss parameter, this was required to be evaluated separately because salt is also transported from the basin during this process.
- SIS Salinity: Assume to vary by about ±15%.

Table 5 shows the parameters used for the primary analysis (1A) and the sensitivity analysis (1B to 1G). All other parameters remain constant in each scenario and it has been assumed that the stop-logs separating the Eastern and Western basins are maintained at 18.6 mAHD.

Table 5 Scenario 1: Primary Option and Sensitivity Analysis Parameters.

ID	Evaporation Coefficient	Infiltration (mm/day)	SIS Salt Concentration (mg/L)
1A	0.65	0.2	26000
1B	0.55	0.2	26000
1C	0.75	0.2	26000
1D	0.65	0.1	26000
1E	0.65	0.4	26000
1F	0.65	0.2	22000
1G	0.65	0.2	30000

3.2.1 Primary Analysis (Scenario 1A)

The model indicates that there is sufficient capacity within Noora Basin to accept the proposed drainage and Bookpurnong, Loxton and Murtho SIS pumping rates. These rates equate to a volume pumped of 747 GL with a salt load of 18.5 million tonnes from 2006 to 2106. Table 6 shows the maximum water levels reached within the basin, indicating that a ponded water level of 18.6 mAHD in the Western Basin and around 18.5 mAHD in the Eastern Basin is likely. Table 7 shows the likely salt properties in the Western and Eastern Basins. At the maximum water level and inundated area, 5.3 million tonnes of precipitated salt with an equivalent volume of 2,432 ML are stored in the Eastern Basin.

Table 6 Maximum Water Levels, Stored Volume and Inundated Areas: Drainage and Loxton, Bookpurnong and Murtho SIS (Scenario 1A).

Period	Maximum Water Level (mAHD)		Total Volume (ML)	Total Inundated Area (Ha)
	Western Basin	Eastern Basin		
2006-2010	18.39	-	4110	790
2011-2020	18.47	-	4749	825
2021-2050	18.60	18.01	6481	1205
2051-2075	18.60	18.20	7346	1433
2076-2106	18.60	18.47	9277	1694

Table 7 Maximum Salt Concentration, Precipitated Salt and Reduced Storage: Drainage and Loxton, Bookpurnong and Murtho SIS (Scenario 1A).

Period	Western Basin			Eastern Basin		
	Maximum Concentration (mg/L)	Precipitated Salt (million tonnes)	Reduced Storage (ML)	Maximum Concentration (mg/L)	Precipitated Salt (million tonnes)	Reduced Storage (ML)
2006-2010	197021	-	-	-	-	-
2011-2020	260000	0.048	62	-	-	-
2021-2050	260000	0.215	99	260000	0.593	263
2051-2075	260000	0.043	20	260000	2.173	988
2076-2106	232016	-	-	260000	5.345	2432

Under Scenario 1A, flow into the Eastern Basin is unlikely until September 2035. Therefore, under the model formulation, precipitation in the Western Basin is likely until the higher salinity water is pushed through to the Eastern Basin. Concentrations in the Western Basin reach saturation within 10 to 15 years, but the basin inflows are not high enough to significantly reduce the salinity of the Western Basin once flow to the Eastern Basin occurs.

Figure 11 shows the changing salt-adjusted water levels in the Eastern and Western Basins. This indicates that although the Western Basin reaches 18.6 mAHD around September 2035 and flow into the Eastern Basin subsequently begins, evaporation and infiltration losses are greater than rainfall and inflow such that storage is limited and the water level does not begin to rise until around five years later. By 2106, the water level has not reached 18.6 mAHD.

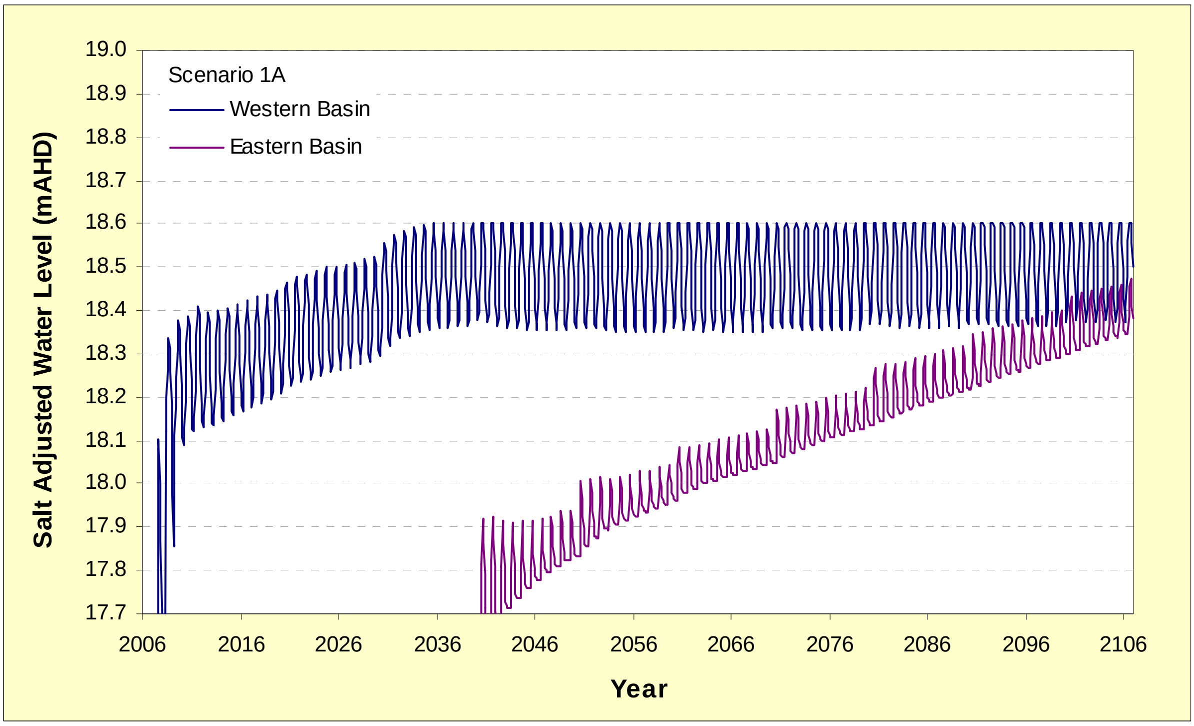


Figure 11 Salt-Adjusted Water Level: Drainage, and Loxton, Bookpurnong and Murtho SIS.

Figure 12 shows the stored volumes between 2006 and 2106. These indicate that without salt precipitation, the water level would only increase slowly after 2040, generally oscillating around a stored volume of 5,000 ML. However, the quantity of salt in the basin increases continuously, as does the amount of precipitated salt, its equivalent volume and hence the total volume stored (water and precipitated salt). This is depicted in the 'salt-adjusted' curve.

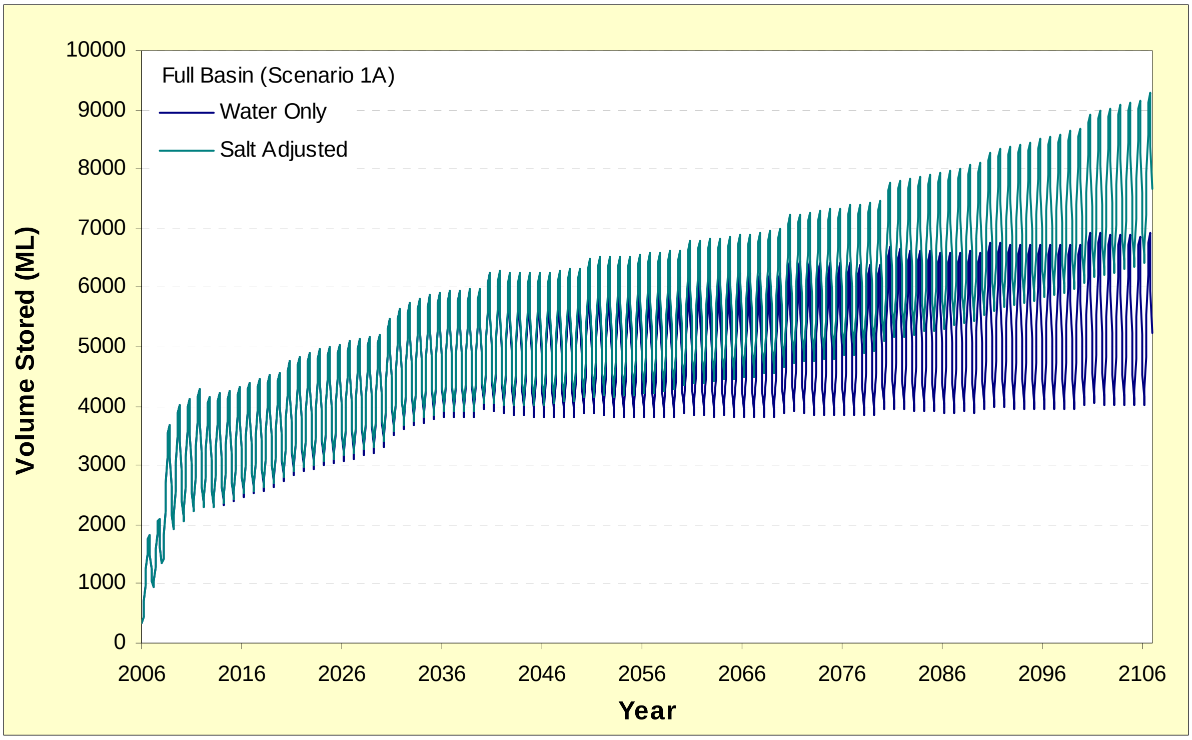


Figure 12 Total Stored Volume (Water and Precipitated Salt): Drainage, and Loxton, Bookpurnong and Murtho SIS.

Figure 13 shows the tonnes of salt stored in the Western and Eastern Basins, and Figure 14 shows the maximum annual salt concentrations from 2006 to 2106.

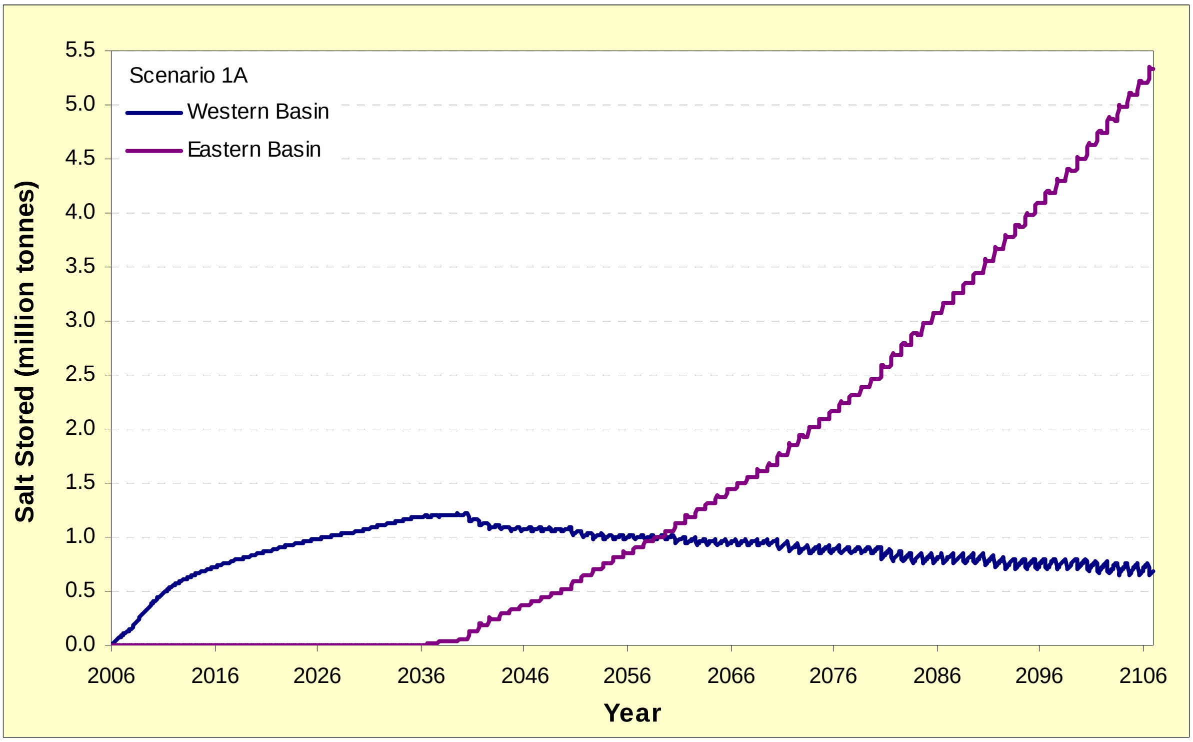


Figure 13 Total Stored Salt: Drainage, and Loxton, Bookpurnong and Murtho SIS.

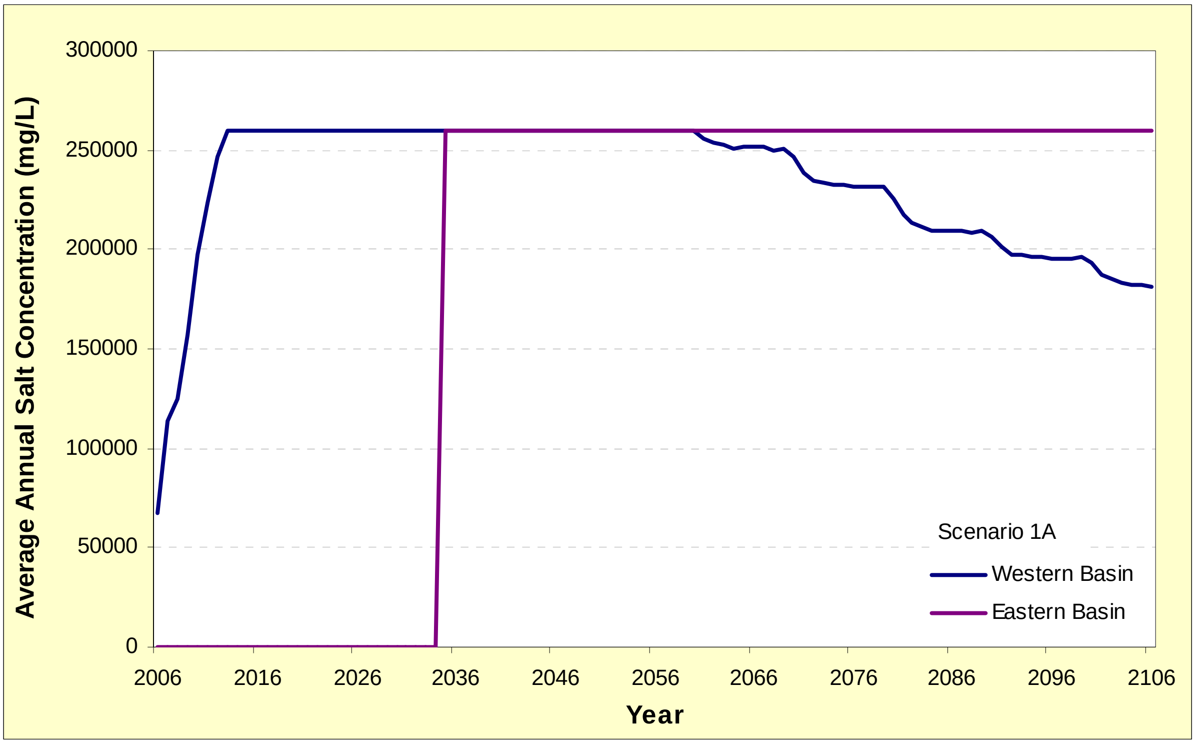
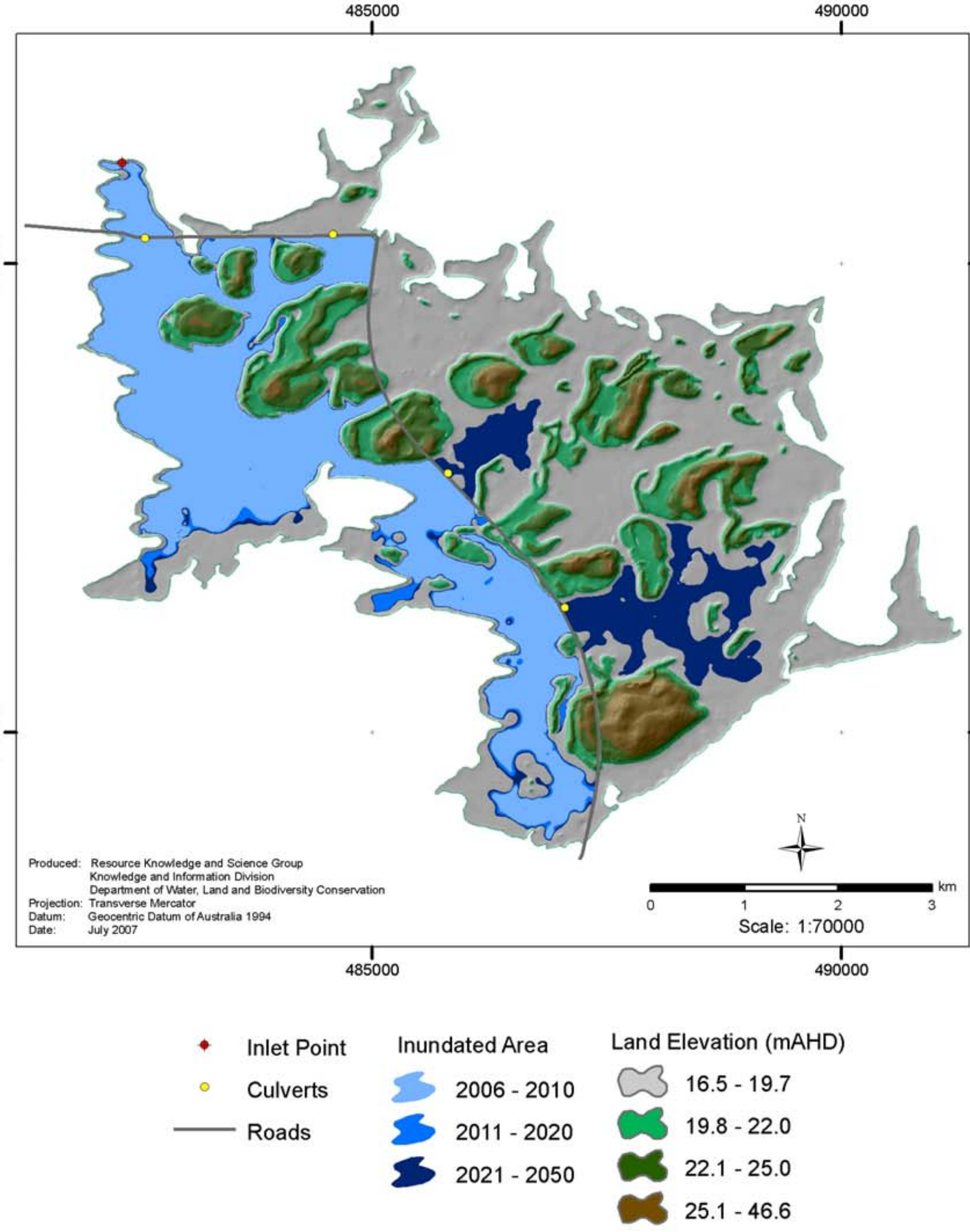


Figure 14 Annual Maximum Salt Concentration: Drainage, and Loxton, Bookpurnong and Murtho SIS.

Initially, all salt is stored in the Western Basin only and the concentration reaches saturation quickly. Once flow into the Eastern Basin begins, the assumption that less saline incoming water to the Western Basin will displace more saline ponded water to the Eastern Basin leads immediately to a stabilisation of the tonnes of salt stored. After a short time, the total salt stored and the salinity in the Western Basin should decrease. In the Eastern Basin, the salt stored increases rapidly and the saturation concentration is reached quickly and maintained. By 2106 it would be expected that the combined basins would store over 6.0 million tonnes of salt.

Figure 15 shows the projected increasing inundated areas for the periods 2006 to 2010, 2011 to 2020, and 2021 to 2050. The nature of the basin is such that there is little increase in inundated area as the level rises from 18.39 to 18.60 mAHD. It also highlights that flow into the Eastern Basin does not occur for at least 15 years.

Figure 16 then shows the projected increasing inundated areas from the extent at 2050, through the periods from 2051 to 2075, and 2076 to 2106. It can be seen that it is likely that large areas of the basin would not be inundated under Scenario 1A.

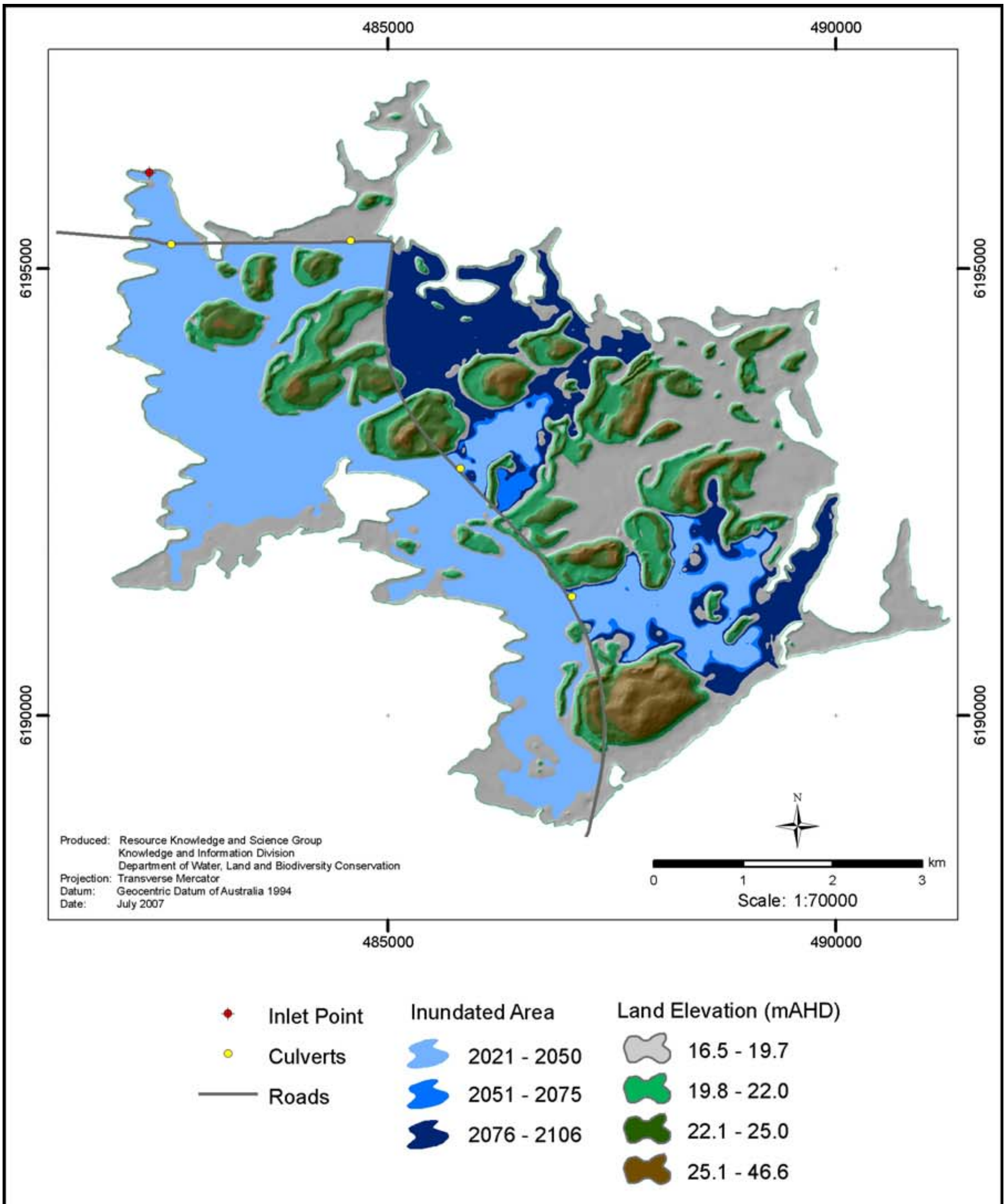


Maximum Water Levels, Stored Volume and Inundated Areas: Drainage and Loxton, Bookpumong and Murtho SIS (Scenario 1A)

Period	Maximum Water Level (mAHD)		Total Volume (ML)	Total Inundated Area (Ha)
	Western Basin	Eastern Basin		
2006-2010	18.39	-	4110	790
2011-2020	18.47	-	4749	825
2021-2050	18.60	18.01	6481	1205

Notes
Control Height between Western and Eastern Basins is 18.6 mAHD.

Figure 15 Noora Basin Projected Maximum Inundated Areas for 2006 to 2050: Drainage, and Loxton, Bookpurnong and Murtho SIS (Scenario 1A).



Maximum Water Levels, Stored Volume and Inundated Areas: Drainage and Loxton, Bookpumong and Murtho SIS (Scenario 1A)

Period	Maximum Water Level (mAHD)		Total Volume (ML)	Total Inundated Area (Ha)
	Western Basin	Eastern Basin		
2021-2050	18.60	18.01	6481	1205
2051-2075	18.60	18.20	7346	1433
2076-2106	18.60	18.47	9277	1694

Notes
Control Height between Western and Eastern Basins is 18.6 mAHD.

Figure 16 Noora Basin Projected Maximum Inundated Areas for 2050 to 2106: Drainage, and Loxton, Bookpurnong and Murtho SIS (Scenario 1A).

3.2.2 Sensitivity Analysis (Scenarios 1B to 1G)

The sensitivity of the model outputs to the evaporation coefficient, infiltration rate and SIS salt concentration were tested. In order to easily compare results, the maximum annual salt-adjusted water levels, stored volumes, total stored salt and salt concentrations were determined within each period and are presented in the following.

Evaporation Coefficient (Scenarios 1A, 1B and 1C)

The assumed evaporation coefficient of 0.65 was varied to 0.55 and 0.75. Table 8 shows the variation in maximum water levels and Table 9 the variation in maximum stored volume and inundated areas.

Table 8 Sensitivity of Maximum Water Levels to Evaporation Coefficient (E): Drainage, and Loxton, Bookpurnong and Murtho SIS.

Period	Maximum Western Basin Water Level (mAHD)		
	1A (E = 0.65)	1B (E = 0.55)	1C (E = 0.75)
2006-2010	18.39	18.50	18.34
2011-2020	18.47	18.60	18.37
2021-2050	18.60	18.60	18.58
2051-2075	18.60	18.60	18.60
2076-2106	18.60	18.62	18.60
Period	**Maximum Eastern Basin Water Level (mAHD)**		
	1A (E = 0.65)	**1B (E = 0.55)**	**1C (E = 0.75)**
2006-2010	-	-	-
2011-2020	-	17.78	-
2021-2050	18.01	18.18	-
2051-2075	18.20	18.37	18.05
2076-2106	18.47	18.62	18.34

Table 9 Sensitivity of Maximum Stored Volume and Inundated Areas to Evaporation Coefficient (E): Drainage, and Loxton, Bookpurnong and Murtho SIS.

Period	Total Volume (ML)		
	1A (E = 0.65)	1B (E = 0.55)	1C (E = 0.75)
2006-2010	4110	5039	3721
2011-2020	4749	6056	4002
2021-2050	6481	7238	5740
2051-2075	7346	8488	6650
2076-2106	9277	10747	8220
Period	**Total Inundated Area (Ha)**		
	1A (E = 0.65)	**1B (E = 0.55)**	**1C (E = 0.75)**
2006-2010	790	840	763
2011-2020	825	980	782
2021-2050	1205	1411	872
2051-2075	1433	1611	1263
2076-2106	1694	1785	1576

As was expected, the lower evaporation coefficient results in less evaporation and hence increased water levels over the period of basin operation. However, these results indicate that even if the evaporation rate has been overestimated, the resulting water levels are well below the maximum operating level of 19.0 mAHD. Conversely, if the evaporation coefficient has been underestimated, there is additional basin capacity available.

Figure 17 shows the changing salt-adjusted water levels in the Eastern and Western Basins for each scenario. This indicates that the water level in the Western Basin reaches 18.6 mAHD 15 years earlier with the reduced evaporation coefficient and 15 years later with the increased coefficient. Water level in the Eastern Basin increases at approximately the same rate in each case and only in Scenario 1C does it reach 18.6 mAHD (around 2100), from which point the water levels in both basins should be equal.

The effect of the changing evaporation coefficient on the total volume stored is then shown in Figure 18 and on the inundated area in Figure 19. The rate of increase of the total volume stored appears similar in each case. In comparison, although the increased evaporation coefficient slows the initial rate of increase in inundated area (by delaying flow into the Eastern Basin), by 2106 the curves can be seen to be converging. This is a product of the nature of the basin topography as shown in Figure 4. Large changes in total stored volume result in only small increases to inundated areas.

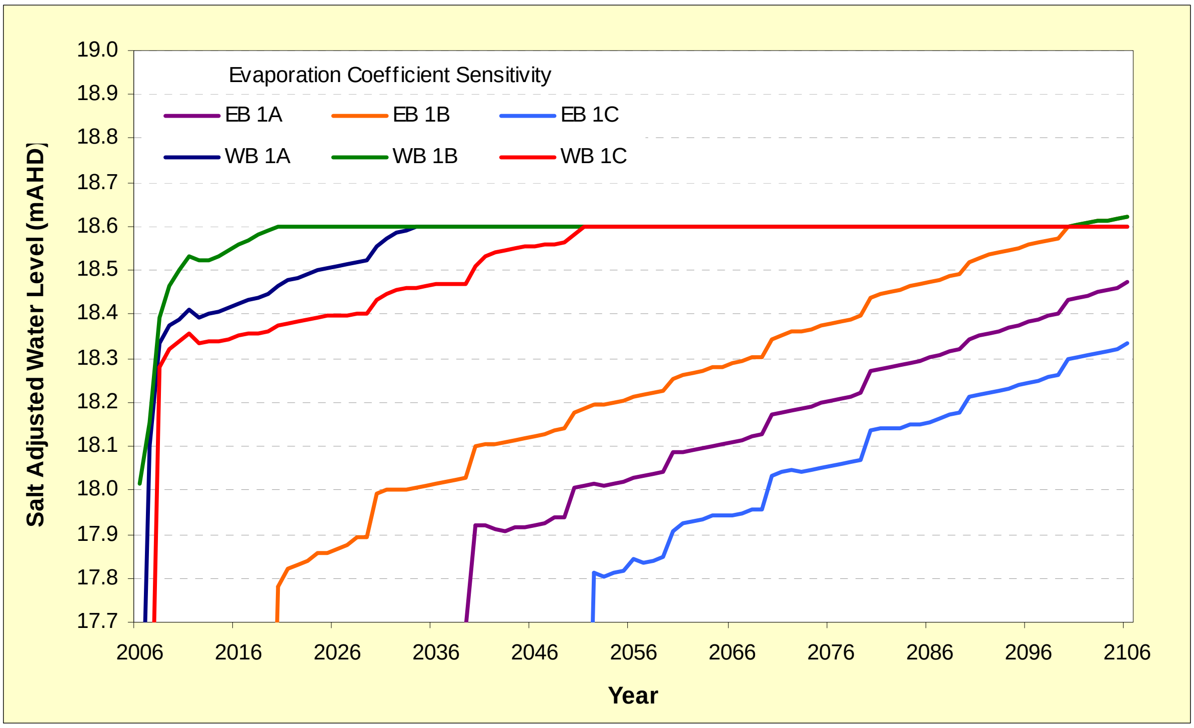


Figure 17 Sensitivity of Water Level to Evaporation Coefficient (E): Drainage, and Loxton, Bookpurnong and Murtho SIS.

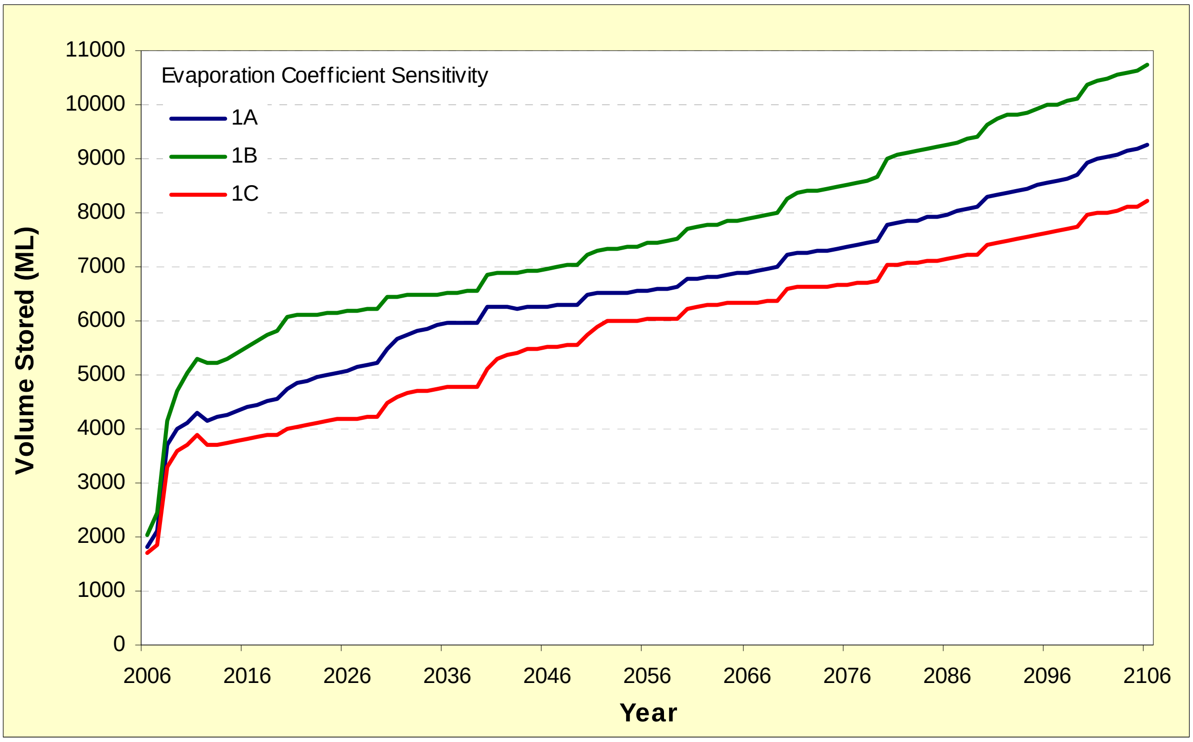


Figure 18 Sensitivity of Volume Stored to Evaporation Coefficient (E): Drainage, and Loxton, Bookpurnong and Murtho SIS.

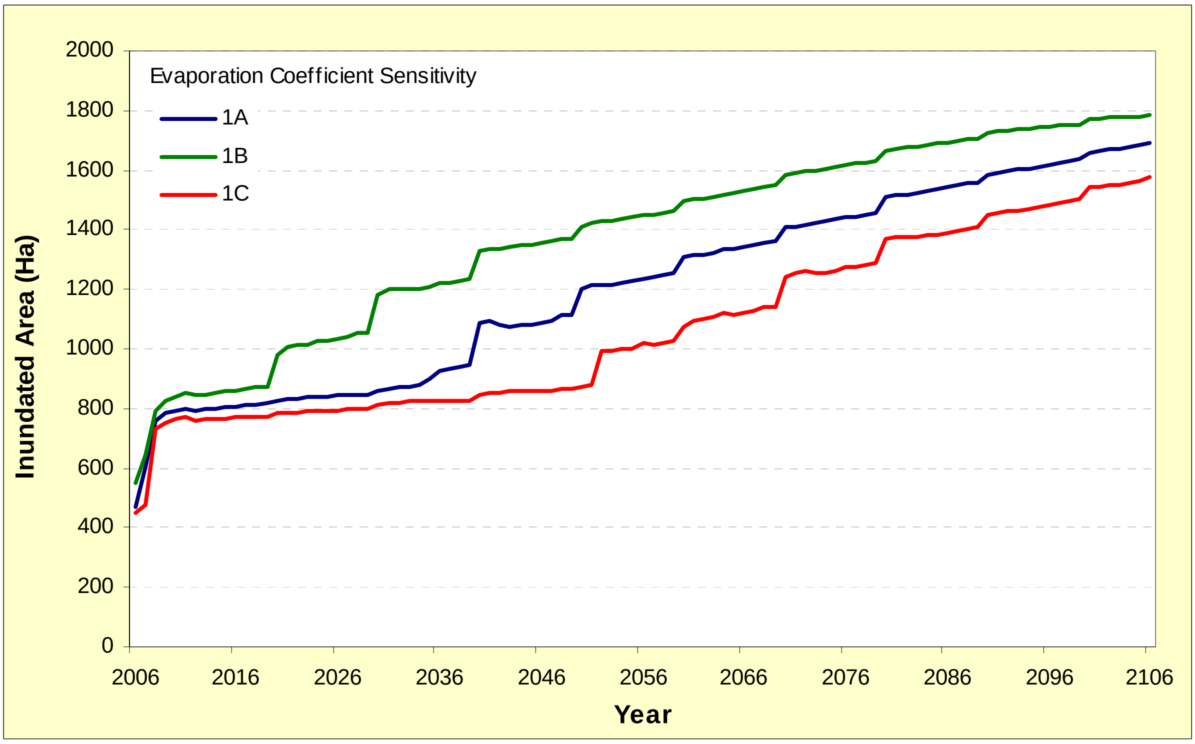


Figure 19 Sensitivity of Inundated Area to Evaporation Coefficient (E): Drainage, and Loxton, Bookpurnong and Murtho SIS.

Table 10 shows the likely levels of precipitated salt in the Western and Eastern Basins under each evaporation coefficient, and Table 11 provides the corresponding maximum salt concentrations. The lower evaporation coefficient leads to water moving into the Eastern Basin earlier, maintaining a lower salinity in the Western Basin and hence precipitation of salt is less likely to occur here. The increased evaporation coefficient results in a slower movement of salt from the Western to the Eastern Basin. Hence, precipitated salt is likely to occur in both basins over the operational life of the basin with salinities remaining at 260,000 mg/L.

At their maximum water level and inundated area, Scenarios 1A, 1B and 1C produce 5.3, 6.8 and 4.0 million tonnes of precipitated salt with equivalent volumes of 2,432, 3,130 and 1,850 ML.

Table 10 Sensitivity of Maximum Precipitated Salt to Evaporation Coefficient (E): Drainage, and Loxton, Bookpurnong and Murtho SIS.

Period	Maximum Western Basin Precipitated Salt (million tonnes)		
	1A (E = 0.65)	1B (E = 0.55)	1C (E = 0.75)
2006-2010	-	-	-
2011-2020	0.048	-	0.301
2021-2050	0.215	-	0.620
2051-2075	0.043	-	0.604
2076-2106	-	-	0.233
Period	**Maximum Eastern Basin Precipitated Salt (million tonnes)**		
	1A (E = 0.65)	**1B (E = 0.55)**	**1C (E = 0.75)**
2006-2010	-	-	-
2011-2020	-	0.018	-
2021-2050	0.593	1.518	-
2051-2075	2.173	3.546	1.125
2076-2106	5.345	6.777	3.772

Table 11 Sensitivity of Maximum Salt Concentration to Evaporation Coefficient (E): Drainage, and Loxton, Bookpurnong and Murtho SIS.

Period	Maximum Western Basin Concentration (mg/L)		
	1A (E = 0.65)	1B (E = 0.55)	1C (E = 0.75)
2006-2010	197000	145000	225000
2011-2020	260000	240000	260000
2021-2050	260000	203000	260000
2051-2075	260000	186000	260000
2076-2106	232000	150000	260000
Period	**Maximum Eastern Basin Concentration (mg/L)**		
	1A (E = 0.65)	**1B (E = 0.55)**	**1C (E = 0.75)**
2006-2010	-	-	-
2011-2020	-	260000	-
2021-2050	260000	260000	-
2051-2075	260000	260000	260000
2076-2106	260000	260000	260000

Figure 20 shows the salt stored in each basin and Figure 21 shows the maximum annual salt concentrations in the Western Basin. In each scenario, once flow into the Eastern Basin occurs, the salinity increases quickly to 260,000 mg/L, similar to Figure 14.

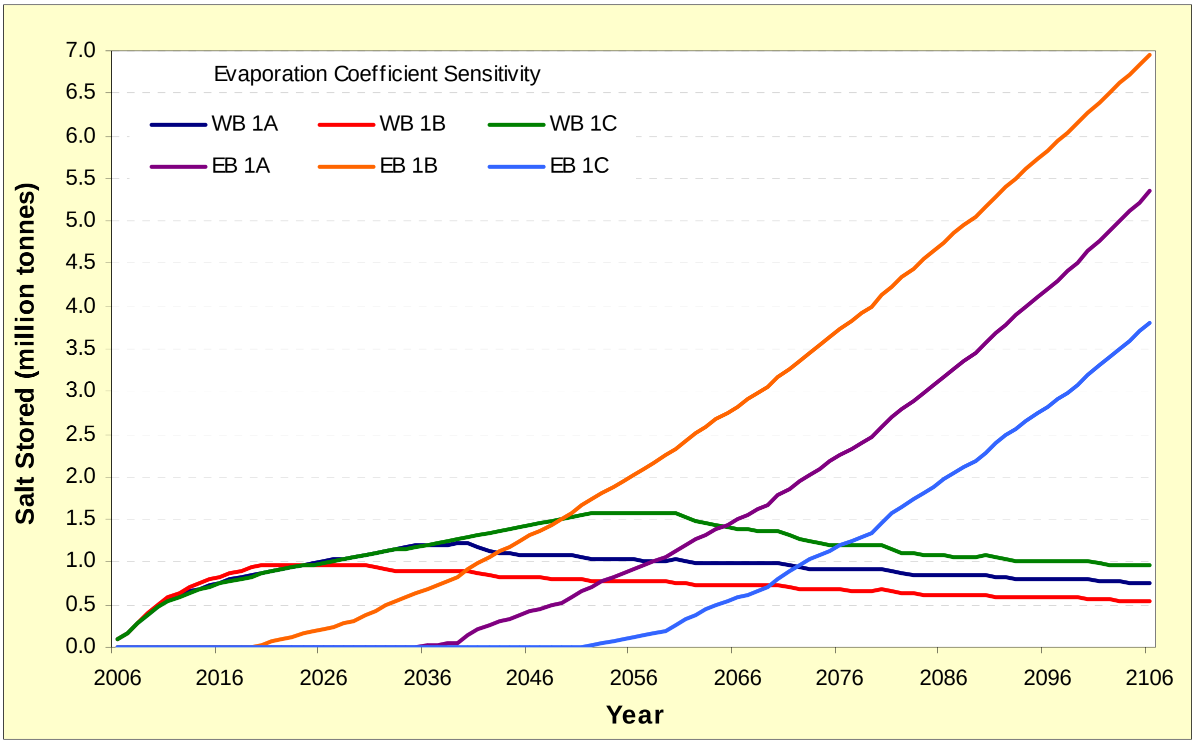


Figure 20 Sensitivity of Total Stored Salt to Evaporation Coefficient (E): Drainage, and Loxton, Bookpurnong and Murtho SIS.

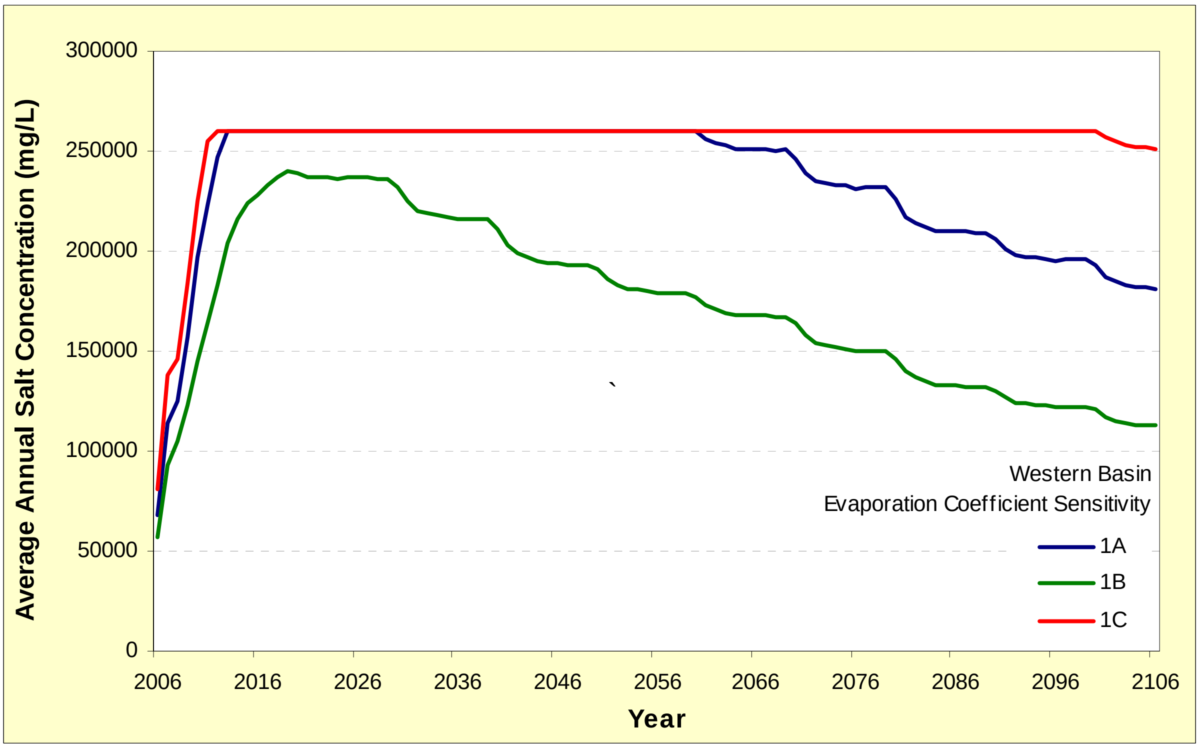


Figure 21 Sensitivity of Salt Concentration to Evaporation Coefficient (E): Drainage, and Loxton, Bookpurnong and Murtho SIS.

Infiltration Rate (Scenarios 1A, 1D and 1E)

The assumed infiltration rate of 0.2 mm/day was varied to 0.1 and 0.4 mm/day. Table 12 shows the variation in maximum water levels and Table 13 provides the variation in maximum stored volumes and inundated areas.

Table 12 Sensitivity of Maximum Water Levels to Infiltration Rate (I): Drainage, and Loxton, Bookpurnong and Murtho SIS.

Period	Maximum Western Basin Water Level (mAHD)		
	1A (I = 0.2)	1D (I = 0.1)	1E (I = 0.4)
2006-2010	18.39	18.43	18.34
2011-2020	18.47	18.60	18.34
2021-2050	18.60	18.60	18.44
2051-2075	18.60	18.60	18.57
2076-2106	18.60	18.69	18.60
Period	**Maximum Eastern Basin Water Level (mAHD)**		
	1A (I = 0.2)	**1D (I = 0.1)**	**1E (I = 0.4)**
2006-2010	-	-	-
2011-2020	-	17.60	-
2021-2050	18.01	18.27	-
2051-2075	18.20	18.48	-
2076-2106	18.47	18.69	18.07

Table 13 Sensitivity of Maximum Stored Volume and Inundated Areas to Infiltration Rate (I): Drainage, and Loxton, Bookpurnong and Murtho SIS.

Period	Total Volume (ML)		
	1A (I = 0.2)	1D (I = 0.1)	1E (I = 0.4)
2006-2010	4110	4424	3723
2011-2020	4749	5932	3672
2021-2050	6481	7776	4562
2051-2075	7346	9320	5617
2076-2106	9277	12037	6739
Period	**Total Inundated Area (Ha)**		
	1A (I = 0.2)	**1D (I = 0.1)**	**1E (I = 0.4)**
2006-2010	790	808	763
2011-2020	825	918	760
2021-2050	1205	1509	815
2051-2075	1433	1698	866
2076-2106	1694	1831	1293

As with adjusting the evaporation coefficient, reducing the infiltration rate leads to increased water levels over the period of basin operation but levels that are still well below the maximum operating level of 19.0 mAHD.

Figure 22 shows the changing salt-adjusted water levels in the Eastern and Western Basins for each scenario. This indicates that the water level in the Western Basin reaches 18.6 mAHD 15 years earlier with the reduced infiltration rate and 45 years later with an increased coefficient. Only in Scenario 1D does the water level in the Eastern Basin reach 18.6 mAHD (around 2088), from which point the water levels in both basins should be equal.

The effect of the changing infiltration rate on the total volume stored is shown in Figure 23 and on the inundated area in Figure 24.

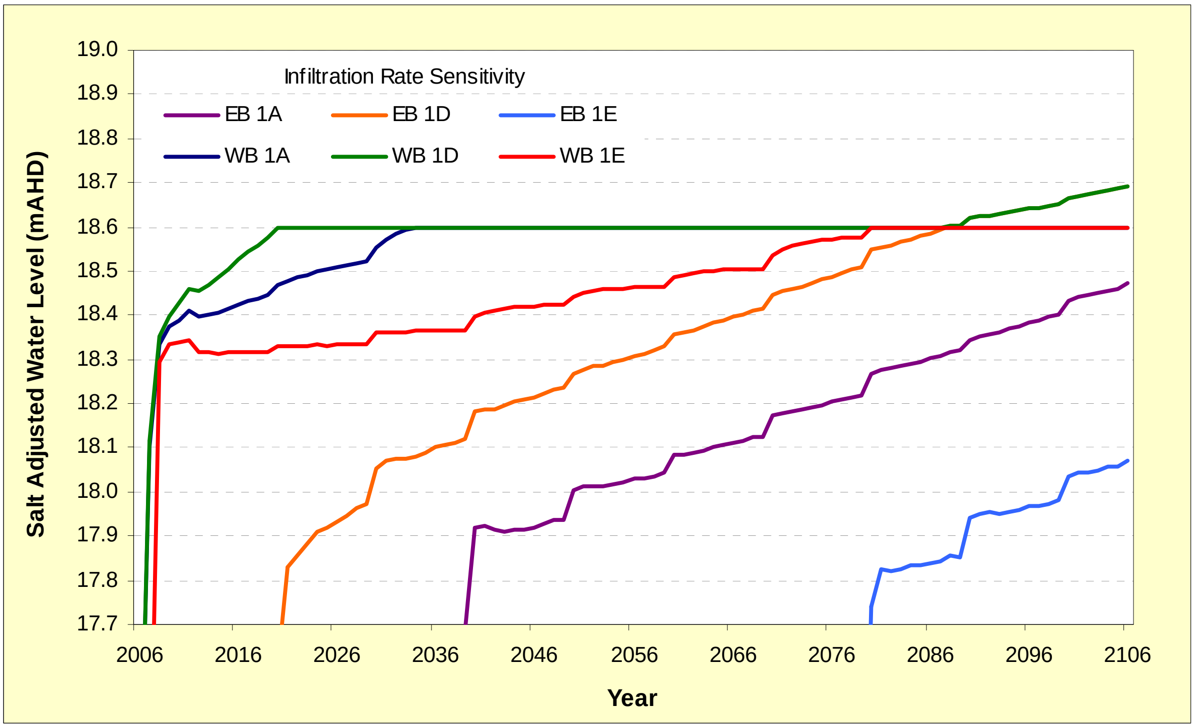


Figure 22 Sensitivity of Water Level to Infiltration Rate (I): Drainage, and Loxton, Bookpurnong and Murtho SIS.

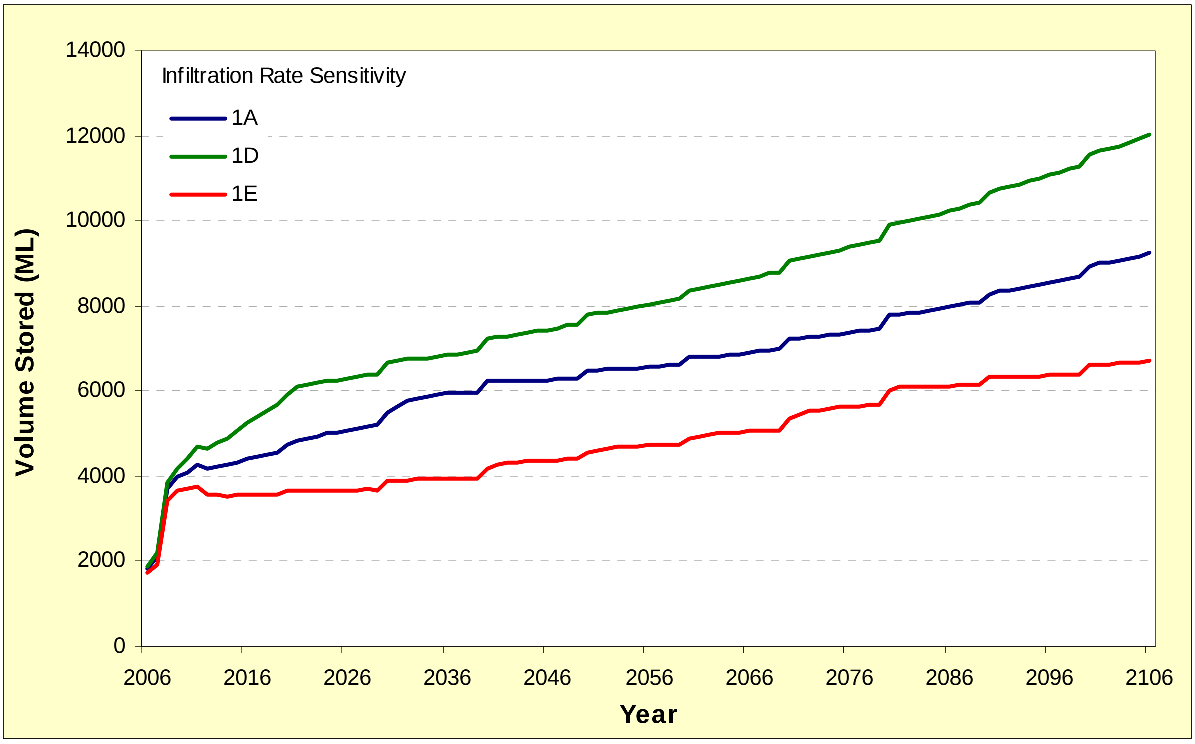


Figure 23 Sensitivity of Volume Stored to Infiltration Rate (I): Drainage, and Loxton, Bookpurnong and Murtho SIS.

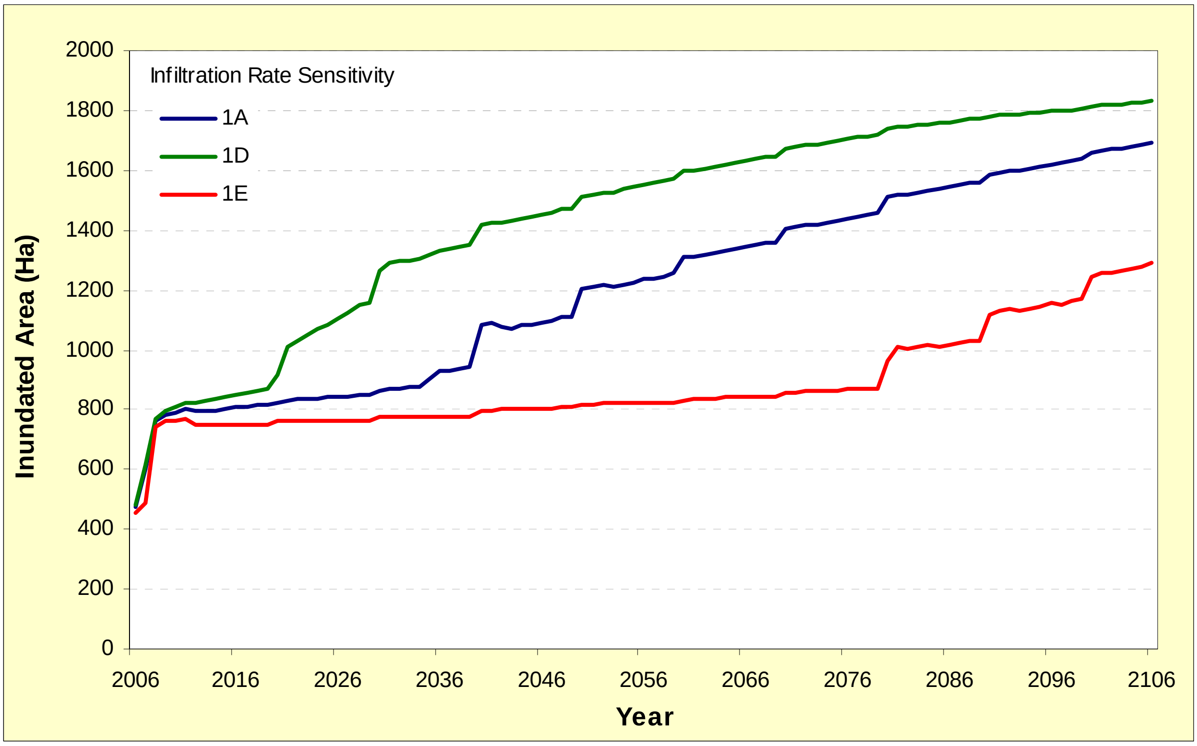


Figure 24 Sensitivity of Inundated Area to Infiltration Rate (I): Drainage, and Loxton, Bookpurnong and Murtho SIS.

Table 14 shows the likely levels of precipitated salt in the Western and Eastern Basins under each infiltration rate and Table 15 provides the corresponding maximum salt concentrations. With the higher infiltration rate of 0.4 mm/day, precipitation is unlikely to occur at all in the Western Basin and potentially only within the last 25 years of basin operation in the Eastern Basin. The Western Basin results for the lower infiltration rate are quite similar to the primary case. In the Eastern Basin however, there is almost twice the volume of precipitating salt. The reduced infiltration rate results in a slower movement of salt from the Western to the Eastern Basin as well as less transport of salt out of the system.

Table 14 Sensitivity of Maximum Precipitated Salt to Infiltration Rate (I): Drainage, and Loxton, Bookpurnong and Murtho SIS.

Period	Maximum Western Basin Precipitated Salt (million tonnes)		
	1A (I = 0.2)	1D (I = 0.1)	1E (I = 0.4)
2006-2010	-	-	-
2011-2020	0.048	0.370	-
2021-2050	0.215	0.163	-
2051-2075	0.043	0.060	-
2076-2106	-	-	-
Period	**Maximum Eastern Basin Precipitated Salt (million tonnes)**		
	1A (I = 0.2)	**1D (I = 0.1)**	**1E (I = 0.4)**
2006-2010	-	-	-
2011-2020	-	0.010	-
2021-2050	0.593	2.826	-
2051-2075	2.173	5.897	-
2076-2106	5.345	10.723	0.736

Table 15 Sensitivity of Maximum Salt Concentration to Infiltration Rate (I): Drainage, and Loxton, Bookpurnong and Murtho SIS.

Period	Maximum Western Basin Concentration (mg/L)		
	1A (I = 0.2)	1D (I = 0.1)	1E (I = 0.4)
2006-2010	197000	211000	165000
2011-2020	260000	260000	220000
2021-2050	260000	260000	223000
2051-2075	260000	260000	223000
2076-2106	232000	235000	217000
Period	**Maximum Eastern Basin Concentration (mg/L)**		
	1A (I = 0.2)	**1D (I = 0.1)**	**1E (I = 0.4)**
2006-2010	-	-	-
2011-2020	-	260000	-
2021-2050	260000	260000	-
2051-2075	260000	260000	-
2076-2106	260000	260000	260000

At their maximum water level and inundated area, Scenarios 1A, 1D and 1E produce 5.3, 10.7 and 0.7 million tonnes of precipitated salt with equivalent volumes of 2432, 4953 and 340 ML respectively.

Figures 25 and 26 show the salt stored in each basin, and Figure 27 shows the maximum annual salt concentrations in the Western Basin. As can be seen, the higher infiltration rate leads to significantly less salt stored in the basin. In each scenario, once flow into the Eastern Basin occurs, the salinity increases quickly to 260,000 mg/L, similar to Figure 14.

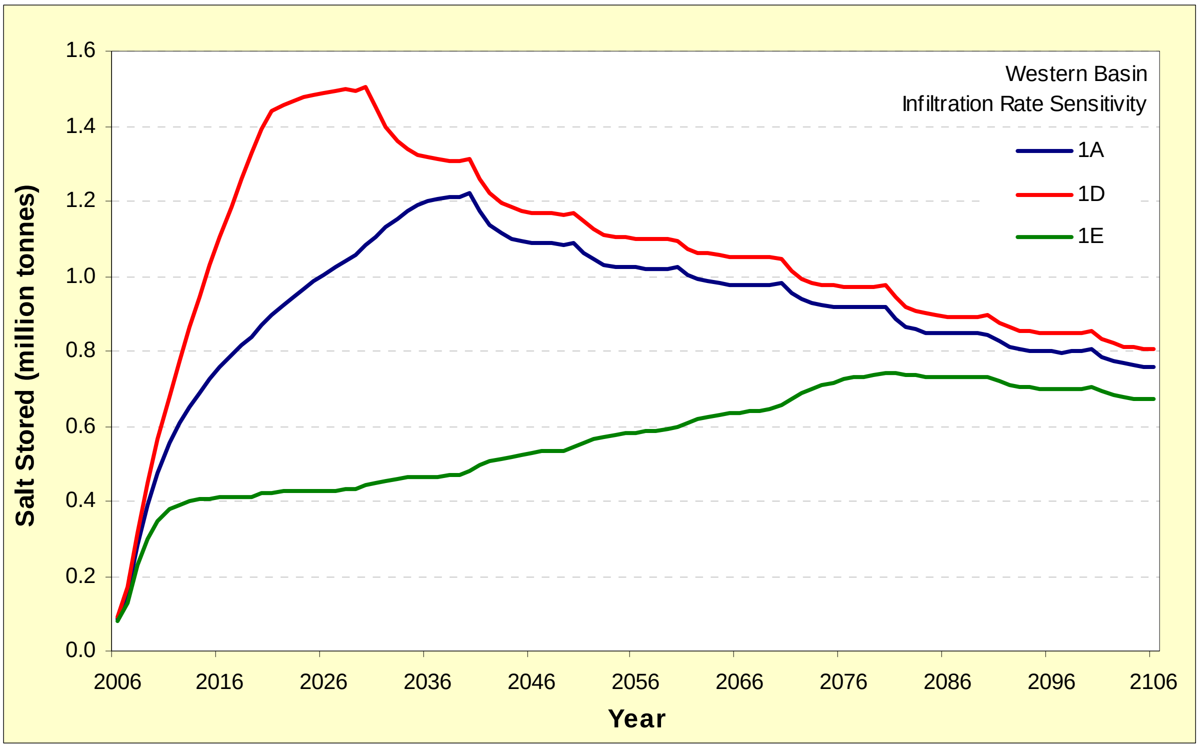


Figure 25 Sensitivity of Salt Stored in the Western Basin to Infiltration Rate(I): Drainage, and Loxton, Bookpurnong and Murtho SIS.

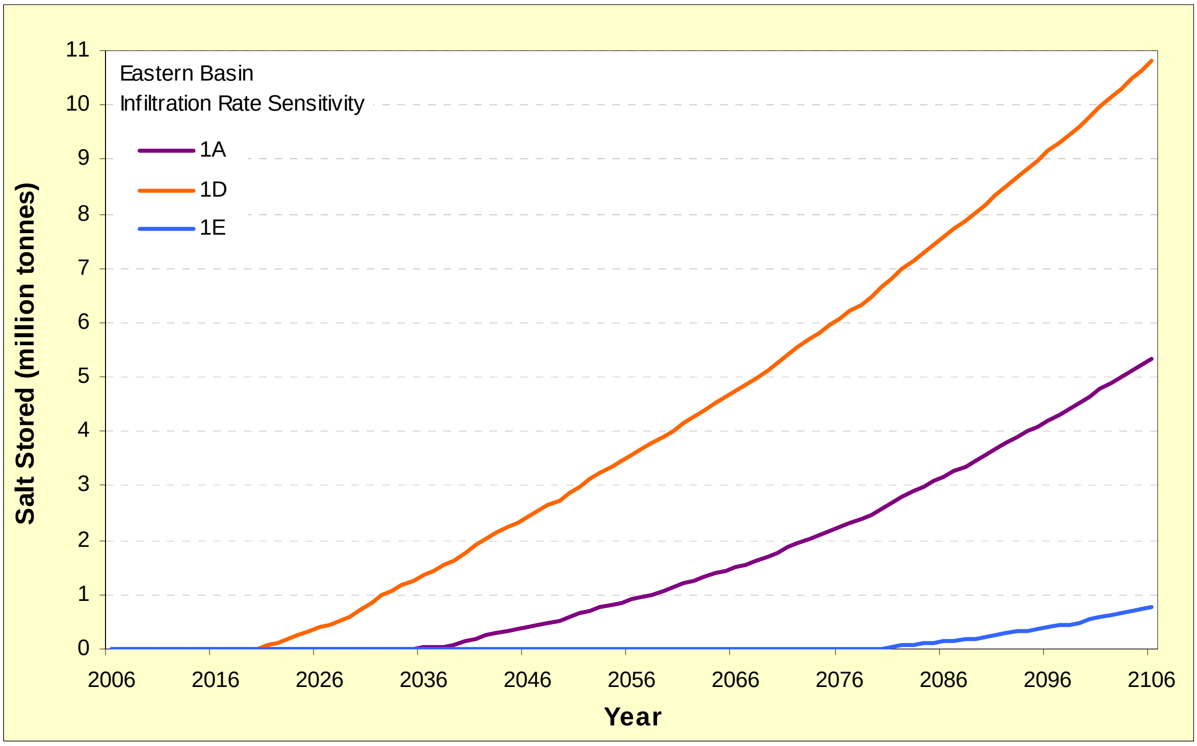


Figure 26 Sensitivity of Salt Stored in the Eastern Basin to Infiltration Rate(I): Drainage, and Loxton, Bookpurnong and Murtho SIS.

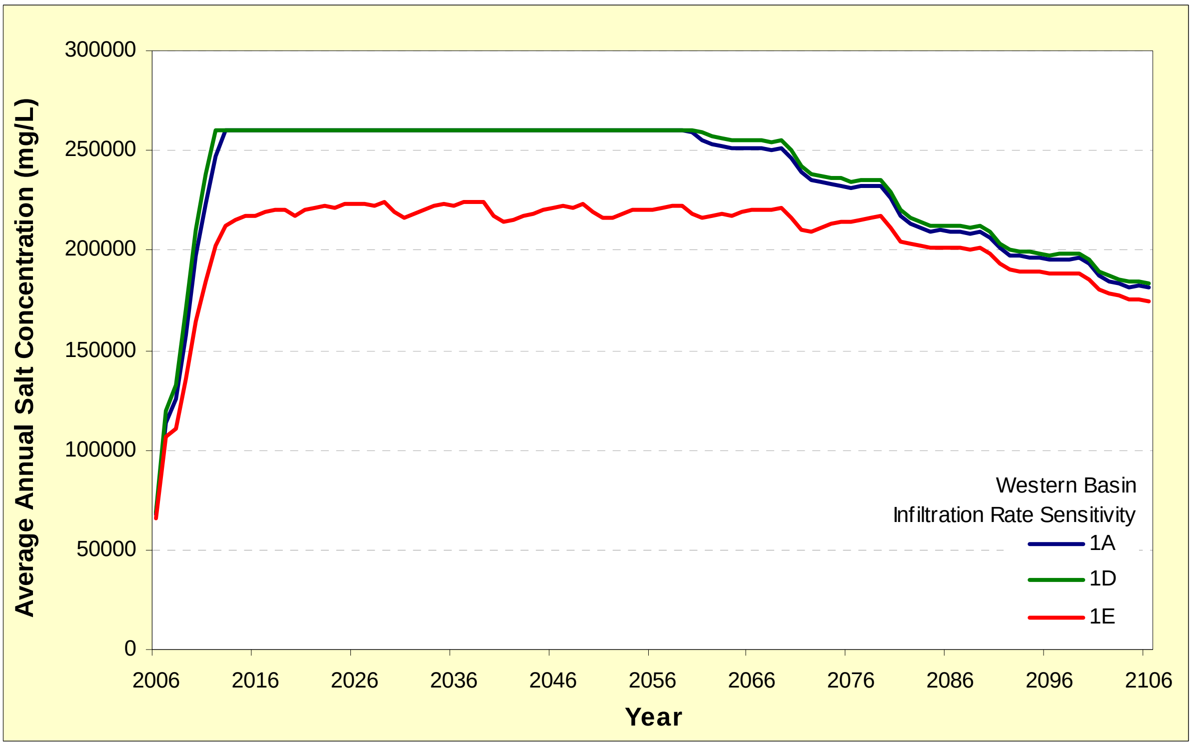


Figure 27 Sensitivity of Salt Concentration to Infiltration Rate (I): Drainage, and Loxton, Bookpurnong and Murtho SIS.

SIS Salt Concentration (Scenarios 1A, 1F and 1G)

The assumed SIS salt concentration of 26,000 mg/L was varied to 22,000 and 30,000 mg/L. Analysis of the sensitivity of model outputs to the evaporation coefficient and infiltration rate showed that water levels are highly likely to be less than 19.0 mAHD. However, the changes to model outputs were less uniform than would perhaps be expected by increasing and decreasing a parameter. Increasing and decreasing the SIS salt concentration produces less complex results.

Table 16 shows the variation in maximum water levels and Table 17 provides the variation in maximum stored volume and inundated areas. There is little difference between the results for these scenarios and this is confirmed in Figure 28 to Figure 30. The small differences are primarily due to the influence of salt concentration on the evaporation rate (refer Section 2.2.4).

Table 16 Sensitivity of Maximum Water Levels to SIS Salt Concentration (S_c): Drainage, and Loxton, Bookpurnong and Murtho SIS.

Period	Maximum Western Basin Water Level (mAHD)		
	1A (S_c = 26000)	1F (S_c = 22000)	1G (S_c = 30000)
2006-2010	18.39	18.38	18.40
2011-2020	18.47	18.43	18.50
2021-2050	18.60	18.60	18.60
2051-2075	18.60	18.60	18.60
2076-2106	18.60	18.60	18.60
Period	**Maximum Eastern Basin Water Level (mAHD)**		
	1A (S_c = 26000)	**1F (S_c = 22000)**	**1G (S_c = 30000)**
2006-2010	-	-	-
2011-2020	-	-	-
2021-2050	18.01	17.91	18.08
2051-2075	18.20	18.11	18.28
2076-2106	18.47	18.38	18.57

Table 17 Sensitivity of Maximum Stored Volume and Inundated Areas to SIS Salt Concentration (S_c): Drainage, and Loxton, Bookpurnong and Murtho SIS.

Period	Total Volume (ML)		
	1A (S_c = 26000)	1F (S_c = 22000)	1G (S_c = 30000)
2006-2010	4110	4048	4218
2011-2020	4749	4481	5020
2021-2050	6481	6249	6764
2051-2075	7346	6897	7834
2076-2106	9277	8538	10083
Period	**Total Inundated Area (Ha)**		
	1A (S_c = 26000)	**1F (S_c = 22000)**	**1G (S_c = 30000)**
2006-2010	790	785	797
2011-2020	825	811	839
2021-2050	1205	1079	1302
2051-2075	1433	1341	1519
2076-2106	1694	1617	1753

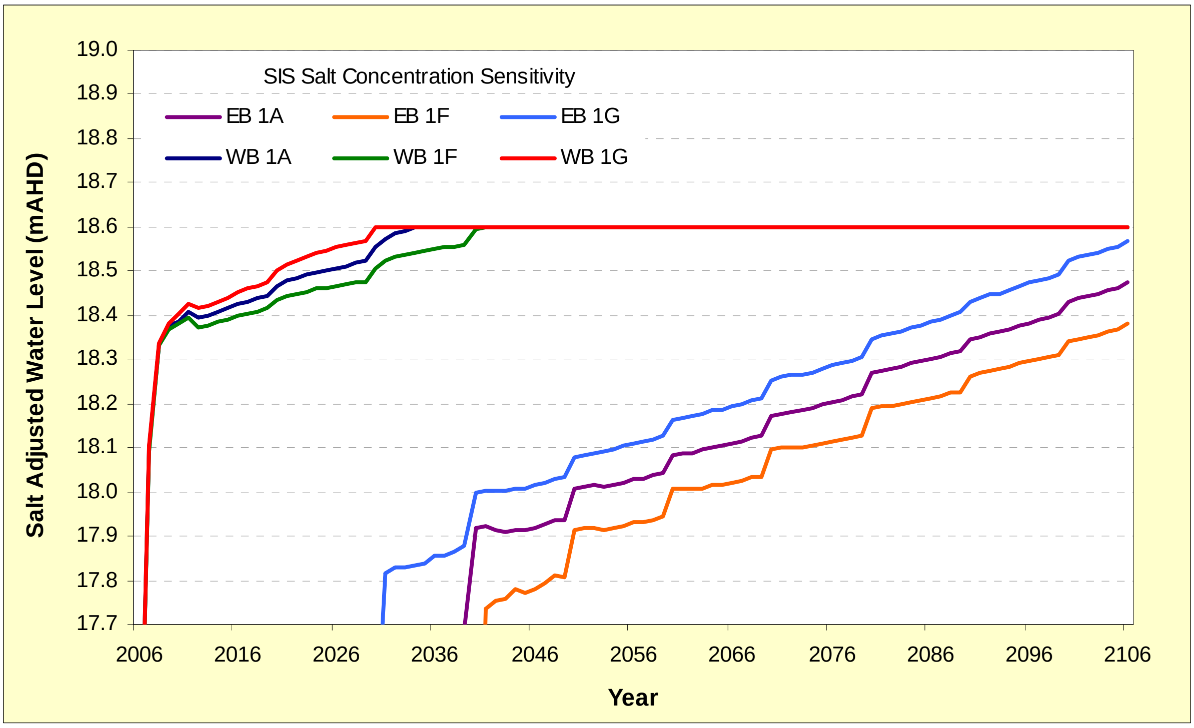


Figure 28 Sensitivity of Water Level to SIS Salt Concentration (S_c): Drainage, and Loxton, Bookpurnong and Murtho SIS.

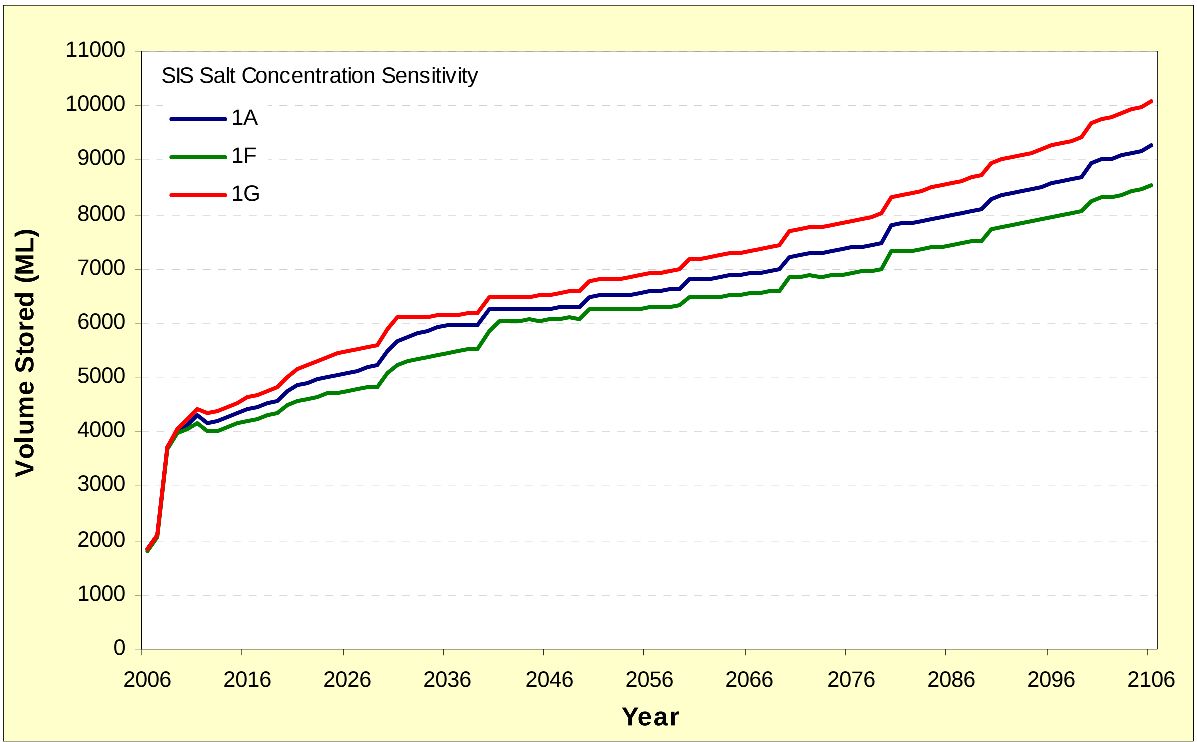


Figure 29 Sensitivity of Volume Stored to SIS Salt Concentration (S_c): Drainage, and Loxton, Bookpurnong and Murtho SIS.

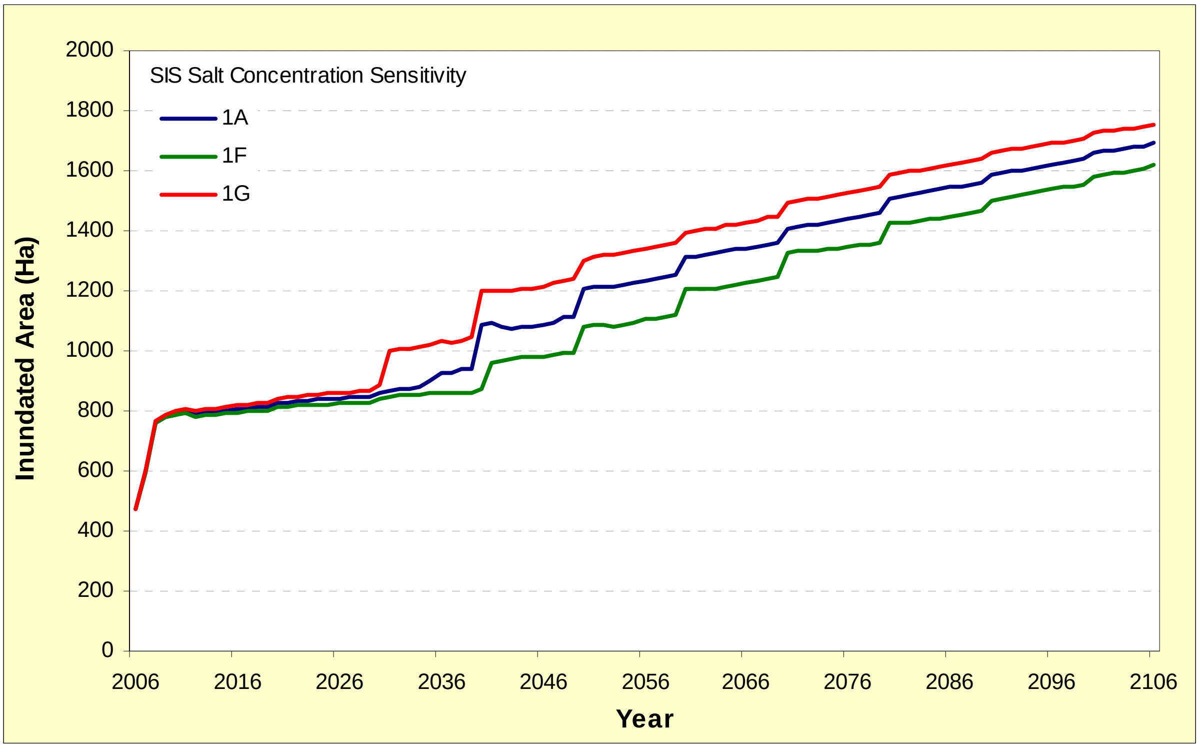


Figure 30 Sensitivity of Inundated Area to SIS Salt Concentration (S_c): Drainage, and Loxton, Bookpurnong and Murtho SIS.

Table 18 shows the likely levels of precipitated salt in the Western and Eastern Basins under each SIS salt concentration and Table 19 provides the corresponding maximum salt concentrations. Again there is little difference between the results for these scenarios and the trends are what was expected.

Table 18 Sensitivity of Maximum Precipitated Salt to SIS Salt Concentration (S_c): Drainage, and Loxton, Bookpurnong and Murtho SIS.

Period	Maximum Western Basin Precipitated Salt (million tonnes)		
	1A (S_c = 26000)	1F (S_c = 22000)	1G (S_c = 30000)
2006-2010	-	-	-
2011-2020	0.048	0.061	0.103
2021-2050	0.215	0.108	3.368
2051-2075	0.043	0.004	0.078
2076-2106	-	-	-
Period	**Maximum Eastern Basin Precipitated Salt (million tonnes)**		
	1A (S_c = 26000)	**1F (S_c = 22000)**	**1G (S_c = 30000)**
2006-2010	-	-	-
2011-2020	-	-	-
2021-2050	0.593	0.225	1.040
2051-2075	2.173	1.362	3.054
2076-2106	5.345	3.870	6.829

Table 19 Sensitivity of Maximum Salt Concentration to SIS Salt Concentration (S_c): Drainage, and Loxton, Bookpurnong and Murtho SIS.

Period	Maximum Western Basin Concentration (mg/L)		
	1A (S_c = 26000)	1F (S_c = 22000)	1G (S_c = 30000)
2006-2010	197000	176000	214000
2011-2020	260000	260000	260000
2021-2050	260000	260000	260000
2051-2075	260000	260000	260000
2076-2106	232000	221000	241000
Period	**Maximum Eastern Basin Concentration (mg/L)**		
	1A (S_c = 26000)	1F (S_c = 22000)	1G (S_c = 30000)
2006-2010	-	-	-
2011-2020	-	-	-
2021-2050	260000	260000	260000
2051-2075	260000	260000	260000
2076-2106	260000	260000	260000

At their maximum water level and inundated area, Scenarios 1A, 1F and 1G produce 5.3, 3.9 and 6.8 million tonnes of precipitated salt with equivalent volumes of 2432, 1787 and 3154 ML respectively.

Figures 31 and 32 show the salt stored in each basin and Figure 33 shows the maximum annual salt concentrations in the Western Basin.

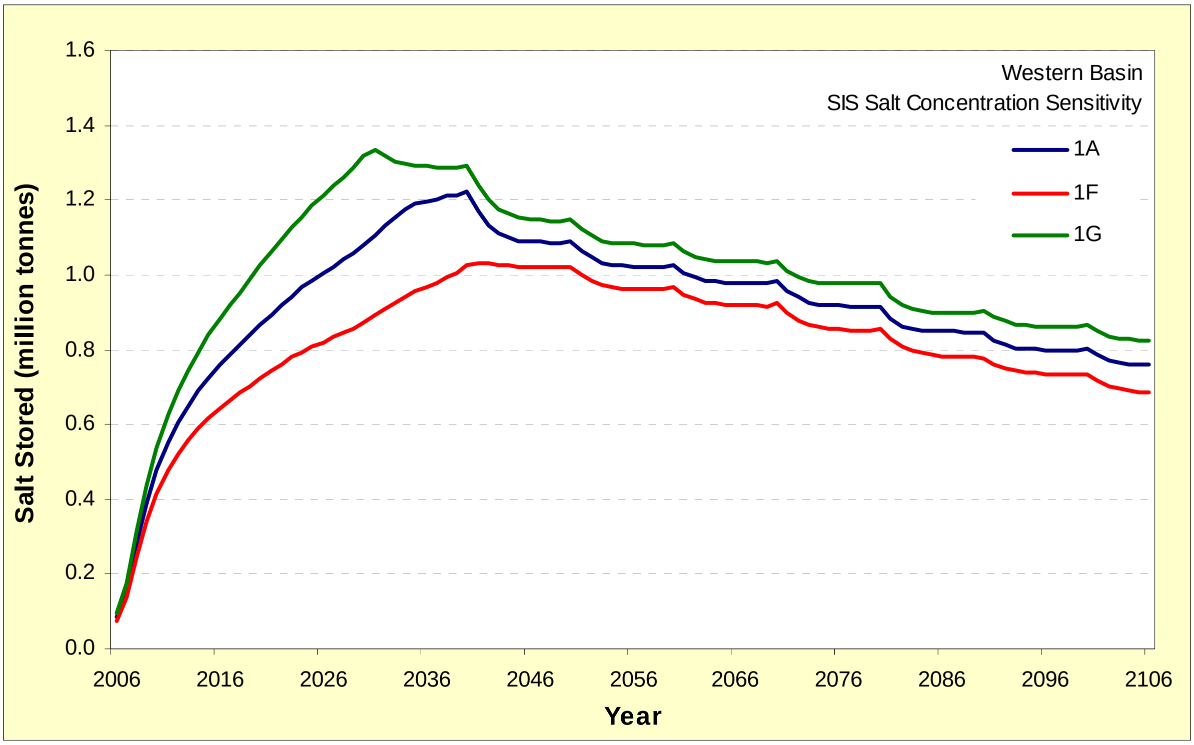


Figure 31 Sensitivity of Salt Stored in the Western Basin to SIS Salt Concentration (S_c): Drainage, and Loxton, Bookpurnong and Murtho SIS.

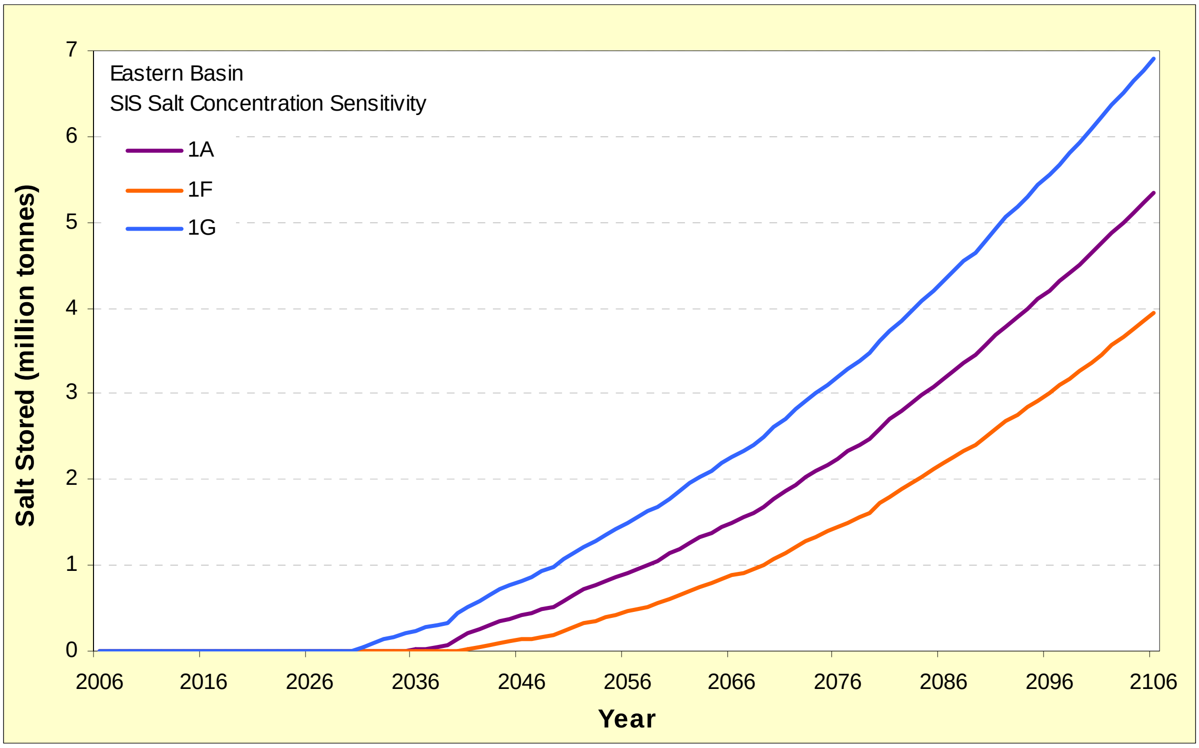


Figure 32 Sensitivity of Salt Stored in the Eastern Basin to SIS Salt Concentration (S_c): Drainage, and Loxton, Bookpurnong and Murtho SIS.

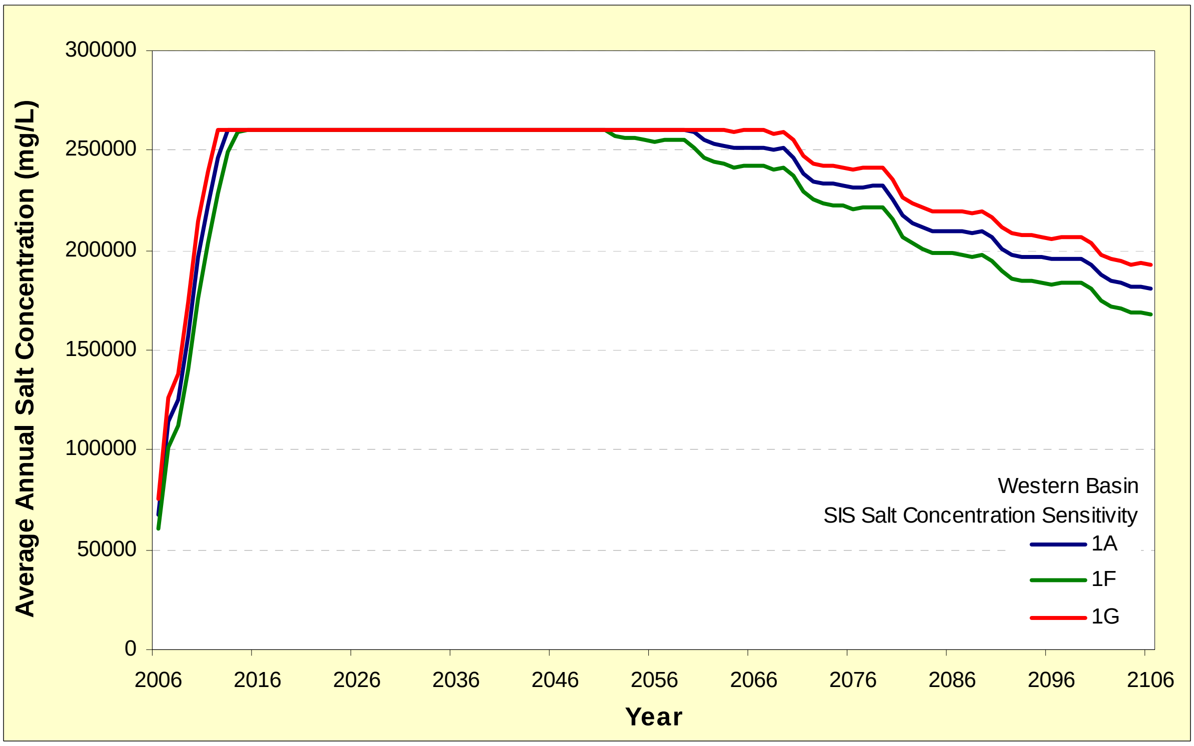


Figure 33 Sensitivity of Salt Concentration to SIS Salt Concentration (S_c): Drainage, and Loxton, Bookpurnong and Murtho SIS.

Comparison of Results of Sensitivity Analysis for Scenario 1

A comparison of Western and Eastern Basin water levels for Scenarios 1A to 1G are shown in Figures 34 and 35 respectively. These indicate that the infiltration rate potentially has the greatest influence on water levels and the SIS salt concentration the least influence.

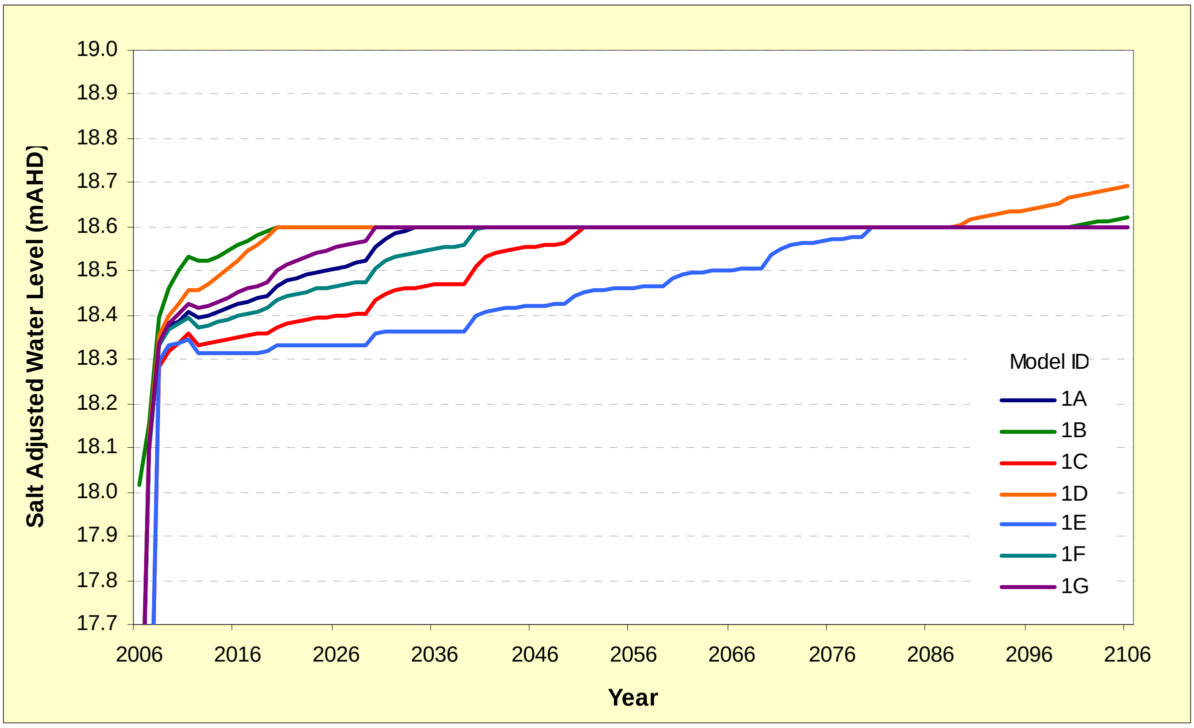


Figure 34 Comparison of Western Basin Water Level Sensitivity to Evaporation Coefficient (E), Infiltration Rate (I) and SIS Salt Concentration (S_c): Scenario 1.

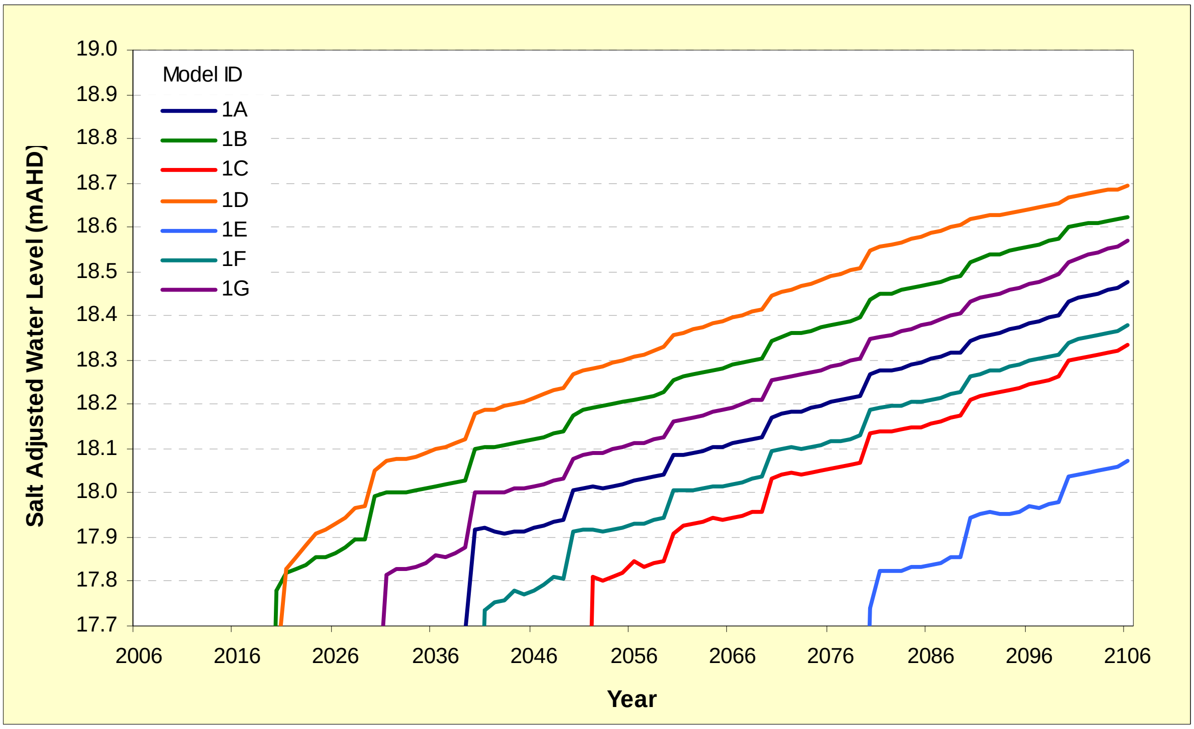


Figure 35 Comparison of Eastern Basin Water Level Sensitivity to Evaporation Coefficient (E), Infiltration Rate (I) and SIS Salt Concentration (S_c): Scenario 1.

3.3 SCENARIO 2: DRAINAGE, AND LOXTON, BOOKPURNONG, MURTHO AND PIKE SIS PUMPING

Scenario 2 consists of the combined drainage and Loxton, Bookpurnong, Murtho and Pike SIS pumping option. Table 20 shows the parameters used for the primary option (2A) and the sensitivity analysis (2B to 2G). All other parameters remain constant and it has been assumed that the stop-logs separating the Eastern and Western basins are maintained at 18.6 mAHD.

Table 20 Scenario 2: Primary Option and Sensitivity Analysis Parameters.

ID	Evaporation Coefficient	Infiltration (mm/day)	SIS Salt Concentration (mg/L)
2A	0.65	0.2	26000
2B	0.55	0.2	26000
2C	0.75	0.2	26000
2D	0.65	0.1	26000
2E	0.65	0.4	26000
2F	0.65	0.2	22000
2G	0.65	0.2	30000

3.3.1 Primary Analysis (Scenario 2A)

The model indicates that there is sufficient capacity to accept the proposed pumping rates from the Bookpurnong, Loxton, Murtho and Pike schemes. These rates equate to a volume pumped of 969 GL with a salt load of 24.3 million tonnes from 2006 to 2106. Table 21 shows the maximum water levels reached within the basin for a series of time periods, indicating that a ponded water level of around 18.8 mAHD is likely. Table 22 shows the likely salt properties in the Western and Eastern Basins. At the maximum water level and inundated area, 11.7 million tonnes of precipitated salt with an equivalent volume of 5412 ML are stored in the Eastern Basin.

Under Scenario 2A, flow into the Eastern Basin is likely by September 2014, 20 years earlier than without the Pike SIS discharges in Scenario 1A. Although salt concentrations in the Western Basin approach saturation prior to this occurring, precipitation is unlikely. The higher basin discharge then leads to a faster lowering of salinity in the Western Basin.

Table 21 Maximum Water Levels, Stored Volume and Inundated Areas: Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS (Scenario 2A).

Period	Maximum Water Level (mAHD)		Total Volume (ML)	Total Inundated Area (Ha)
	Western Basin	Eastern Basin		
2006-2010	18.39	-	4110	790
2011-2020	18.60	18.02	6554	1230
2021-2050	18.60	18.38	8519	1615
2051-2075	18.62	18.62	10664	1782
2076-2106	18.79	18.79	14039	1965

Table 22 Maximum Salt Concentration, Precipitated Salt and Reduced Storage: Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS (Scenario 2A).

Period	Western Basin			Eastern Basin		
	Maximum Concentration (mg/L)	Precipitated Salt (million tonnes)	Reduced Storage (ML)	Maximum Concentration (mg/L)	Precipitated Salt (million tonnes)	Reduced Storage (ML)
2006-2010	197000	-	-	-	-	-
2011-2020	239000	-	-	260000	0.372	172
2021-2050	235000	-	-	260000	3.270	1510
2051-2075	176000	-	-	260000	6.697	3093
2076-2106	133000	-	-	260000	11.716	5412

Figure 36 shows the changing adjusted water levels in the Western and Eastern Basins. Once the water levels in both basins are equal (at and above 18.6 mAHD) then the Eastern Basin water level represents the full basin water level. Unlike Scenario 1A, the sum of evaporation and infiltration is not greater than the sum of rainfall and inflow, and hence once flow into the Eastern Basin begins, so does the storage of water and salt in this basin.

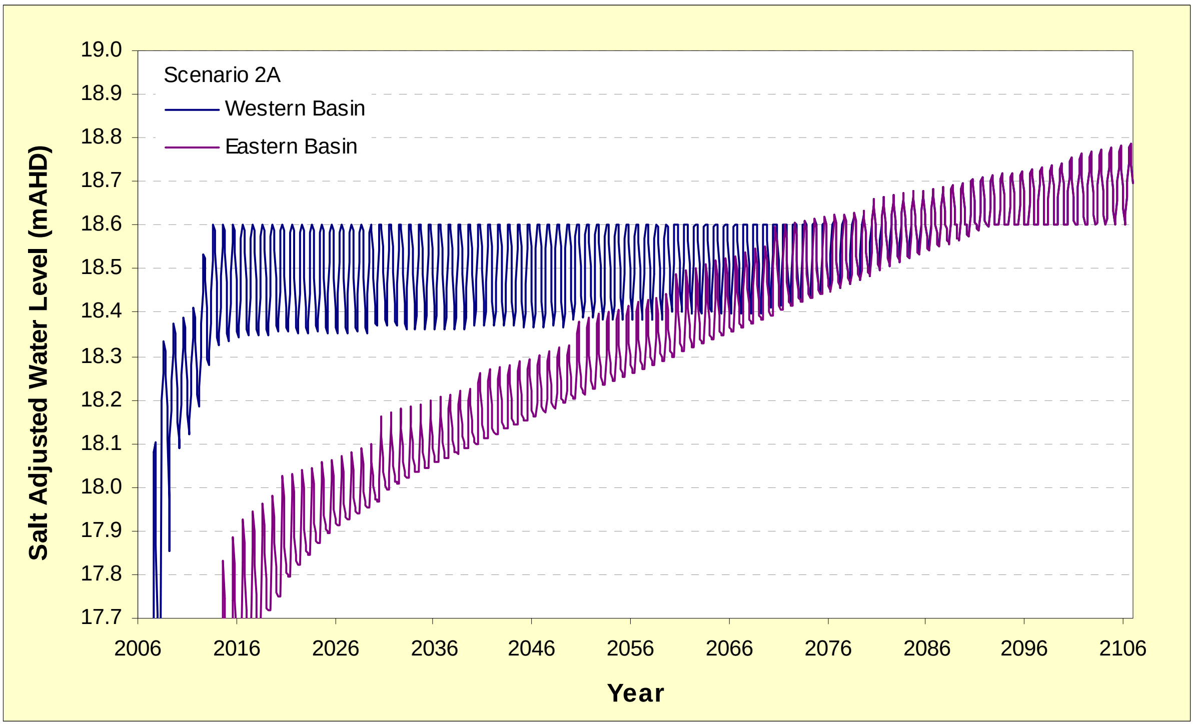


Figure 36 Salt-Adjusted Water Level: Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS.

Figure 37 shows the stored volumes between 2006 and 2106. These indicate that without salt precipitation, the water level would only increase slowly after 2020, generally oscillating around a stored volume of between 5000 and 7000 ML. However, as for the results without the Pike SIS inflows, because the quantity of salt in the basin increases continuously, so does the amount of precipitated salt and its equivalent volume.

Figure 38 shows the tonnes of salt stored in the Western and Eastern Basins and Figure 39 shows the maximum annual salt concentrations from 2006 to 2106. The trend of salt stored in the Western Basin is similar to (although slightly lower than) Scenario 1A. In the Eastern

Basin, the salt stored again increases rapidly and the saturation concentration is reached quickly and maintained. By 2106, there is likely to be more than double the amount of salt stored than when discharges from the Pike SIS were not considered, and it would be expected that the combined basins would store over 12.6 million tonnes of salt.

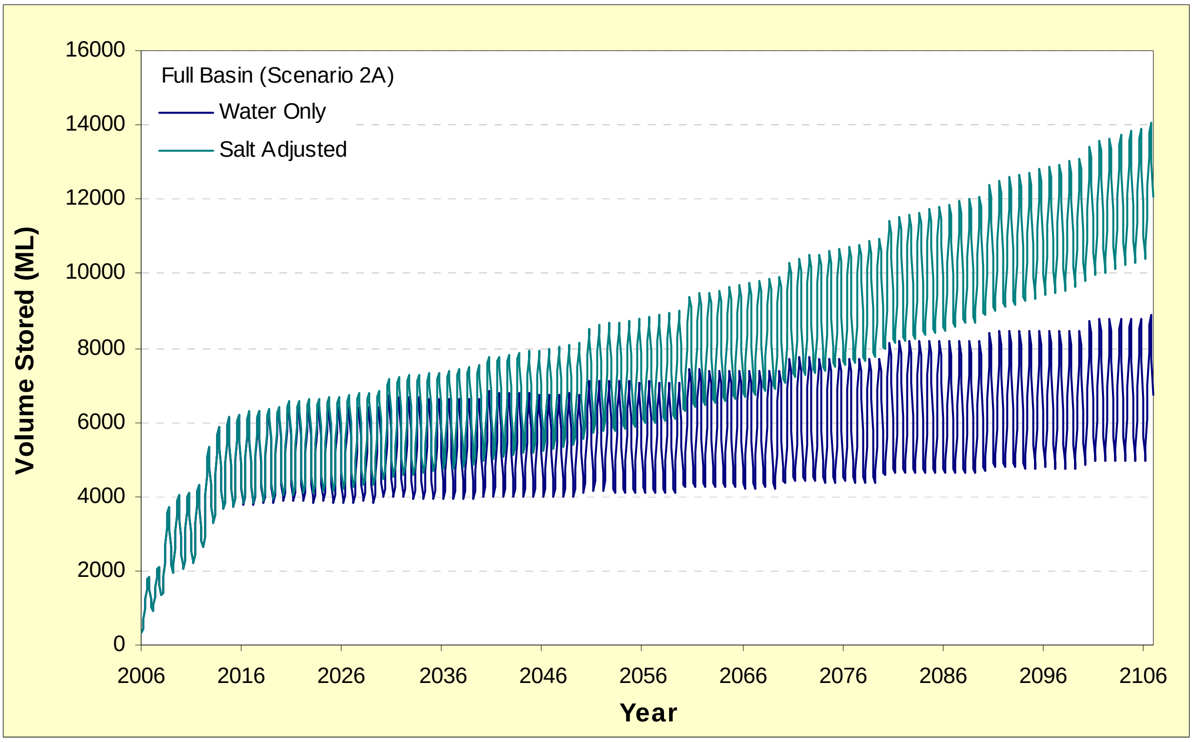


Figure 37 Total Stored Volume (Water and Precipitated Salt): Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS.

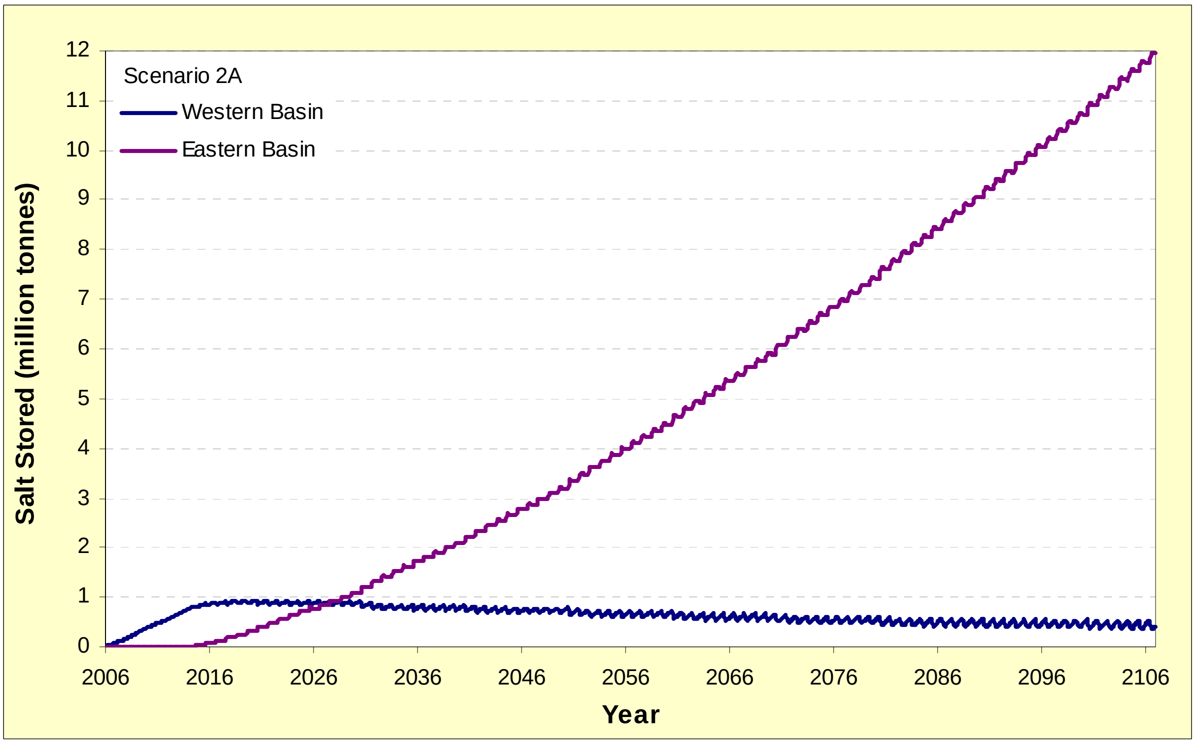


Figure 38 Total Stored Salt: Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS.

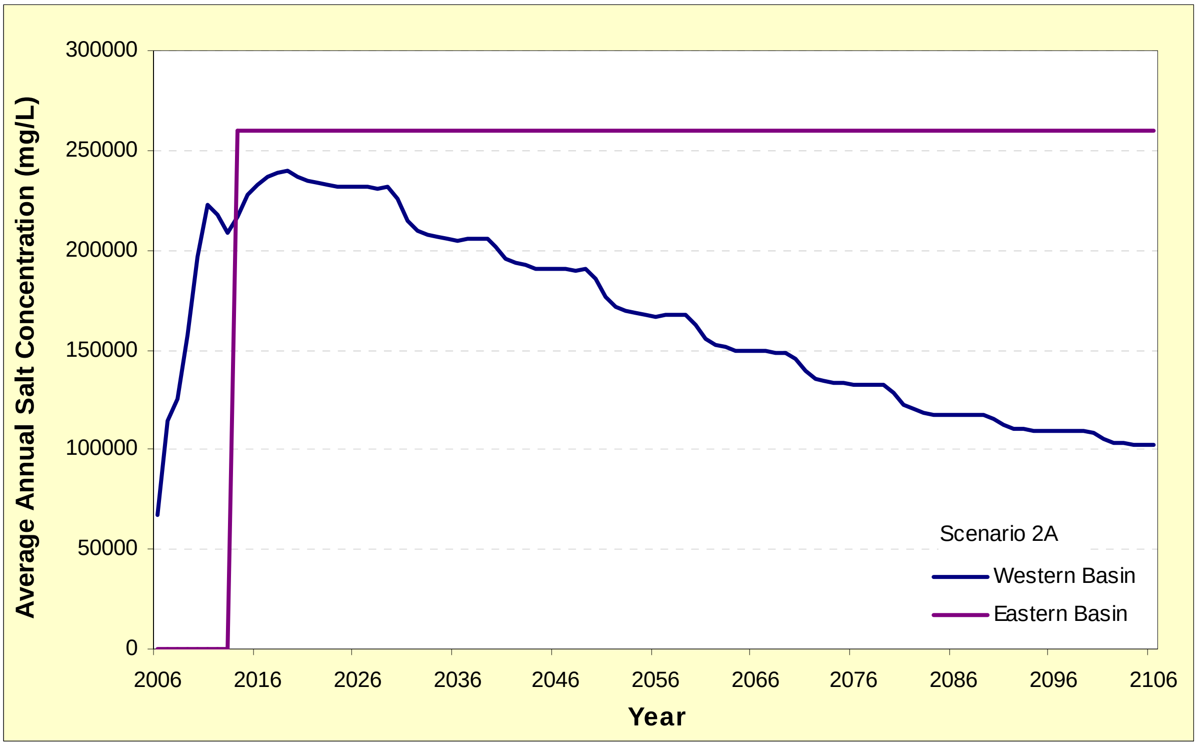
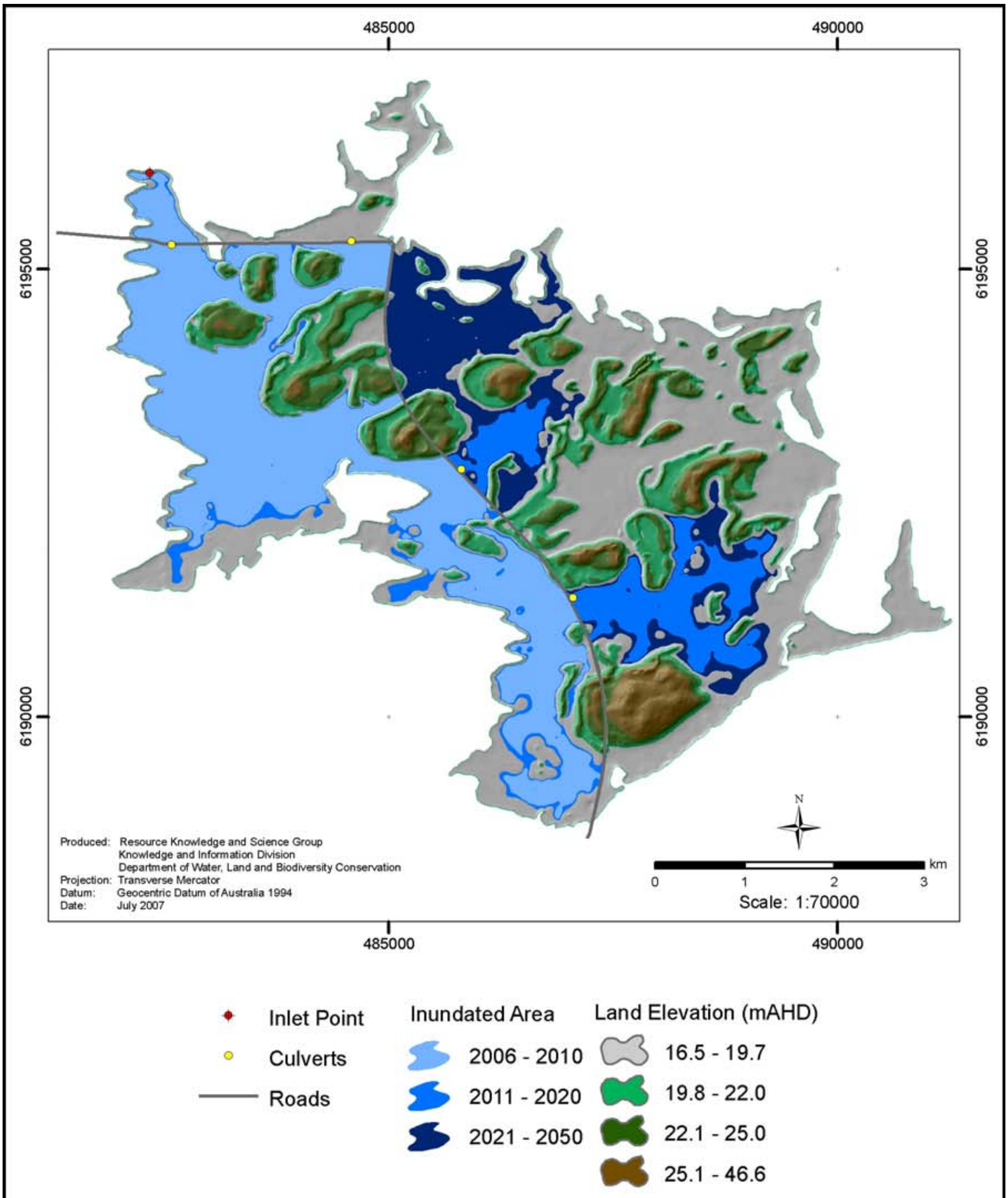


Figure 39 Annual Maximum Salt Concentration: Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS.

Figure 40 shows the projected increasing inundated areas for the periods 2006 to 2010, 2011 to 2020, and 2021 to 2050. The nature of the basin is such that there is little increase in inundated area as the level rises from 18.39 mAHD to 18.60 mAHD in the Western Basin. Compared to Scenario 1A, a much larger area in the Eastern Basin is likely to be inundated by 2050.

Figure 41 shows the projected increasing inundated areas from the extent at 2050, through the periods from 2051 to 2075, and 2076 to 2106. The figure shows that it is likely that large areas of the basin not inundated under Scenario 1A would be inundated under Scenario 2A.

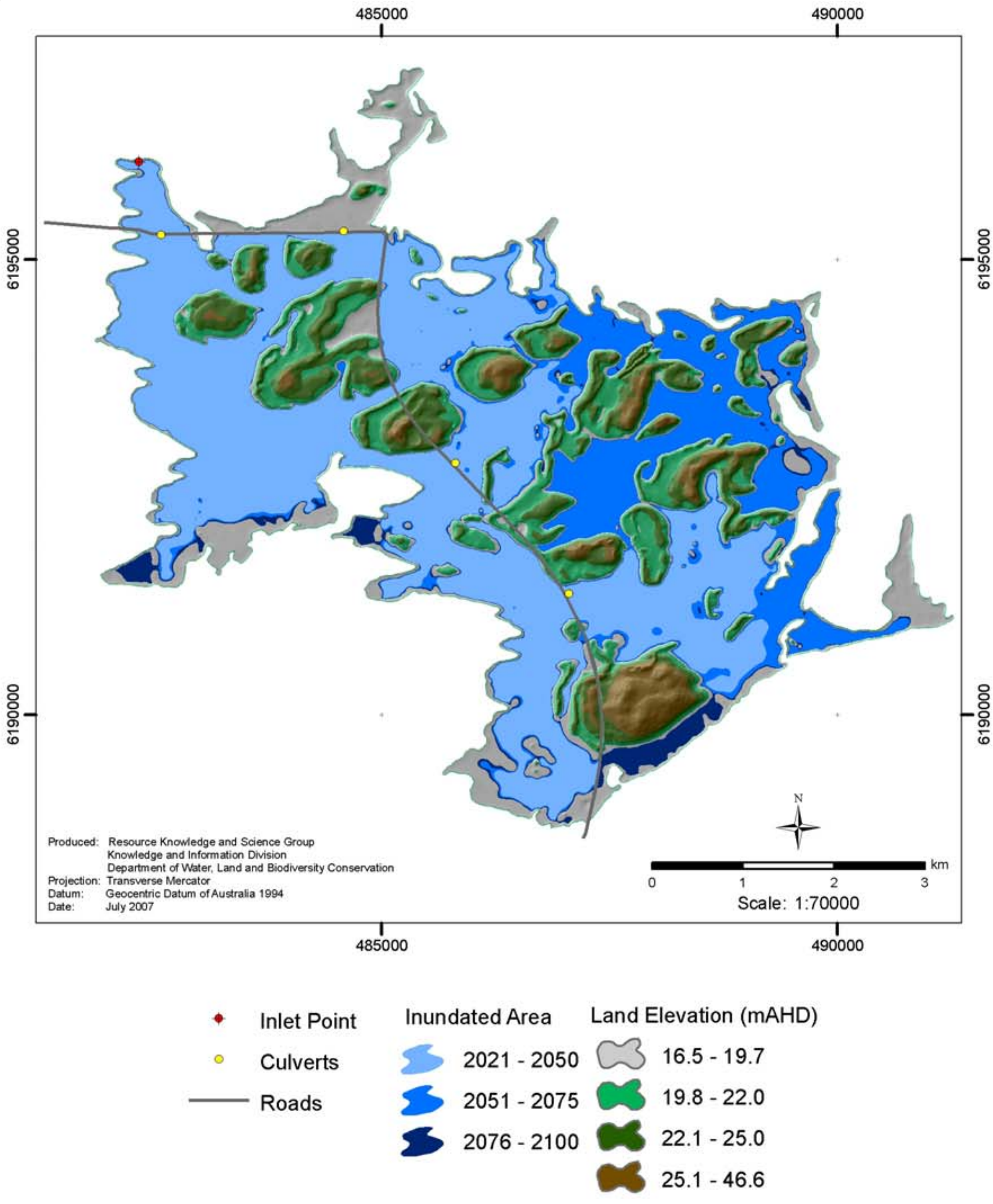


Maximum Water Levels, Stored Volume and Inundated Areas: Drainage and Loxton, Bookpurnong, Murtho and Pike SIS (Scenario 2A)

Period	Maximum Water Level (mAHD)		Total Volume (ML)	Total Inundated Area (Ha)
	Western Basin	Eastern Basin		
2006-2010	18.39	-	4110	790
2011-2020	18.60	18.02	6554	1230
2021-2050	18.60	18.38	8519	1615

Notes
Control Height between Western and Eastern Basins is 18.6 mAHD.

Figure 40 Noora Basin Projected Maximum Inundated Areas for 2006 to 2050: Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS (Scenario 2A).



Maximum Water Levels, Stored Volume and Inundated Areas: Drainage and Loxton, Bookpurnong, Murtho and Pike SIS (Scenario 2A)

Period	Maximum Water Level (mAHD)		Total Volume (ML)	Total Inundated Area (Ha)
	Western Basin	Eastern Basin		
2021-2050	18.60	18.38	8519	1615
2051-2075	18.62	18.62	10664	1782
2076-2106	18.79	18.79	14039	1965

Notes
Control Height between Western and Eastern Basins is 18.6 mAHD.

Figure 41 Noora Basin Projected Maximum Inundated Areas for 2050 to 2106: Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS (Scenario 2A).

3.3.2 Sensitivity Analysis (Scenarios 2B to 2G)

The sensitivity of the model outputs to the evaporation coefficient, infiltration rate and SIS salt concentration were tested. In order to easily compare results, the maximum annual salt-adjusted water levels, stored volumes, total stored salt and salt concentrations were determined within each period and are presented in the following.

Evaporation Coefficient (Scenarios 2A, 2B and 2C)

The assumed evaporation coefficient of 0.65 was varied to 0.55 and 0.75. Table 23 shows the variation in maximum water levels and Table 24 provides the variation in maximum stored volume and inundated areas.

Table 23 Sensitivity of Maximum Water Levels to Evaporation Coefficient (E): Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS.

Period	Maximum Western Basin Water Level (mAHD)		
	2A (E = 0.65)	**2B (E = 0.55)**	**2C (E = 0.75)**
2006-2010	18.39	18.50	18.34
2011-2020	18.60	18.60	18.60
2021-2050	18.60	18.60	18.60
2051-2075	18.62	18.68	18.60
2076-2106	18.79	18.86	18.72
Period	**Maximum Eastern Basin Water Level (mAHD)**		
	2A (E = 0.65)	**2B (E = 0.55)**	**2C (E = 0.75)**
2006-2010	-	-	-
2011-2020	18.02	18.16	17.82
2021-2050	18.38	18.50	18.26
2051-2075	18.62	18.68	18.51
2076-2106	18.79	18.86	18.72

Table 24 Sensitivity of Maximum Stored Volume and Inundated Areas to Evaporation Coefficient (E): Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS.

Period	Total Volume (ML)		
	2A (E = 0.65)	**2B (E = 0.55)**	**2C (E = 0.75)**
2006-2010	4110	5039	3721
2011-2020	6554	7173	6104
2021-2050	8519	9507	7750
2051-2075	10664	11864	9576
2076-2106	14039	15410	12762
Period	**Total Inundated Area (Ha)**		
	2A (E = 0.65)	**2B (E = 0.55)**	**2C (E = 0.75)**
2006-2010	790	840	763
2011-2020	1230	1398	1004
2021-2050	1615	1715	1504
2051-2075	1782	1825	1720
2076-2106	1965	2010	1917

As was expected, the lower evaporation coefficient results in less evaporation and hence increased water levels over the period of basin operation. As for Scenario 1, these results indicate that even if the evaporation rate has been overestimated, the resulting water levels are well below the maximum operating level of 19.0 mAHD. Conversely, if the evaporation coefficient has been underestimated, there is additional basin capacity available.

Figure 42 shows the changing salt-adjusted water levels in the Eastern and Western Basins for each scenario. This indicates that the water level in the Western Basin reaches 18.6 mAHD one year earlier with the reduced evaporation coefficient and six years later with the increased coefficient. Water level in the Eastern Basin increases at approximately the same rate in each case, and in all cases the water level reaches and exceeds 18.6 mAHD. From this point the water levels in both basins should be equal and in Figure 42 the total basin water level is shown by the Eastern Basin lines.

The effect of the changing evaporation coefficient on the total volume stored is then shown in Figure 43 and on the inundated area in Figure 44. The rate of increase of the total volume stored appears similar in each case. In comparison, although reducing the evaporation coefficient increases the inundated area more rapidly (by bringing forward the timing of flow into the Eastern Basin), by 2106 the curves can be seen to be converging. This is a product of the nature of the basin topography as shown in Figure 4. Large changes in total stored volume results in only small increases to inundated areas.

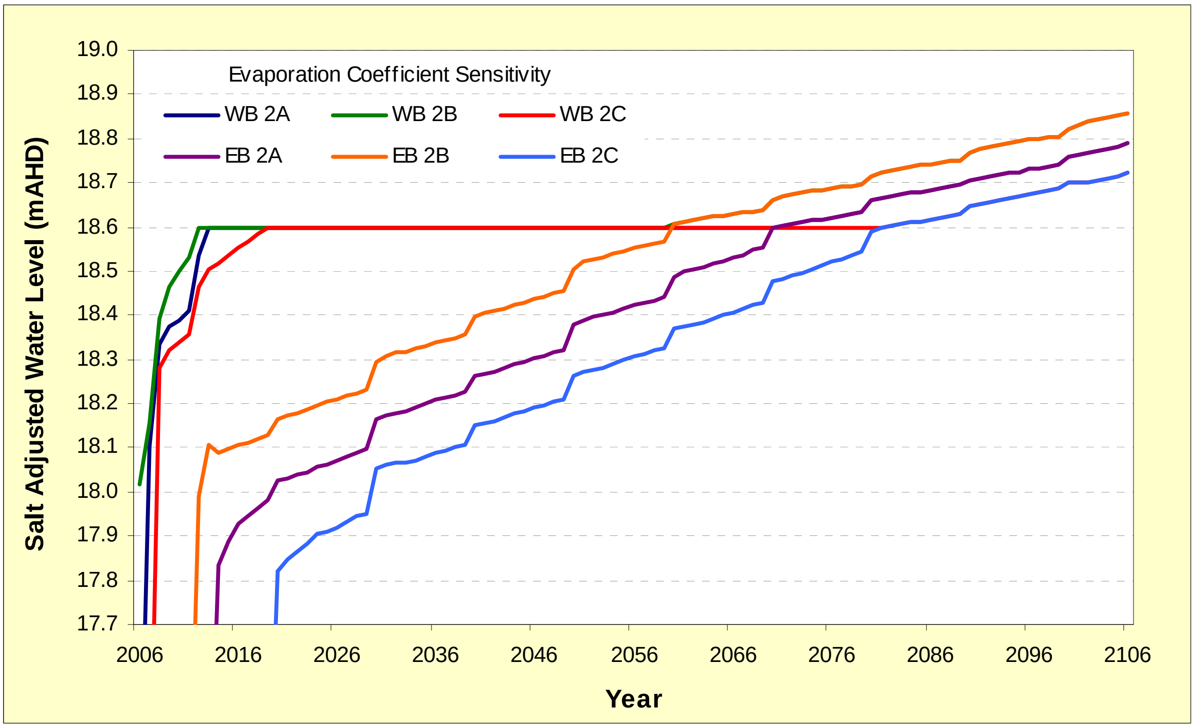


Figure 42 Sensitivity of Water Level to Evaporation Coefficient (E): Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS.

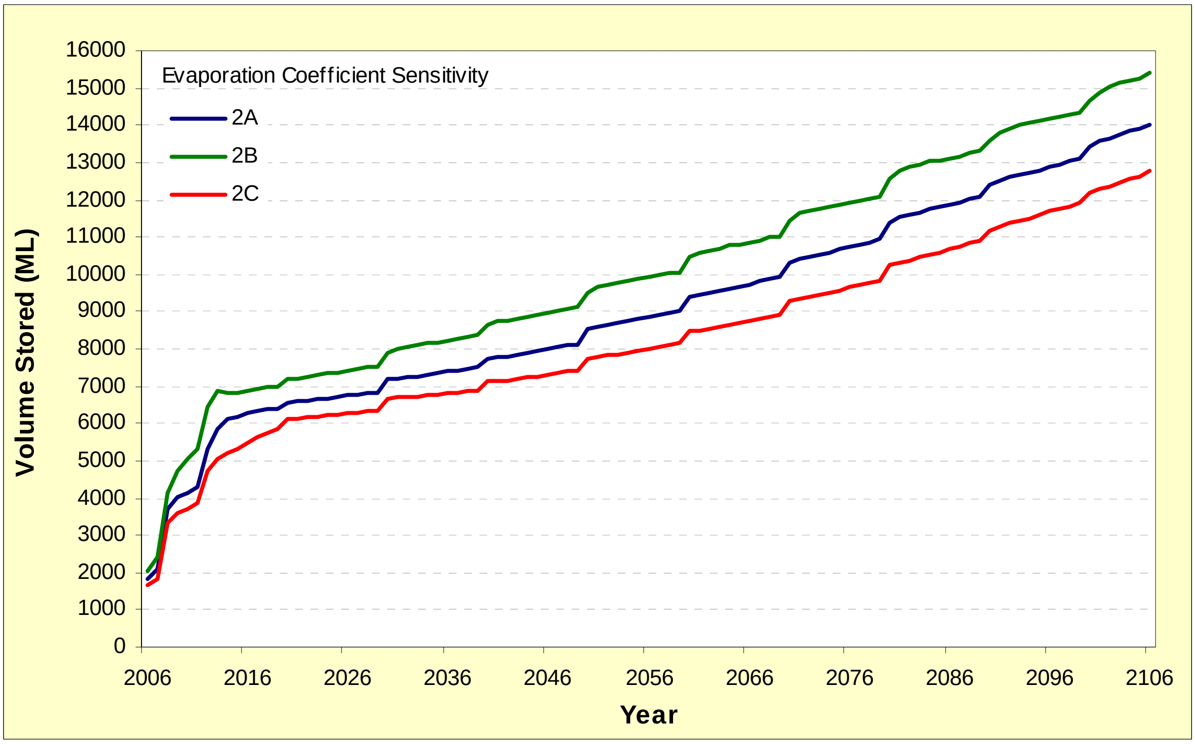


Figure 43 Sensitivity of Volume Stored to Evaporation Coefficient (E): Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS.

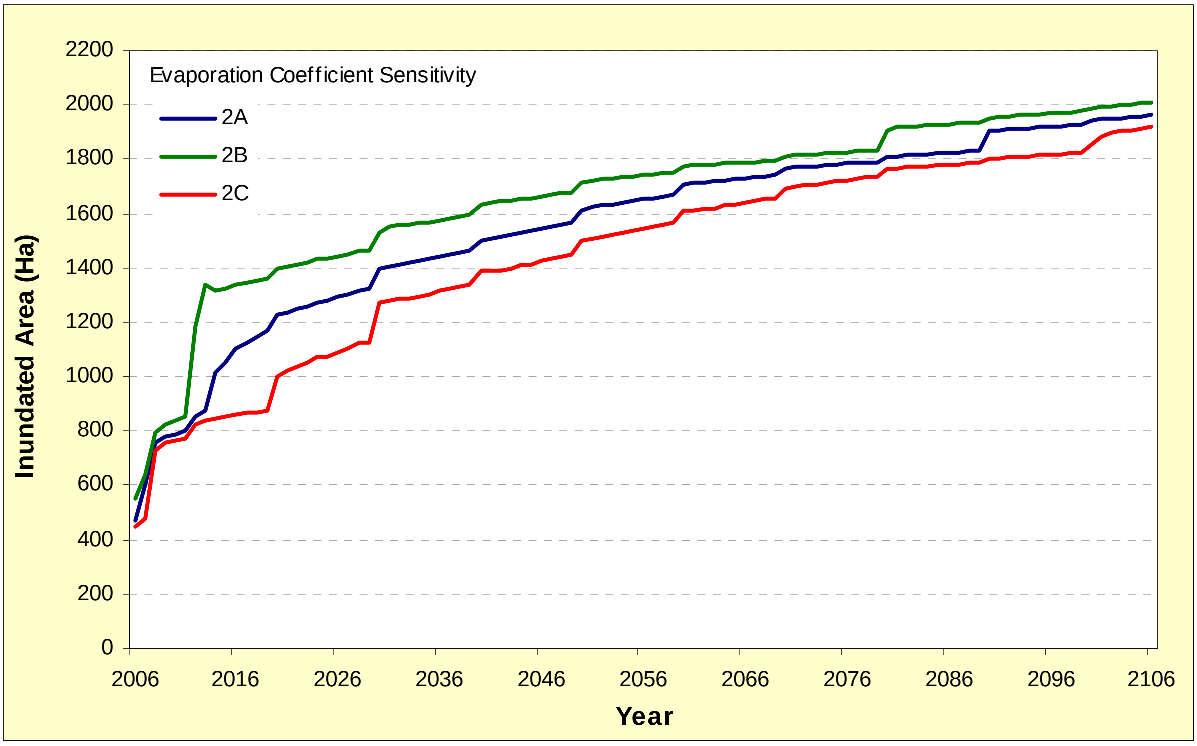


Figure 44 Sensitivity of Inundated Area to Evaporation Coefficient (E): Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS.

Table 25 shows the likely levels of precipitated salt in the Western and Eastern Basins under each evaporation coefficient and Table 26 provides the corresponding maximum salt concentrations. The higher evaporation coefficient leads to water moving into the Eastern Basin later, which increases the salinity in the Western Basin such that precipitation of salt is likely to occur in both basins. The reduced evaporation coefficient results in a lower salinity in the Western Basin and around 10% less precipitated salt in the Eastern Basin.

At their maximum water level and inundated area, Scenarios 2A, 2B and 2C produce 10.4, 11.7 and 11.0 million tonnes of precipitated salt with an equivalent volume of 5412, 4802 and 5083 ML respectively.

Table 25 Sensitivity of Maximum Precipitated Salt to Evaporation Coefficient (E): Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS.

Period	Maximum Western Basin Precipitated Salt (million tonnes)		
	2A (E = 0.65)	2B (E = 0.55)	2C (E = 0.75)
2006-2010	-	-	-
2011-2020	-	-	0.219
2021-2050	-	-	0.231
2051-2075	-	-	0.027
2076-2106	-	-	-
Period	**Maximum Eastern Basin Precipitated Salt (million tonnes)**		
	2A (E = 0.65)	**2B (E = 0.55)**	**2C (E = 0.75)**
2006-2010	-	-	-
2011-2020	0.372	0.685	0.039
2021-2050	3.270	3.729	2.434
2051-2075	6.697	6.711	5.712
2076-2106	11.716	10.396	11.005

Table 26 Sensitivity of Maximum Salt Concentration to Evaporation Coefficient (E): Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS.

Period	Maximum Western Basin Concentration (mg/L)		
	2A (E = 0.65)	2B (E = 0.55)	2C (E = 0.75)
2006-2010	197000	145000	225000
2011-2020	239000	157000	260000
2021-2050	235000	153000	260000
2051-2075	176000	110000	244000
2076-2106	133000	86000	195000
Period	**Maximum Eastern Basin Concentration (mg/L)**		
	2A (E = 0.65)	**2B (E = 0.55)**	**2C (E = 0.75)**
2006-2010	-	-	-
2011-2020	260000	260000	260000
2021-2050	260000	260000	260000
2051-2075	260000	260000	260000
2076-2106	260000	260000	260000

Figure 45 shows the salt stored in each basin and Figure 46 shows the maximum annual salt concentrations in the Western Basin. In each scenario, once flow into the Eastern Basin occurs, the salinity increases quickly to 260,000 mg/L.

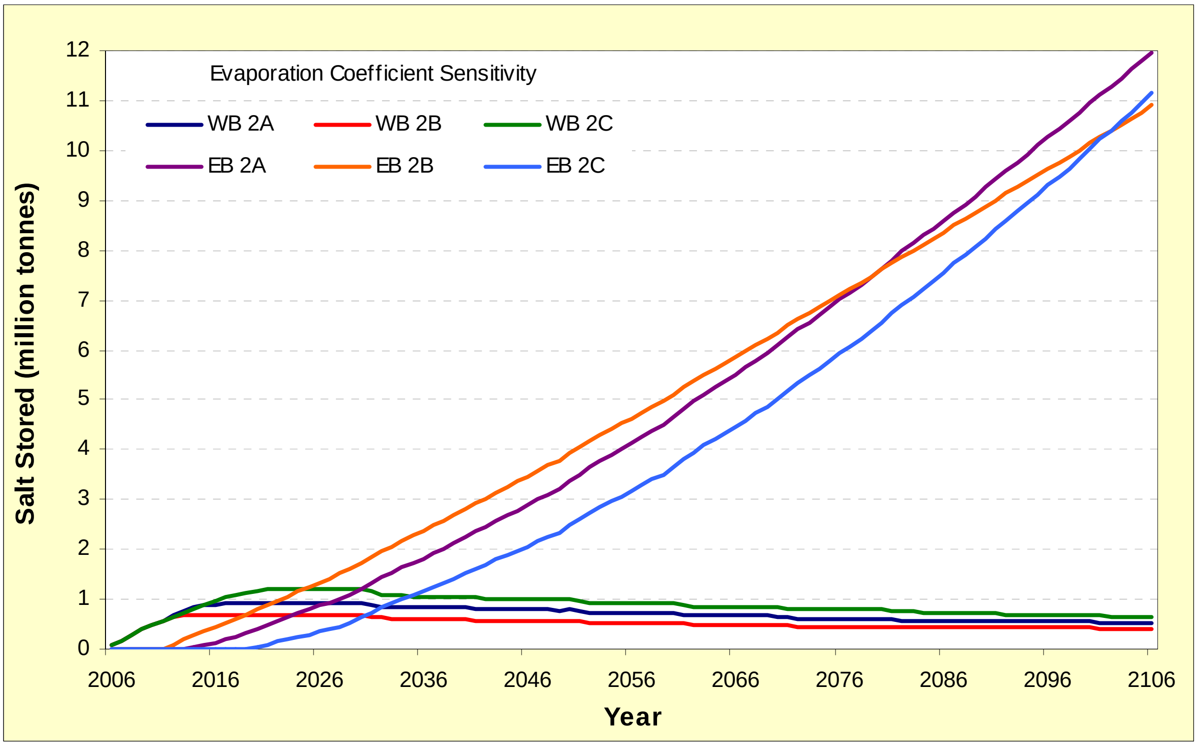


Figure 45 Sensitivity of Total Stored Salt to Evaporation Coefficient (E): Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS.

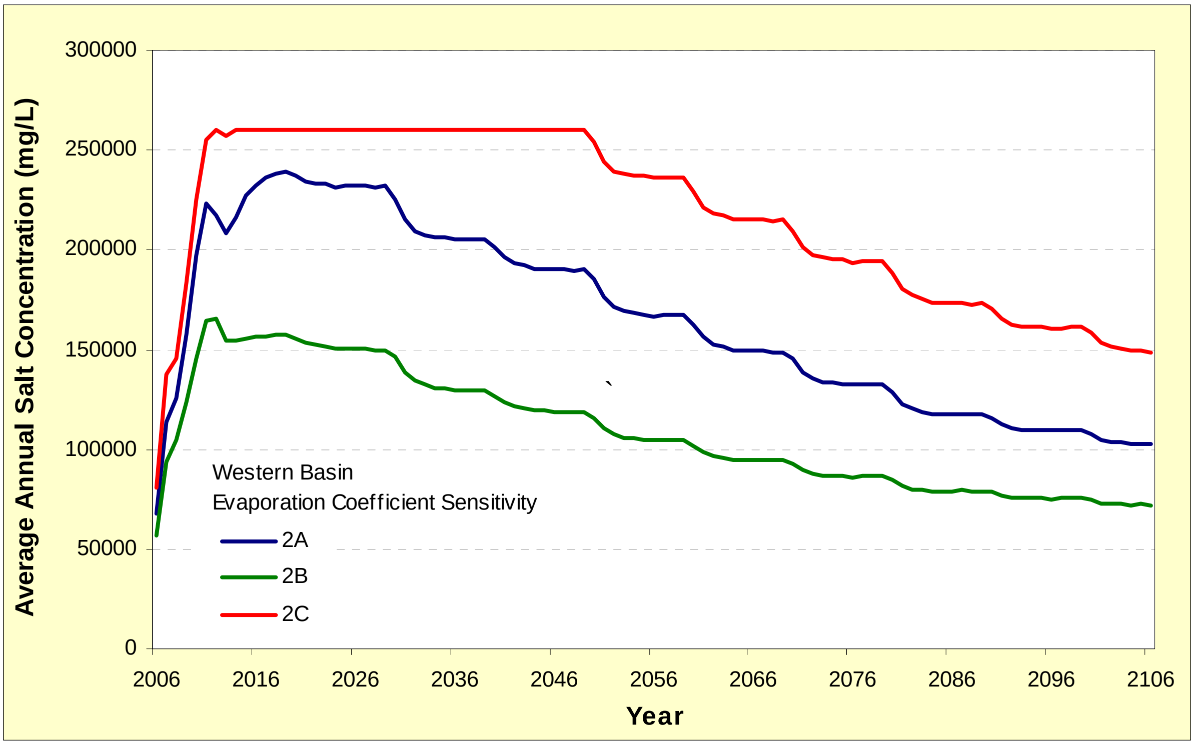


Figure 46 Sensitivity of Western Basin Salt Concentration to Evaporation Coefficient (E): Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS.

Infiltration Rate (Scenarios 2A, 2D and 2E)

The assumed infiltration rate of 0.2 mm/day was varied to 0.1 and 0.4 mm/day. Table 27 shows the variation in maximum water levels and Table 28 provides the variation in maximum stored volume and inundated areas.

Table 27 Sensitivity of Maximum Water Levels to Infiltration Rate (I): Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS.

Period	Maximum Western Basin Water Level (mAHD)		
	2A (I = 0.2)	2D (I = 0.1)	2E (I = 0.4)
2006-2010	18.39	18.43	18.34
2011-2020	18.60	18.60	18.54
2021-2050	18.60	18.60	18.60
2051-2075	18.62	18.71	18.60
2076-2106	18.79	18.93	18.60
Period	**Maximum Eastern Basin Water Level (mAHD)**		
	2A (I = 0.2)	**2D (I = 0.1)**	**2E (I = 0.4)**
2006-2010	-	-	-
2011-2020	18.02	18.14	-
2021-2050	18.38	18.53	18.10
2051-2075	18.62	18.71	18.31
2076-2106	18.79	18.93	18.56

Table 28 Sensitivity of Maximum Stored Volume and Inundated Areas to Infiltration Rate (I): Drainage, and Loxton, Bookpurnong and Murtho SIS.

Period	Total Volume (ML)		
	2A (I = 0.2)	2D (I = 0.1)	2E (I = 0.4)
2006-2010	4110	4424	3723
2011-2020	6554	7035	5404
2021-2050	8519	9781	6833
2051-2075	10664	12572	8029
2076-2106	14039	16828	9993
Period	**Total Inundated Area (Ha)**		
	2A (I = 0.2)	**2D (I = 0.1)**	**2E (I = 0.4)**
2006-2010	790	808	763
2011-2020	1230	1369	857
2021-2050	1615	1733	1325
2051-2075	1782	1910	1551
2076-2106	1965	2055	1747

As with adjusting the evaporation coefficient, reducing the infiltration rate leads to increased water levels over the period of basin operation but levels that are still below the maximum operating level of 19.0 mAHD.

Figure 47 shows the changing salt-adjusted water levels in the Eastern and Western Basins for each scenario. This indicates that the water level in the Western Basin reaches 18.6 mAHD two years earlier with the reduced infiltration rate and 16 years later with an increased coefficient. Only in Scenario 2E does the water level in the Eastern Basin not reach 18.6 mAHD. The effect of the changing infiltration rate on the total volume stored is then shown in Figure 48 and on the inundated area in Figure 49.

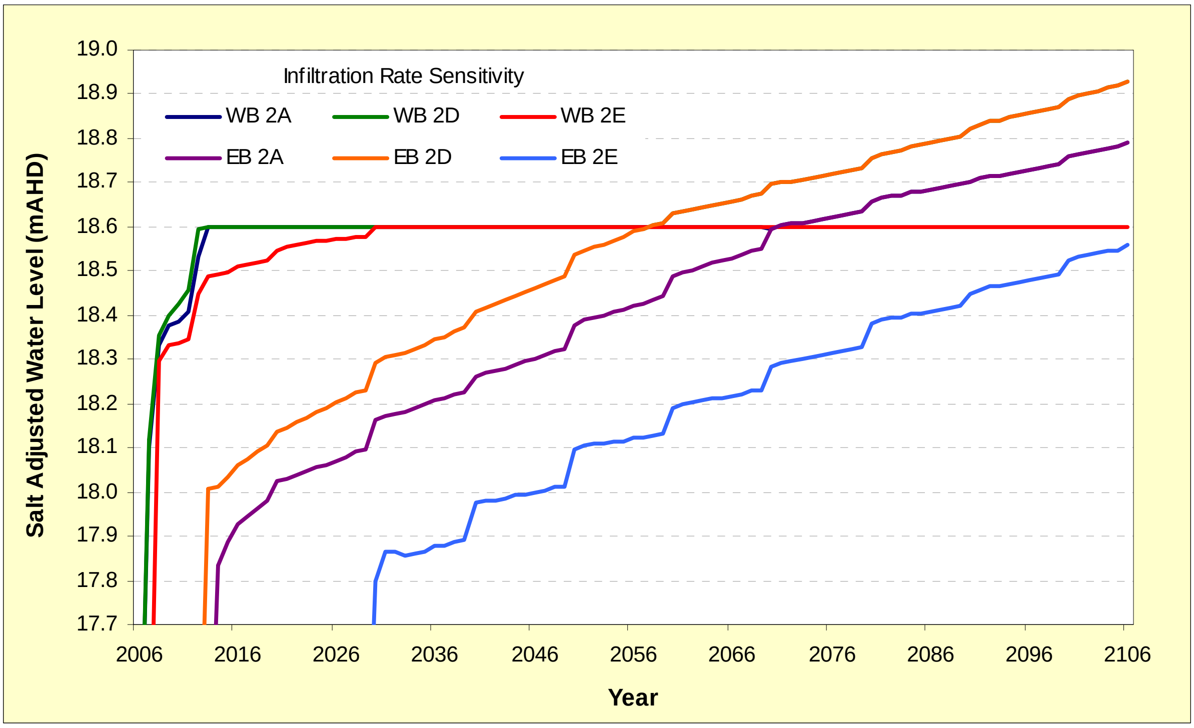


Figure 47 Sensitivity of Water Level to Infiltration Rate (I): Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS.

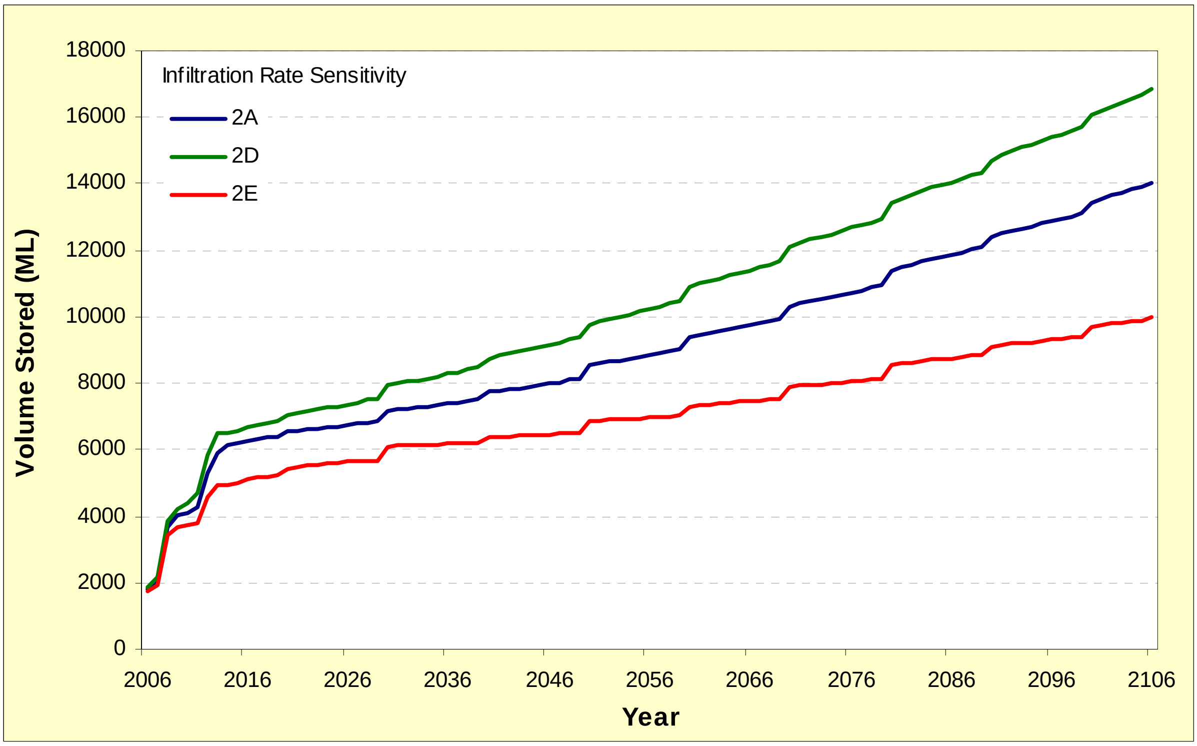


Figure 48 Sensitivity of Volume Stored to Infiltration Rate (I): Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS.

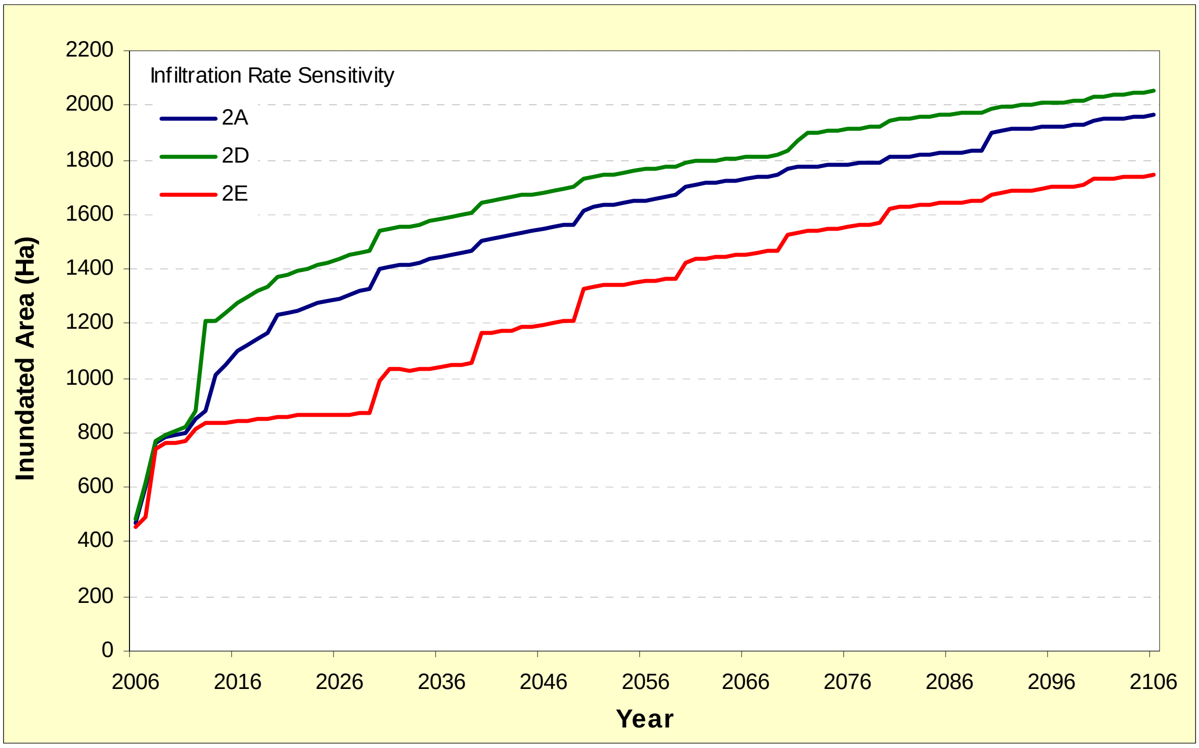


Figure 49 Sensitivity of Inundated Area to Infiltration Rate (I): Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS.

Table 29 shows the likely levels of precipitated salt in the Western and Eastern Basins under each infiltration rate and Table 30 provides the corresponding maximum salt concentrations. With both the higher and lower infiltration rates, precipitation is unlikely to occur at all in the Western Basin. The Western Basin results for the lower infiltration rate are quite similar to the primary case. In the Eastern Basin however, there is around 50% less precipitating salt. The reduced infiltration rate results in a slower movement of salt from the Western to the Eastern Basin as well as less transport of salt out of the system. The increased infiltration rate highlights the removal of salt from the basin, with less than half the precipitated salt.

Table 29 Sensitivity of Maximum Precipitated Salt to Infiltration Rate (I): Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS.

Period	Maximum Western Basin Precipitated Salt (million tonnes)		
	2A (I = 0.2)	2D (I = 0.1)	2E (I = 0.4)
2006-2010	-	-	-
2011-2020	-	-	-
2021-2050	-	-	-
2051-2075	-	-	-
2076-2106	-	-	-
Period	**Maximum Eastern Basin Precipitated Salt (million tonnes)**		
	2A (I = 0.2)	**2D (I = 0.1)**	**2E (I = 0.4)**
2006-2010	-	-	-
2011-2020	0.372	0.884	-
2021-2050	3.270	5.433	0.582
2051-2075	6.697	10.197	2.015
2076-2106	11.716	17.040	4.252

Table 30 Sensitivity of Maximum Salt Concentration to Infiltration Rate (I): Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS.

Period	Maximum Western Basin Concentration (mg/L)		
	2A (I = 0.2)	2D (I = 0.1)	2E (I = 0.4)
2006-2010	197000	211000	165000
2011-2020	239000	244000	211000
2021-2050	235000	238000	217000
2051-2075	176000	179000	170000
2076-2106	133000	133000	130000
Period	**Maximum Eastern Basin Concentration (mg/L)**		
	2A (I = 0.2)	**2D (I = 0.1)**	**2E (I = 0.4)**
2006-2010	-	-	-
2011-2020	260000	260000	-
2021-2050	260000	260000	260000
2051-2075	260000	260000	260000
2076-2106	260000	260000	260000

At their maximum water level and inundated area, Scenarios 2A, 2D and 2E produce 11.7, 17.0 and 4.3 million tonnes of precipitated salt with an equivalent volume of 5412, 7871 and 1934 ML respectively.

Figures 50 and 51 show the salt stored in each basin and Figure 52 shows the maximum annual salt concentrations in the Western Basin. As can be seen, the higher infiltration rate leads to significantly less salt stored in the basin initially, but from 2080 the concentrations in each scenario are almost the same. Once flow into the Eastern Basin occurs, the salinity increases quickly to 260,000 mg/L in each case.

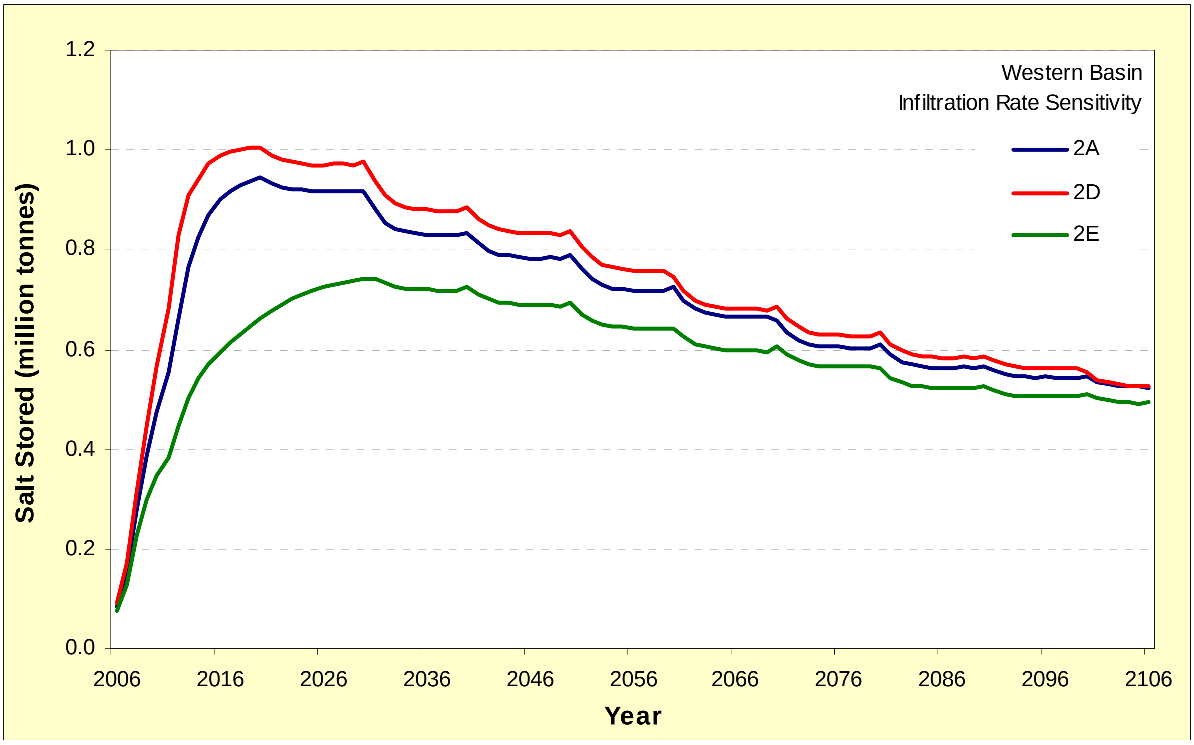


Figure 50 Sensitivity of Salt Stored in the Western Basin to Infiltration Rate(I): Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS.

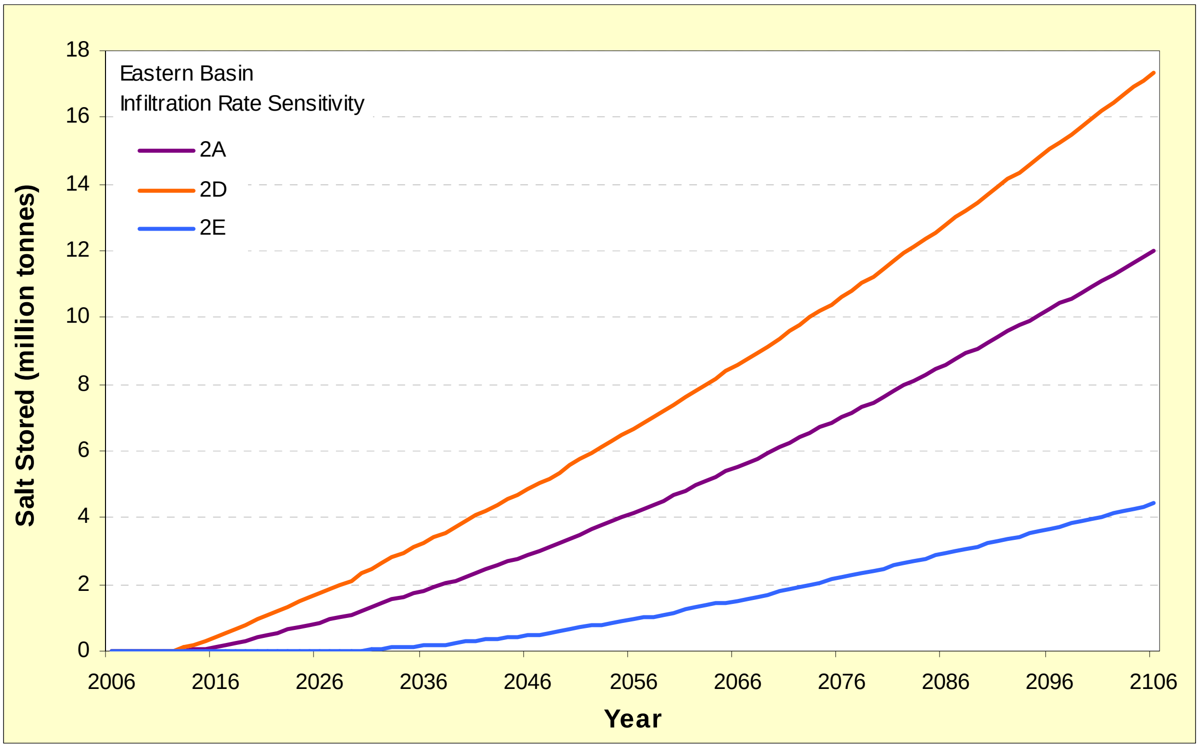


Figure 51 Sensitivity of Salt Stored in the Eastern Basin to Infiltration Rate(I): Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS.

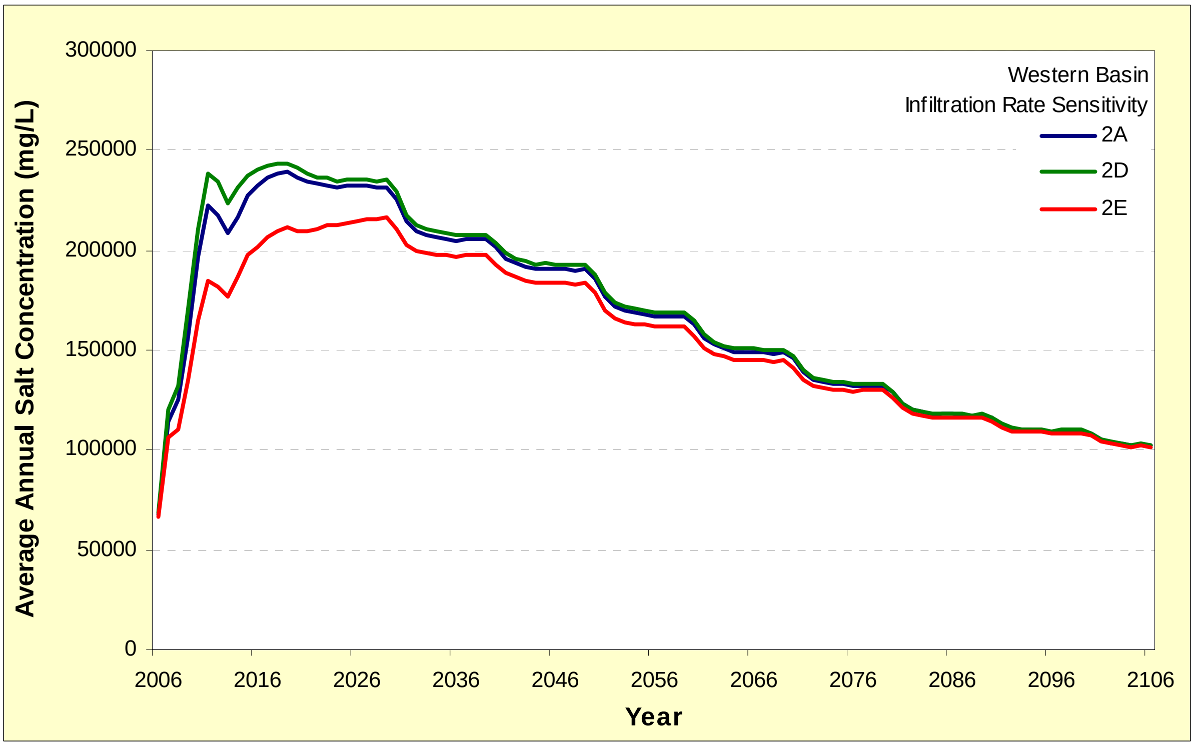


Figure 52 Sensitivity of Western Basin Salt Concentration to Infiltration Rate (I): Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS.

SIS Salt Concentration (Scenarios 2A, 2F and 2G)

The assumed SIS salt concentration of 26,000 mg/L was varied to 22,000 and 30,000 mg/L. Analysis of the sensitivity of model outputs to the evaporation coefficient and infiltration rate showed that water levels are highly likely to be less than 19.0 mAHD. However, the changes to model outputs were less uniform than would perhaps be expected by increasing and decreasing a parameter. Increasing and decreasing the SIS salt concentration produces less complex results.

Table 31 shows the variation in maximum water levels and Table 32 provides the variation in maximum stored volume and inundated areas. There is little difference between the results for these scenarios and this is confirmed in Figure 53 to Figure 55. The small differences are primarily due to the influence of salt concentration on the evaporation rate (refer Section 2.2.4).

Table 31 Sensitivity of Maximum Water Levels to SIS Salt Concentration (S_c): Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS.

Period	Maximum Western Basin Water Level (mAHD)		
	2A (S_c = 26000)	2F (S_c = 22000)	2G (S_c = 30000)
2006-2010	18.39	18.38	18.40
2011-2020	18.60	18.60	18.60
2021-2050	18.60	18.60	18.60
2051-2075	18.62	18.60	18.66
2076-2106	18.79	18.73	18.85
Period	**Maximum Eastern Basin Water Level (mAHD)**		
	2A (S_c = 26000)	**2F (S_c = 22000)**	**2G (S_c = 30000)**
2006-2010	-	-	-
2011-2020	18.02	17.98	18.07
2021-2050	18.38	18.32	18.43
2051-2075	18.62	18.56	18.66
2076-2106	18.79	18.73	18.85

Table 32 Sensitivity of Maximum Stored Volume and Inundated Areas to SIS Salt Concentration (S_c): Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS.

Period	Total Volume (ML)		
	2A (S_c = 26000)	2F (S_c = 22000)	2G (S_c = 30000)
2006-2010	4110	4048	4218
2011-2020	6554	6402	6717
2021-2050	8519	8099	8958
2051-2075	10664	9977	11383
2076-2106	14039	12881	15225
Period	**Total Inundated Area (Ha)**		
	2A (S_c = 26000)	**2F (S_c = 22000)**	**2G (S_c = 30000)**
2006-2010	790	785	797
2011-2020	1230	1165	1286
2021-2050	1615	1560	1663
2051-2075	1782	1746	1807
2076-2106	1965	1921	2004

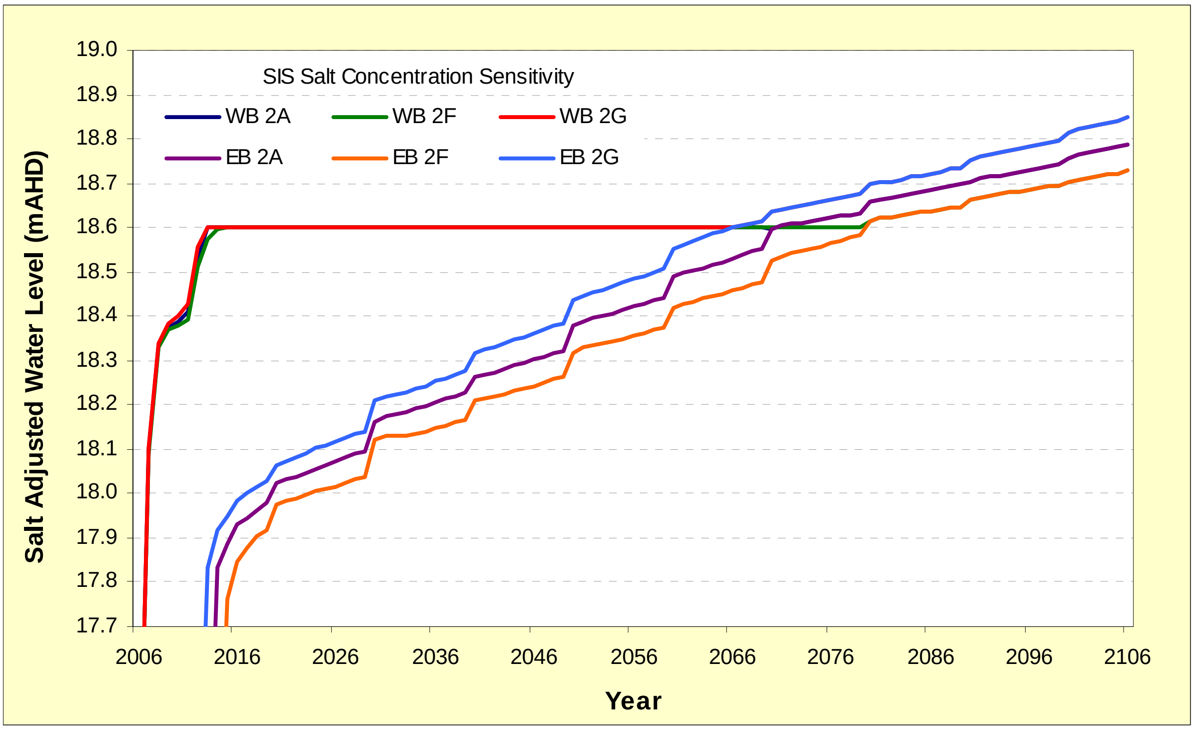


Figure 53 Sensitivity of Water Level to SIS Salt Concentration (S_c): Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS.

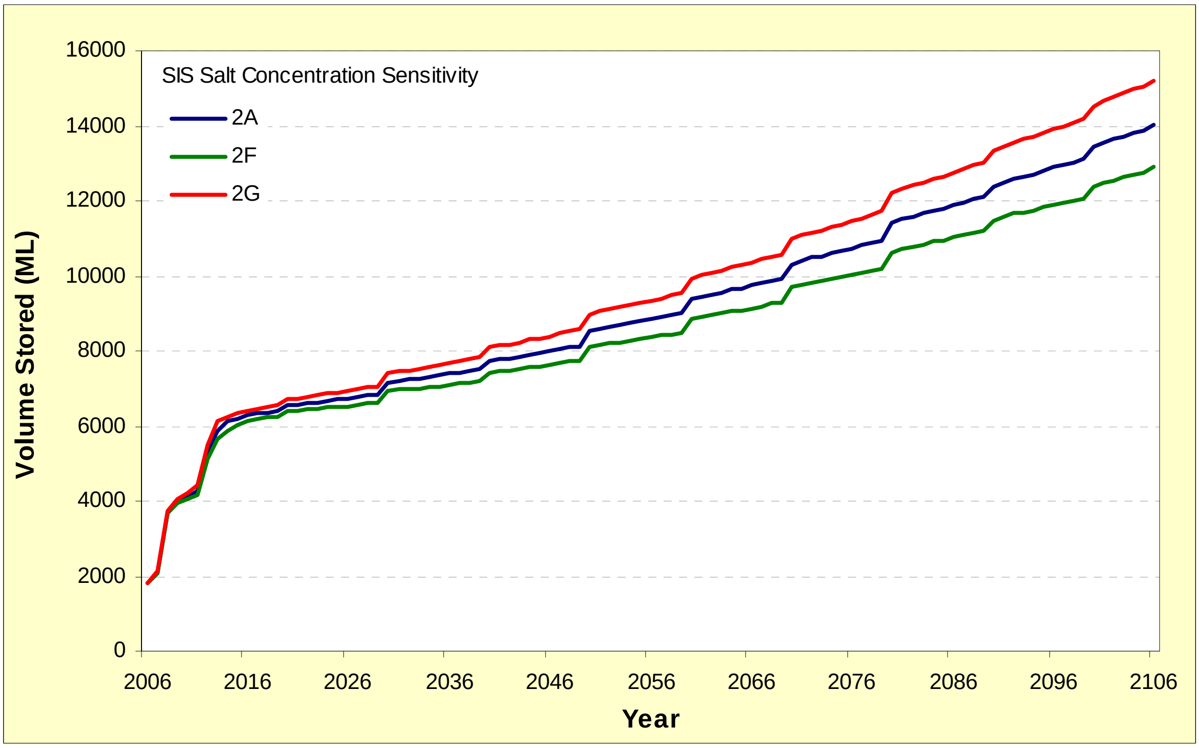


Figure 54 Sensitivity of Volume Stored to SIS Salt Concentration (S_c): Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS.

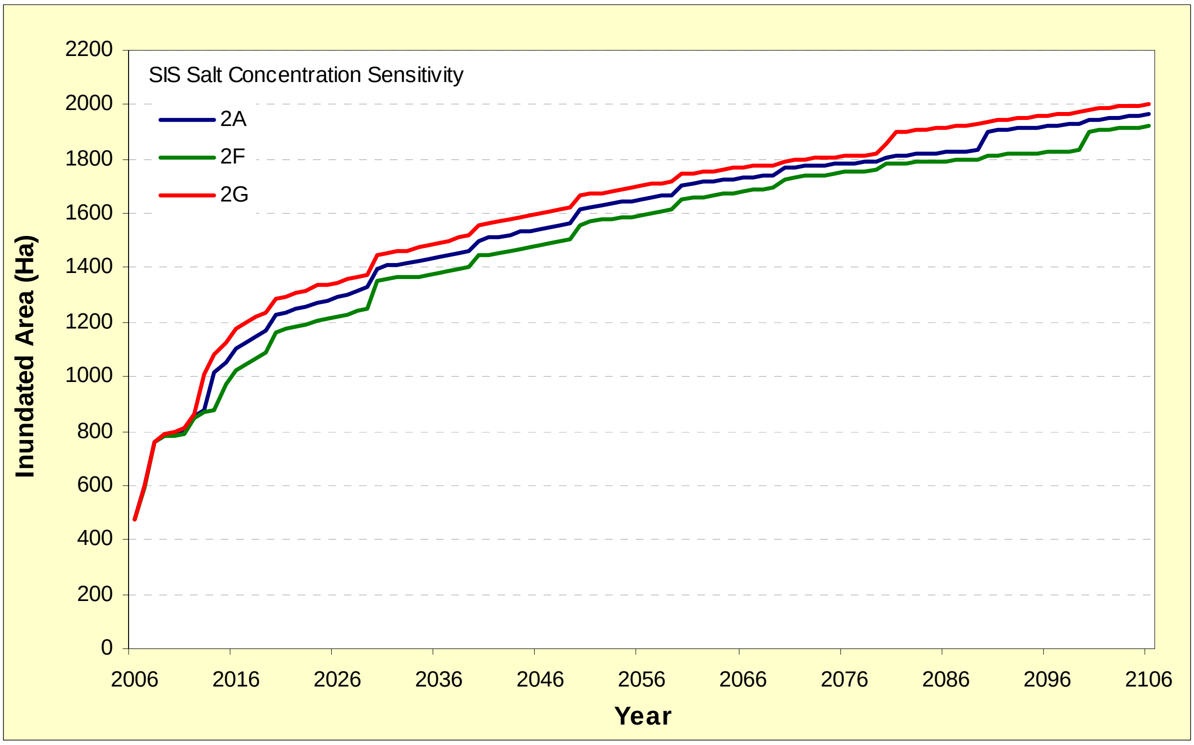


Figure 55 Sensitivity of Inundated Area to SIS Salt Concentration (S_c): Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS.

Table 33 shows the likely levels of precipitated salt in the Western and Eastern Basins under each SIS salt concentration and Table 34 provides the corresponding maximum salt concentrations. Even with the increased SIS salt concentration there is no precipitation of salt in the Western Basin, although the salinity is higher.

Table 33 Sensitivity of Maximum Precipitated Salt to SIS Salt Concentration (S_c): Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS.

Period	Maximum Western Basin Precipitated Salt (million tonnes)		
	2A (S_c = 26000)	2F (S_c = 22000)	2G (S_c = 30000)
2006-2010	-	-	-
2011-2020	-	-	-
2021-2050	-	-	-
2051-2075	-	-	-
2076-2106	-	-	-
Period	**Maximum Eastern Basin Precipitated Salt (million tonnes)**		
	2A (S_c = 26000)	**2F (S_c = 22000)**	**2G (S_c = 30000)**
2006-2010	-	-	-
2011-2020	0.372	0.221	0.540
2021-2050	3.270	2.527	4.053
2051-2075	6.697	5.322	8.125
2076-2106	11.716	9.364	14.129

Table 34 Sensitivity of Maximum Salt Concentration to SIS Salt Concentration (S_c): Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS.

Period	Maximum Western Basin Concentration (mg/L)		
	2A (S_c = 26000)	2F (S_c = 22000)	2G (S_c = 30000)
2006-2010	197000	176000	214000
2011-2020	239000	228000	249000
2021-2050	235000	224000	244000
2051-2075	176000	164000	188000
2076-2106	133000	118000	146000
Period	**Maximum Eastern Basin Concentration (mg/L)**		
	2A (S_c = 26000)	**2F (S_c = 22000)**	**2G (S_c = 30000)**
2006-2010	-	-	-
2011-2020	260000	260000	260000
2021-2050	260000	260000	260000
2051-2075	260000	260000	260000
2076-2106	260000	260000	260000

At their maximum water level and inundated area, Scenarios 1A, 1F and 1G produce 11.7, 9.4 and 14.1 million tonnes of precipitated salt with an equivalent volume of 5412, 4325 and 6526 ML respectively.

Figures 56 and 57 show the salt stored in each basin and Figure 58 shows the maximum annual salt concentrations in the Western Basin.

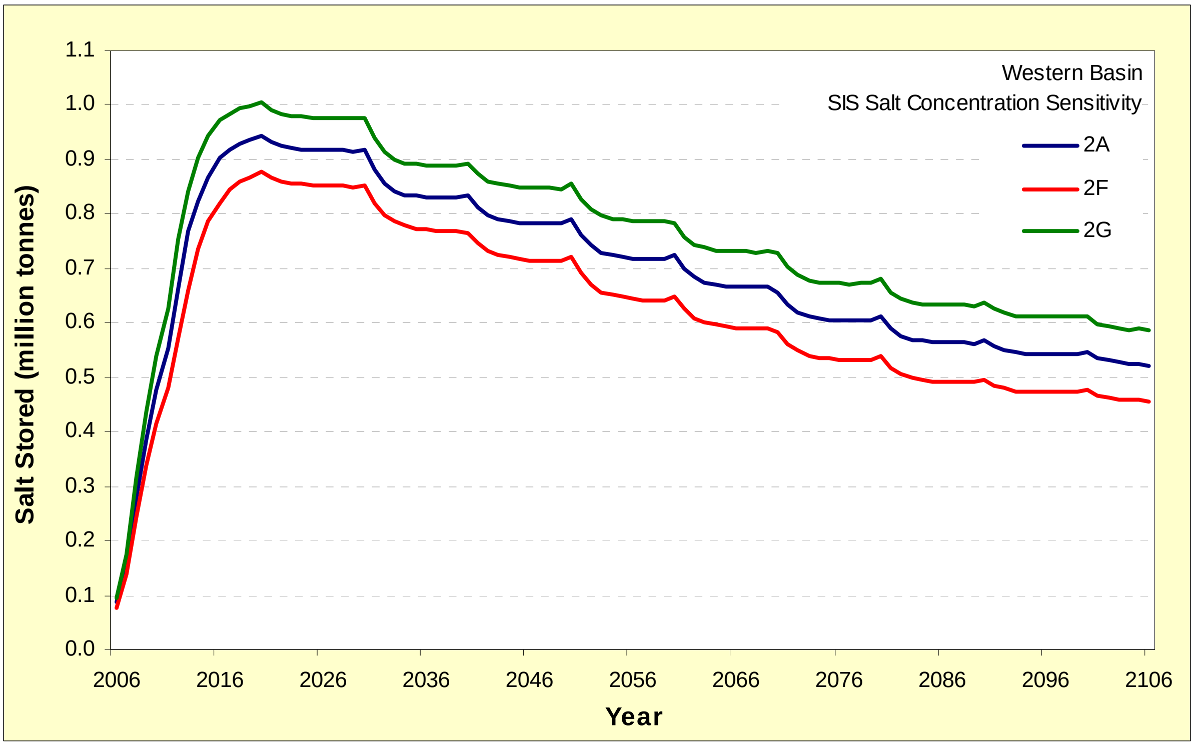


Figure 56 Sensitivity of Salt Stored in the Western Basin to SIS Salt Concentration (S_c): Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS.

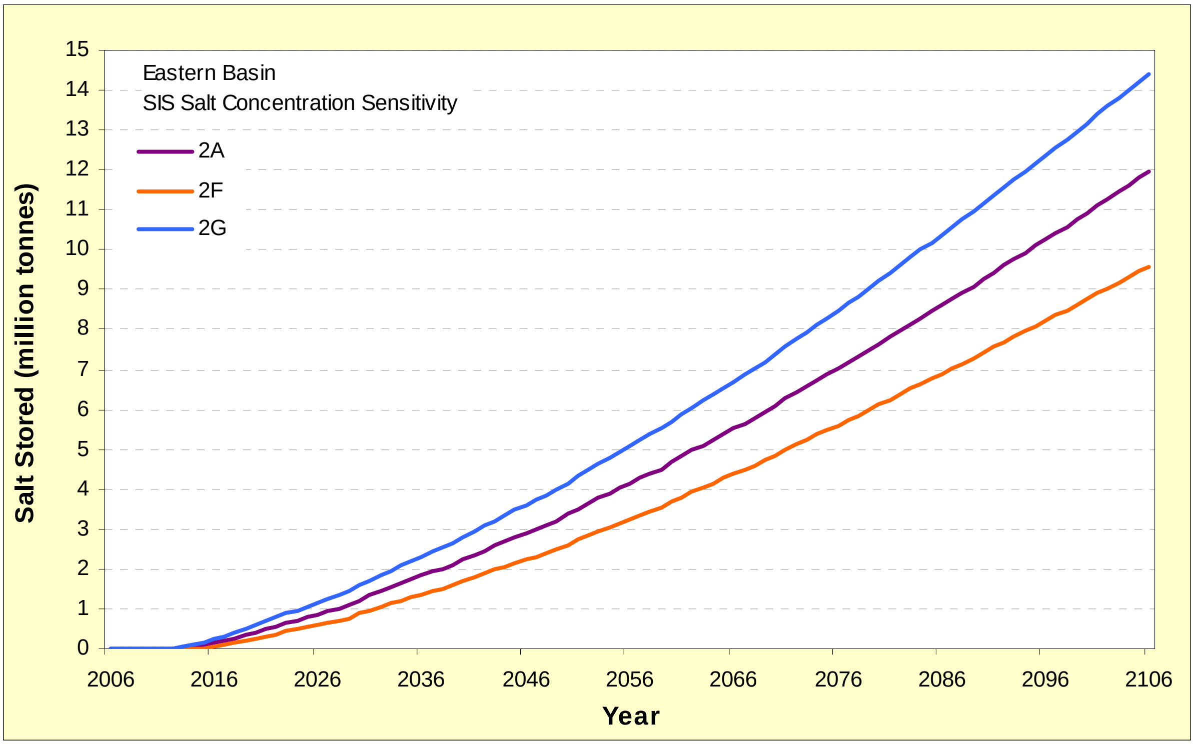


Figure 57 Sensitivity of Salt Stored in the Eastern Basin to SIS Salt Concentration (S_c): Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS.

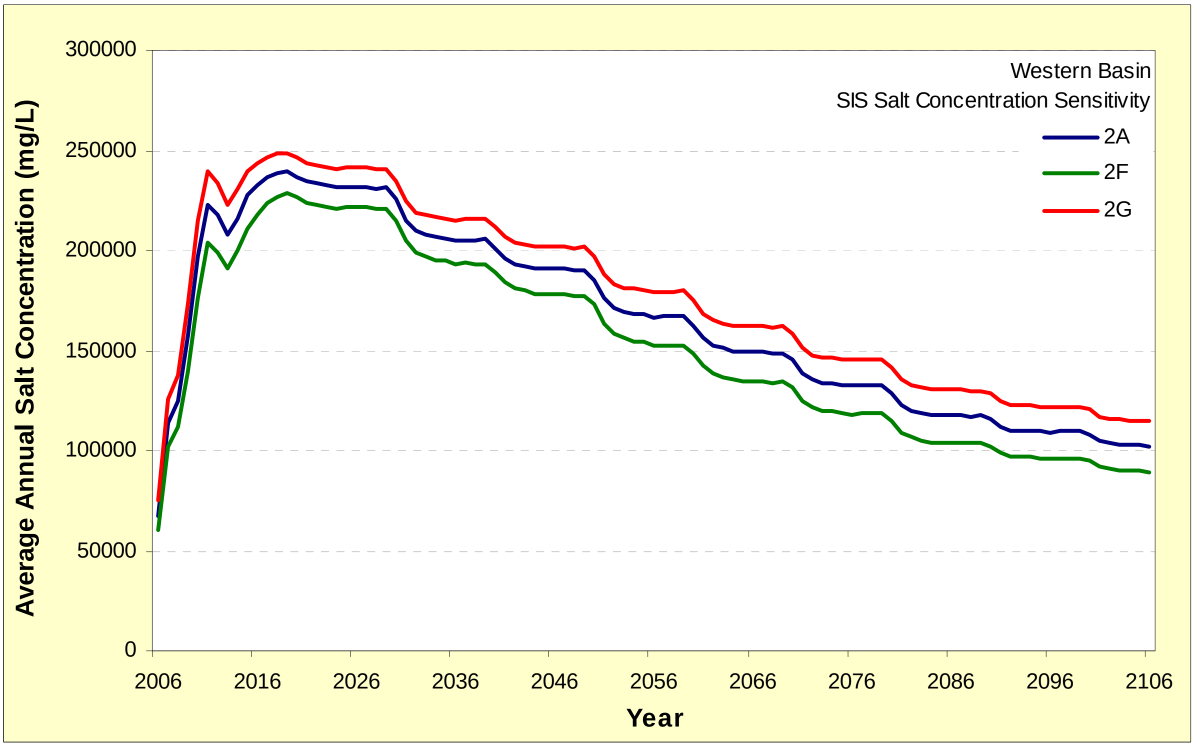


Figure 58 Sensitivity of Western Basin Salt Concentration to SIS Salt Concentration (S_c): Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS.

Comparison of Results of Sensitivity Analysis for Scenario 2

A comparison of Western and Eastern Basin water levels for Scenarios 2A to 2G are shown in Figures 59 and 60 respectively. These indicate that the infiltration rate again potentially has the greatest influence on water levels and the SIS salt concentration the least influence.

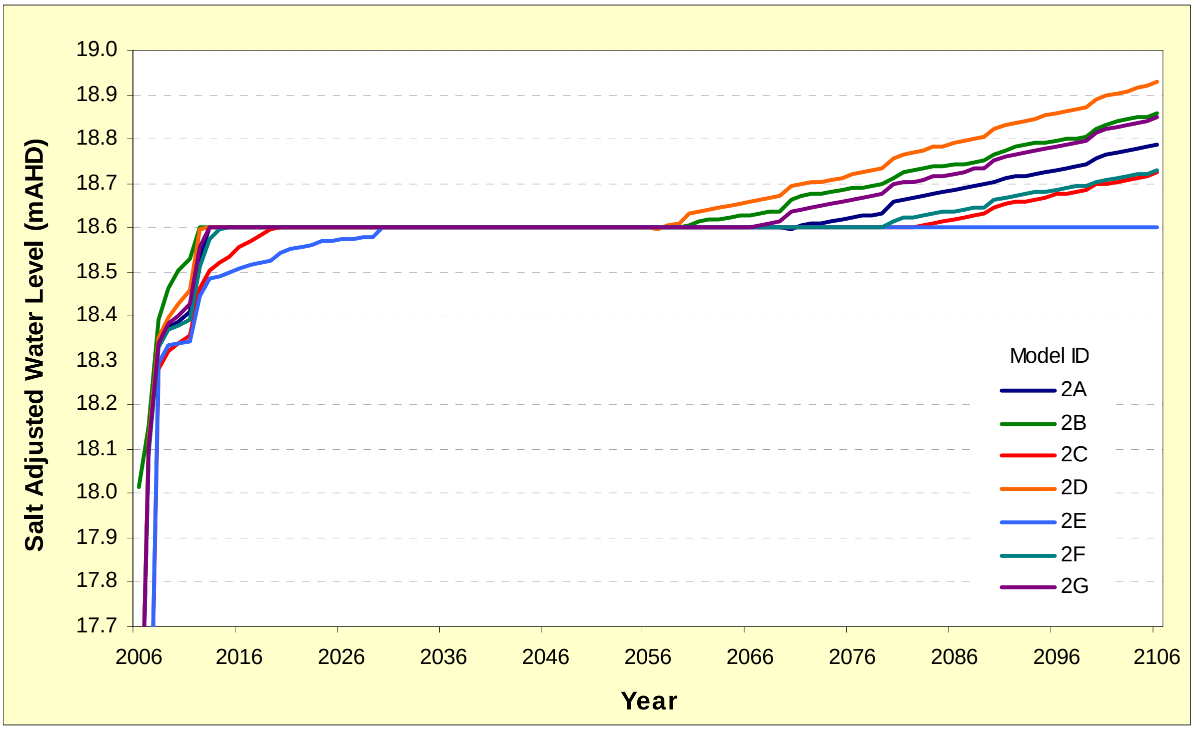


Figure 59 Comparison of Western Basin Water Level Sensitivity to Evaporation Coefficient (E), Infiltration Rate (I) and SIS Salt Concentration (S_c): Scenario 2.

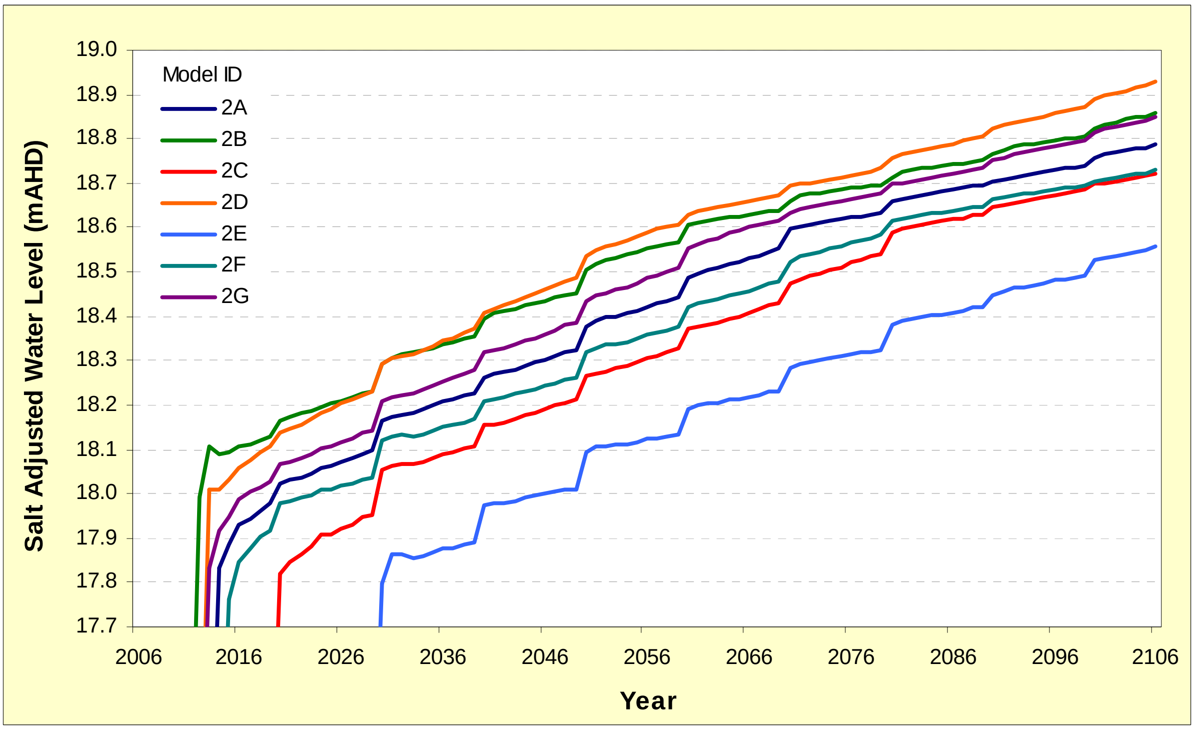


Figure 60 Comparison of Eastern Basin Water Level Sensitivity to Evaporation Coefficient (E), Infiltration Rate (I) and SIS Salt Concentration (S_c): Scenario 2.

3.4 VARIATION IN PUMPING RATES TO ACHIEVE TARGETED OPERATIONAL LEVELS

In Sections 3.2 and 3.3, it was shown that there is sufficient capacity within Noora Basin to accept the proposed drainage and Bookpurnong, Loxton, Murtho and Pike SIS pumping rates assuming a design maximum operating level of 19.0 mAHD. In this section, long-term average SIS pumping rates have been determined in order to achieve a range of maximum operating levels within the basin.

Figure 61 shows the maximum SIS discharges, assuming a constant drainage discharge of 40 L/s, that are possible for a given maximum operating level. This assumed a uniform pumping rate from 2006 to 2106 and uniform SIS salinity of 26,000 mg/L. The likely non-uniform nature of any pumping regime, will influence the final maximum water level as this alters the time that flows between the Western and Eastern Basins occur, which influences the water and salt lost through the evaporation and infiltration processes. However, Figure 61 does provide an indicative guide for easy reference.

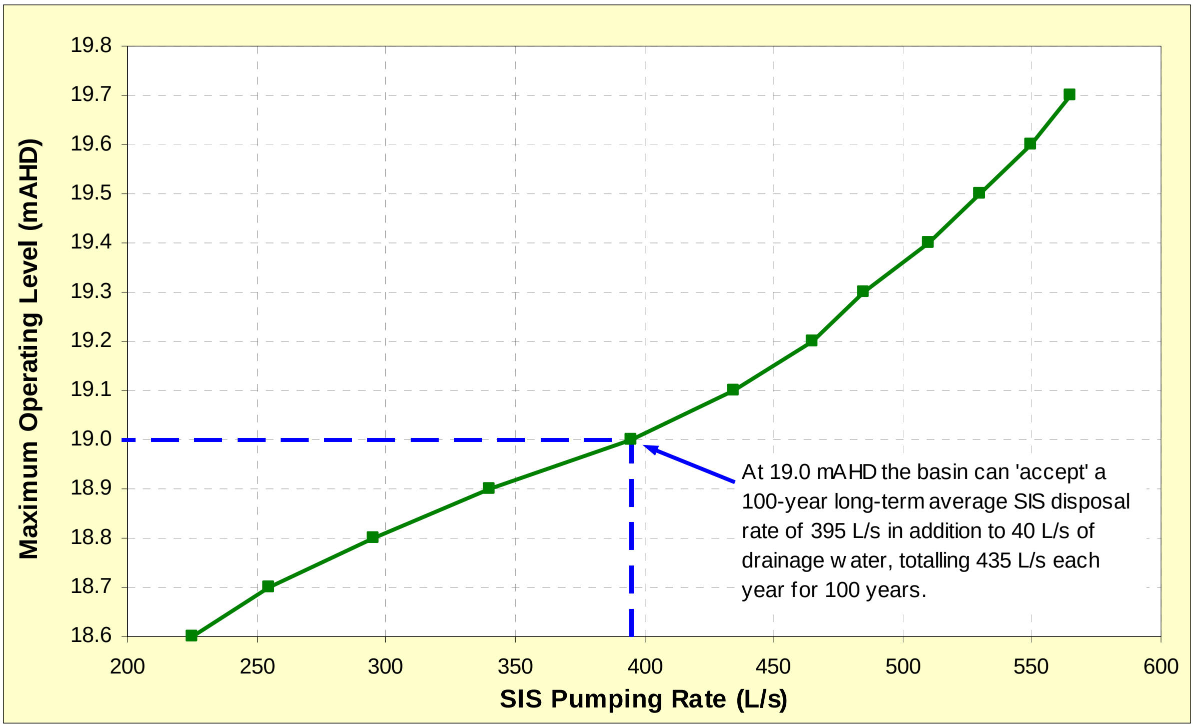


Figure 61 Maximum SIS Pumping Rates for Design Maximum Operating Levels.

Figure 61 highlights the significant level of surplus capacity that Noora Basin has at 19.0 mAHD in terms of potential SIS discharges. At 19.0 mAHD the basin has the capacity to receive 395 L/s of SIS water on average each year for 100 years. The Scenario 2 disposal schedule (for Bookpurnong, Loxton, Murtho and Pike SIS), when weighted against time, has a 100-year average yearly disposal rate of only 303 L/s.

4. SUMMARY AND DISCUSSION

Salt Interception Schemes (SIS) along the River Murray intercept highly saline groundwater before it discharges into the river. A crucial component to the development of new schemes at Bookpurnong, Loxton, Murtho and Pike was the identification of a site with enough capacity to store and evaporate this intercepted groundwater. Noora Basin currently receives discharges from the Bookpurnong SIS and from the Renmark and Berri irrigation areas but is under-utilised and hence has excess capacity available. Therefore, it has been proposed to use this area to store the additional intercepted water from the Loxton SIS currently under construction, the proposed Murtho SIS and potentially from a future Pike SIS.

This report presents an evaluation of the disposal capacity of Noora Basin, to assess the ability of this primary disposal area to accept the planned increases in pumping volumes and salinities over the next 100 years, as well as to assess disposal capacity at different operating levels, notably 19.0 mAHD. This evaluation was mainly driven by the need to:

- Support the Murtho SIS approval submission currently before the Murray-Darling Basin Commission (MDBC). The model results will provide SA and the other MDBC-partner governments with a technical confidence assessment of the basin capacity to form a viable and sustainable part of the Murtho SIS.
- Help refine the South Australian Regional Disposal Strategy (RDS) by predicting the long-term capacity of the basin and its potential to receive water from future possible SIS schemes such as Pike.
- Provide predictive estimates of basin inundation and water levels that will enable groundwater modelling to proceed to predict groundwater level changes within aquifers beneath and surrounding Noora Basin. These groundwater predictions in turn will be used by SA to undertake risk assessments of the potential impacts from the expanded Noora Basin operation on surrounding vegetation and land use.

To enable this evaluation, a monthly salt-water balance model was developed. This allowed the continuous accounting of water and salt moving into and out of the basin, as well as permitting the easy evaluation of changing input parameters such as pumping rates.

Three scenarios were evaluated, in particular:

- Scenario 1: Drainage, and Loxton, Bookpurnong and Murtho SIS disposal.
- Scenario 2: Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS disposal.
- Scenario 3: Variation in pumping rates to achieve targeted operational levels.

The extent of Noora Basin covers around 16,000 Ha, but topography encloses a primary disposal area of approximately 3,300 Ha, which is primarily Government owned. This area is enclosed at a height of 19.7 mAHD. There are two roads crossing the basin, one running north-south and the other east-west, which are at an elevation of 20 mAHD. Therefore, engineering works are likely to be required to prevent erosion and ensure stability of these roads and associated infrastructure if or when the water level is raised above 19.0 mAHD. As such, 19.0 mAHD was considered an upper limit for ponded water levels.

The results from the scenarios above are described in the following, together with the results of the sensitivity analysis and recommendations for monitoring.

Pumping from Drainage Basins

Volumes pumped from the Renmark and Berri irrigation areas to the basin have decreased from a peak discharge of 6,000 ML/year in 1982-83 to generally less than 2,000 ML/year since 2000-01. The salinities of the discharged water have ranged from 3,000 to 37,000 mg/L. Recently, the lower volumes of drainage water pumped have been of higher salinities due to increased evapo-concentration within the temporary basins located in the irrigation areas before pumping to Noora. However, due to the lower volumes pumped, the overall salt loads pumped to the basin have been lower.

The non-uniform nature of the drainage volumes pumped has necessitated an estimation of an equivalent continuous volume or average equivalent pumping rate. This equivalent average pumping rate equates to the total annual volume pumped continuously over each year. This was calculated at 40 L/s, based on the volumes pumped since 2001-02 and the high probability of similar volumes being pumped into the future, and equated to these volumes.

At 40 L/s, the total volume of drainage pumped between 2006 and 2106 would be 127 GL, with a salt load of 2.42 million tonnes.

Scenario 1: Drainage, and Loxton, Bookpurnong and Murtho SIS Pumping

The model indicates that there is sufficient capacity within Noora Basin to accept the proposed drainage and Bookpurnong, Loxton and Murtho SIS pumping rates. Under this scenario it was shown that:

- the proposed rates equate to a volume pumped of 747 GL with a salt load of 18.5 million tonnes.
- flow into the Eastern Basin is unlikely before 2035.
- precipitation of salt in the Western Basin is likely prior to flow into the Eastern Basin and for a number of years afterwards (until salinities reduce).
- the maximum water level reached is 18.60 mAHD in the Western Basin and 18.47 mAHD in the Eastern Basin.
- the maximum stored volume (water and salt) is around 9300 ML, inundating an area of 1700 Ha.
- at the maximum water level and inundated area, the combined basins are likely to store over 6.0 millions tonnes of salt, of which 5.3 million tonnes precipitated in the Eastern Basin, displacing 2,432 ML of water.
- it is likely that large areas of the basin would not be inundated under this scenario.

Scenario 2: Drainage, and Loxton, Bookpurnong, Murtho and Pike SIS Pumping

The model indicates that there is sufficient capacity within Noora Basin to accept the proposed drainage and Bookpurnong, Loxton, Murtho and Pike SIS pumping rates. Under this scenario it was shown that:

- the proposed rates equate to a volume pumped of 969 GL with a salt load of 24.3 million tonnes.
- flow into the Eastern Basin is likely by 2014.
- precipitation of salt in the Western Basin is unlikely as the higher discharges cause flow into the Eastern Basin to occur much earlier than in Scenario 1A; once flow to the Eastern Basin occurs, salinities in the Western Basin also decrease more quickly.
- the maximum basin water level reached is 18.79 mAHD.

- the maximum stored volume (water and salt) is around 14,000 ML, inundating an area of 1950 Ha.
- at the maximum water level and inundated area the combined basins are likely to store over 12.6 million tonnes of salt, of which 11.7 million tonnes precipitated in the Eastern Basin, displacing 5412 ML of water.
- it is likely that large areas of the basin not inundated under Scenario 1A would be inundated under Scenario 2A

Sensitivity Analysis

The sensitivity of the model outputs from Scenarios 1 and 2 to the evaporation coefficient, infiltration rate and SIS salt concentration were tested. Each parameter was increased and decreased from the assumed value to determine the sensitivity of that individual parameter, in particular:

- the evaporation coefficient model value of 0.65 decreased to 0.55 and increased to 0.75 (and effectively incorporates rainfall variation)
- the infiltration rate model value of 0.2 mm/day decreased to 0.1 mm/day and increased to 0.4 mm/day, based on results of previous modelling studies
- the SIS salt concentration model value of 26,000 mg/L decreased to 22,000 mg/L and increased to 30,000 mg/L.

It was found that:

- with reduced evaporation or infiltration or increased SIS salt concentrations, the resulting water levels were still below the maximum operating level of 19.0 mAHD over 100 years.
- the infiltration rate potentially has the greatest influence on water levels and the SIS salt concentration the least influence.
- an infiltration rate of 0.4 mm/day leads to significantly reduced levels of precipitated salt, but some precipitation is still predicted at this infiltration rate.
- lower evaporation rates are likely to lead to less salt precipitation in the Western Basin as water begins moving into the Eastern Basin earlier.

Scenario 3: Variation in Pumping Rates to Achieve Targeted Operational Levels

Maximum SIS pumping rates, coupled with drainage discharges of 40 L/s, have been determined in order to achieve a range of maximum operating levels within the basin. These SIS rates varied from 255 L/s to achieve a maximum water level of 18.7 mAHD to 555 L/s if water could be retained to a level of 19.7 mAHD. The likely non-uniform nature of any pumping regime will influence the final maximum water level, as this alters the time that flows between the Western and Eastern Basins occur, which influences the water and salt lost through the evaporation and infiltration processes. However, the calculated discharges shown highlight the significant level of surplus capacity that Noora Basin has (at 19.0 mAHD) above that required for development of new salt interception schemes at Murtho and/or Pike.

Monitoring

Limited volumes of drainage water have historically been discharged into Noora Basin and Section 2.3 indicated that the monitoring of these discharges, in particular, the resulting water levels, salinities and inundated areas has been limited. Therefore, monitoring should be an important component to ongoing basin operation to allow verification and reconciliation of the modelled results contained in this report. It will also allow an understanding of the impact that salt has on the evaporation process as well as the precipitation mechanisms to be developed.

The volume and quality of water discharge to the basin should be continuously recorded. Continuous water level and salinity recorders should be placed at strategic locations throughout the Western Basin. In addition to providing the benefit of an ongoing record of water levels and salinities, downloading data every few months is likely to be as cost effective as regular manual readings over long periods. Continuous recording will allow any effects of wind to be taken into account. Monitoring in the Eastern Basin can be implemented once flow into this basin occurs. It may be beneficial to install a rain gauge and evaporation pan on site to remove uncertainties related to the translation of data from existing sites.

The model assumes that there will be good circulation within the Western Basin as water moves from the discharge point in the north-west to the south and east, and through the culverts on the north-south road. Therefore, regular, visual inspections of the basin should also be undertaken, particularly in areas where reduced circulation is likely, to determine the locations of any precipitating salt.

The levels of basin water and salt monitoring adopted for the expanded basin operation are expected to be driven by the need to reconcile actual and predicted disposal capacity and for reconciling groundwater impact modelling.

The basin modelling results show a significant surplus disposal capacity at 19.0 mAHD, so the need for detailed monitoring and reconciliations of the salt and water balance may not be immediately significant. However, given the current policy of SA to optimise the use of the two existing disposal basins (Stockyard Plain and Noora) instead of developing new basins, it is conceivable that additional waters may be considered for discharge to Noora, which would reduce the predicted surplus and make reconciliations of actual versus predicted more important.

Any future revisions or reconciliations of the associated Noora Basin groundwater model will depend on being able to stipulate actual areas of basin inundation, operating levels and salinities to a reasonable level of accuracy.

The Infrastructure and Business Division of DWLBC, with the assistance of other DWLBC Divisions, Rural Solutions SA, SA Water and REM, is currently preparing a comprehensive Noora Basin Monitoring Framework and Monitoring Plan that will address the environmental and technical management issues associated with expanded operation of the Noora Basin.

5. REFERENCES

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GLOSSARY

Adaptive management — A management approach, often used in natural resource management, where there is little information and/or a lot of complexity, and there is a need to implement some management changes sooner rather than later. The approach is to use the best available information for the first actions, implement the changes, monitor the outcomes, investigate the assumptions, and regularly evaluate and review the actions required. Consideration must be given to the temporal and spatial scale of monitoring and the evaluation processes appropriate to the ecosystem being managed.

Ambient — The background level of an environmental parameter (e.g. a background water quality such as salinity).

Ambient water monitoring — All forms of monitoring conducted beyond the immediate influence of a discharge pipe or injection well, and may include sampling of sediments and living resources.

BoM — Bureau of Metrology, 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 to indicate the salinity of water.

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

Geomorphology — The scientific study of the landforms on the Earth's surface and of the processes that have fashioned them.

GL — Gigalitre**.** One thousand million litres (1 000 000 000).

GIS — Geographic information system. Computer software linking geographic data (for example land parcels) to textual data (soil type, land value, ownership). It allows for a range of features, from simple map production to complex data analysis.

Groundwater — *See underground water.*

Hydrogeology — The study of groundwater, which includes its occurrence, recharge and discharge processes, and the properties of aquifers. *(See hydrology.)*

Hydrography — The discipline related to the measurement and recording of parameters associated with the hydrological cycle, both historic and real time.

Hydrology — The study of the characteristics, occurrence, movement and utilisation of water on and below the Earth's surface and within its atmosphere. *(See hydrogeology.)*

Hydrometric — Literally relating to *water measurement*, from the Greek words *hydro* (water) and *metrikos* (measurement). See also DWLBC fact sheet FS1 <http://www.dwlbc.sa.gov.au/assets/files/fs0001_hydrometric_surface_water_monitoring.pdf>.

HYDSTRA — A time series data management system that stores continuously recorded water-related data such as water level, salinity and temperature. It provides a powerful data analysis, modelling and simulation system. Contains details of site locations, setup and other supporting information.

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.

MDBC — Murray–Darling Basin Commission.

ML — Megalitre**.** One million litres (1 000 000).

Natural recharge — The infiltration of water into an aquifer from the surface (rainfall, streamflow, irrigation etc.). *(See recharge area.)*

Recharge area — The area of land from which water from the surface (rainfall, streamflow, irrigation, etc.) infiltrates into an aquifer. *(See natural recharge.)*

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

Underground water (groundwater) — Water occurring naturally below ground level or water pumped, diverted or released into a well for storage underground.

Water-use year — The period between 1 July in any given calendar year and 30 June the following calendar year. This is also called a licensing year.