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Department for Water

COORONG SOUTH LAGOON FLOW RESTORATION PROJECT

– Hydrological modelling and transmission loss analysis

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EXECUTIVE SUMMARY

The Coorong, along with the Lower Lakes and Murray Mouth, is one of the largest of the internationally significant wetlands recognised under the Ramsar Convention within the Murray Darling Basin in South Australia. Severe drought in the Basin over recent years has resulted in record low inflows and has had a significant impact on the ecological health of the Coorong.

The Coorong South Lagoon Flow Restoration Project has to date investigated options for diverting significant volumes of water from the South East drainage network northwards to the Coorong using a combination of purpose-built floodways and existing flow -paths. However, there are still further volumes that flow west and out to sea through the Lower South East constructed drainage network that could potentially be diverted north and delivered to the Coorong South Lagoon (CSL).

The aim of this study is to extend previous studies (Way and Heneker 2007; AWE 2009a) and provide greater confidence in the estimates of water availability from the untapped resources of the South East drainage network for possible diversion to the south lagoon of the Coorong. This study focuses on three flow-paths that extend from Drain M to the CSL via:

- the Taratap and Tilley Swamp area (Flow-path 02)
- the Southern Ephemeral Lakes (Flow-path 03—SELs)
- a floodway that bypasses the Southern Ephemeral Lakes path (Flow-path 03—Floodway).

The median and average yield expected to be delivered to the CSL was modelled for existing flow-paths that have been identified in previous studies (Flow-path 02 and Flow-path 03—SELs), as well as a new flow-path that has been proposed in an attempt to reduce the losses involved in diverting water through lagoons (Flow-path 03—Floodway). The study also considered three climate scenarios to assess the potential reduction in yield due to climate change: historic climate, 2030 median climate (CCM) and 2030 dry climate (CCD). The annual volume delivered to the CSL for different rainfall events has also been considered for each flow-path with each climate condition.

The key components of the investigations undertaken as part of this study involve:

- hydrologic modelling of the South East to generate time-series of flows from runoff and diversions
- hydraulic modelling of the flow-paths to provide estimates of carrying capacity of the floodways/drains and the surface water levels for a range of flows
- transmission loss analysis to estimate losses to groundwater for various flow-paths and flow rates
- water balance modelling to estimate annual yield volumes to the CSL.

The findings of the investigation indicate that:

- Flow-path 02 is predicted to deliver the largest volume of water with an annual average of 53 GL under historic climate condition, as it has the least losses in comparison to the other two flow-paths and also a significantly larger local catchment contribution which includes the contribution of the existing drainage network.
- Flow-path 03—SELs delivered approximately half of that of Flow-path 02 with an annual average of 19 GL under historic climate condition as there is a significantly reduced local catchment contribution, particularly the contribution of the existing drainage network. Including the existing drainage network, which is delivered to the CSL via a different flow-path, the total annual average volume expected at the CSL under historic climate conditions was 48 GL.
- Flow-path 03—Floodway delivered the least volume of water of the three options, with slightly higher groundwater losses along the floodway compared to the evaporation losses involved with the Flow-path 03—SELs route. The floodway route alone was expected to deliver an annual average of 16 GL to

the CSL under the historic climate scenario, which increased to 45 GL after including the existing drainage network.

Flow-path 02 was also found to be more reliable, with some yield expected from this path for all years considered under historic climate conditions. In comparison some flows were delivered to the CSL every year considered for the Flow-path 03 routes. The reliability of Flow-path 03 (both SELs and floodway) also reduced much quicker for the climate change scenarios. This reduction in the reliability of the Flow-path 03 routes was due in part to the requirement to fill the ephemeral lagoons before they will spill on to the CSL, and in drier years the volume simulated was not sufficient for this to occur. Hence, when the variability of flows is considered, Flow-path 02 is likely to provide the highest volume to restore flows to the CSL.

The potential groundwater losses involved in the drainage network and lagoons provides the largest source of uncertainty in the estimated yields presented in this study. These losses are the most likely to influence the most suitable flow-path to be adopted to help restore flows to the CSL. For example, in this study it is assumed that there is a certain volume that will be sustained in each of the four lagoons and the groundwater level will be high enough to make any losses to groundwater negligible. If this is not the case and the lagoons are a losing system, the yield expected from Flow-path 03—SEL will be significantly reduced and no longer comparable to Flow-path 02. However, there is also the possibility that the lagoons and surrounding drainage network are a gaining system, increasing the yield expected from this flow-path. The groundwater losses presented in this report are comparable to those presented by AWE (2009a) for certain reaches where a comparison is possible.

The key assumptions and limitations associated with this study are as follows:

- The effect of clogging on transmission loss is likely to occur but has not been considered due to lack of data. Clogging is the process whereby the permeability of an infiltration surface may be reduced by accumulation of suspended solids delivered by the channel water. This process would result in reduced transmission loss and hence, in this sense the losses simulated are likely to be conservative.
- The analysis of loss is based on groundwater levels measured in spring, typically when they are at their peak. Periods of intense rainfall may generate surface water flows at other times of the year, when the watertable is lower. In these instances, more transmission loss would be expected to occur because of the increased gradient between surface water and groundwater. This potential underestimate is a limitation in the current study.
- Climate data (evaporation and rainfall) and flow records are relatively sparse in the South East. This presents a challenge for hydrological modelling. Modelling of catchments in the Upper South East has relied on calibration results, principally from the well gauged Drain L and Drain K catchments to the south and applying the assumption that these dune and swale catchments are similar to those encountered further north. This, along with the paucity of climate data, will introduce significant uncertainty into the estimates of yield from catchments of the Upper South East.
- The conceptual hydraulic modelling of contributing flow-paths was undertaken to provide meaningful inputs to transmission loss and hydrological analysis. Further detailed hydraulic modelling and civil design, for example modelling of new culverts, would be required to confirm the optimum channel configurations. Also, any future civil works proposal, such as widening of drains, cut and fill operations and construction of culverts, would need to thoroughly assess the environmental impacts of such actions; as such assessments were beyond the scope of this study. The types of environmental impacts that would need to be considered include changes in groundwater supply and also changes in application of lands, which in turn can affect the ecosystem's flora and fauna.

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INTRODUCTION

The Coorong, along with the Lower Lakes and Murray Mouth, is one of the largest of the internationally significant wetlands recognised under the Ramsar Convention within the Murray-Darling Basin. Until very recently, severe drought in the basin over consecutive years has resulted in record low inflows. This, combined with over-allocation of basin water resources, has caused inflows to drop to the point that they have been consistently exceeded by evaporation from the Lower Lakes. A lack of flow from the lakes to the Murray Mouth has in turn had a significant impact on the ecological health of the Coorong.

Historically, the hydrology of the Coorong has been influenced by significant fluctuations in seasonal discharge from the River Murray to the Lower Lakes, surface water flows from the South East of South Australia (SE), as well as local surface water and groundwater inputs.

Since European settlement, construction of the system of barrages to maintain water levels in the Lower Lakes, over allocation in the Murray-Darling Basin, construction of the extensive drainage network in the South East and changes in land use locally have all influenced the hydrology of the Coorong. While the North Lagoon is most affected by tidal flushing from the Murray estuary, historically the salinity regime in the South Lagoon may have been more strongly influenced by surface runoff from the South East. The available evidence suggests that under current conditions, the Coorong is significantly more saline than it would have been historically, which is detrimental to the local ecology as seen by the impact on migratory birds and estuarine fish spawning and recruitment.

The Coorong South Lagoon Flow Restoration Project has to date investigated options for diverting significant volumes of water from the drainage network of the South East northwards to the Coorong using a combination of purpose-built floodways and existing flow-paths. However, there are still further volumes that flow west and out to sea through the Lower South East constructed drainage network that could potentially be diverted north and potentially delivered to the Coorong South Lagoon (CSL).

The aim of this study is to extend and provide greater confidence in estimates of water availability from the untapped resources in the South East drainage system potentially available for diversion to the South lagoon of the Coorong. The hydrological modelling undertaken as part of the NWI South East Regional Flows Management Strategy (Wood and Way 2011) has been extended to provide estimates of the yields available to be diverted in the region to the CSL, also accounting for transmission losses in the network and lagoons. Concurrent projects that will influence the water availability have also been incorporated, most notably the Restoring Flows to the Upper South East of South Australia (REFLOWS) project (SA State Government 2002). A significant hydraulic analysis has also been undertaken to identify capacity constraints along the proposed flow-paths and determine potential inundation of floodways.

The results are presented for existing routes that have been identified in previous studies, as well as a new route that has been proposed in an attempt to reduce the losses involved in diverting water through lagoons. The volume delivered to the CSL for different rainfall events are presented for each route, for historic and future climate change scenarios and for different stages of the flow diversion paths. The following section outlines the study area considered and further details on the scenarios considered.

STUDY AREA AND SCENARIOS

The study area is broadly defined by three flow-paths and their contributing catchments previously investigated for the Coorong South Lagoon Flow Restoration Project. This analysis focuses on three paths that extend from Drain M to the CSL—one via the Taratap and Tilley Swamp area (Flow-path 02) and the other two via the Southern Ephemeral Lakes (Flow-path 03—SELs and Flow-path 03—Floodway). For consistency with AWE (2009a), the flow-path names used in that report have also been adopted here. The flow-paths considered along with the relevant contributing catchments are presented in Figure 1. The catchment areas have been derived from the 2 m digital elevation model for the region, hence natural contributing areas for the drainage network are identified. However, this approach does not identify small-scale modifications to the system, for example drain overpasses for local catchments. Existing diversions for the system, for example REFLOWS, Bool Lagoon and Bald Hills Drain, have been adopted based on the current rules (as of 18 November 2010) specified by the Upper South East Decision Support System (USE DSS).

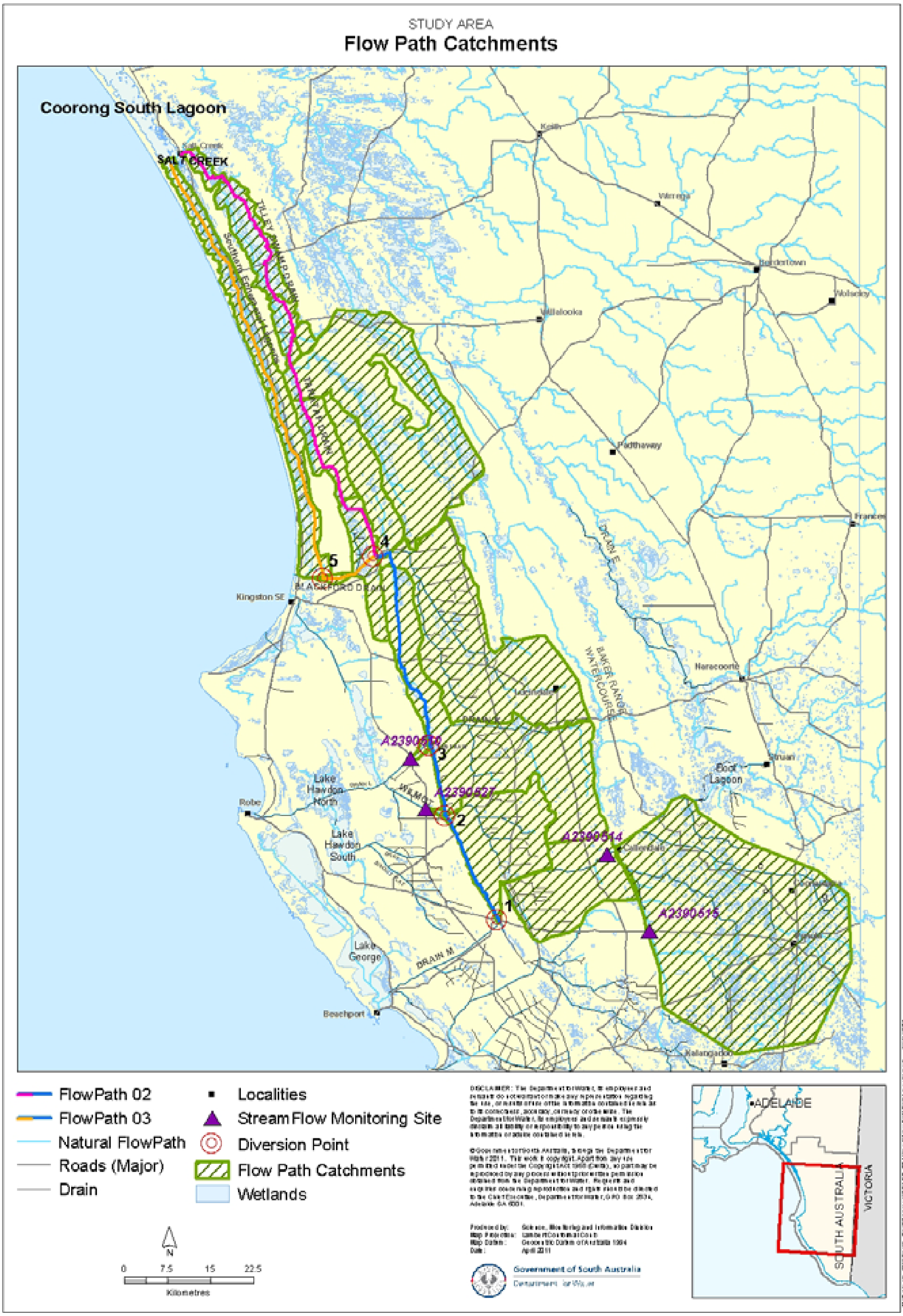


Figure 1 Study area

A breakdown of each flow-path component is described in Table 1. Diversion points are listed in Table 2 and illustrated in Figure 1.

Table 1 Flow routes description

Option	Flow-path component
Flow-path 2	Reedy Creek (Drain M—Wilmot Drain)
	Reedy Creek (Wilmot Drain—Drain K)
	Reedy Creek (Drain K—BlackFord Drain)
	BlackFord Drain
	BlackFord Drain Murrabinna Flats
	Taratap Flat
	Taratap and Tilley Swamp Drain
Flow-path 03	Reedy Creek (Drain M—Wilmot Drain)
	Reedy Creek (Wilmot Drain—Drain K)
	Reedy Creek (Drain K—BlackFord Drain)
	BlackFord Drain
	Southern Ephemeral Lakes (Flow-path 03—SELs) or Southern Ephemeral Floodway (Flow-path 03—Floodway)

Table 2 Diversion points

Node	Location
1	intersection of Drain M and Reedy Creek
2	intersection of Wilmot Drain and Reedy Creek
3	intersection of Drain K and Reedy Creek
4	intersection of Blackford Drain and proposed Taratap Drain
5	intersection of Blackford Drain and Southern Ephemeral Lakes

A range of scenarios were considered in the analysis:

- Three climate change scenarios were included in the hydrological model, in line with those adopted by AWE (2009a). Input rainfall data were based on historic records, as well as rainfall data modified for the effects of climate change using dry and median case factors.
- Four scenarios relating to the extent of the scheme have been analysed, which is relevant for the Flow-path 03 option only. The initial stage includes the diversion of flows only from the immediate catchments around Salt Creek, such as S-bend and Henry Creek. A second stage assumes that the Taratap and Tilley Swamps have been constructed, so that the contributing catchment also includes Blackford Drain. A third stage includes diversions from Wilmot Drain and Drain K, while the final stage also includes Drain M.
- A range of maximum diversion rates at each of the diversion points was tested.
- Two estimates of soil saturated hydraulic conductivity (K) were considered. After the selection of one method of estimation of K values, high and low estimates around the original values were also considered as part of a sensitivity analysis into the impact of the soil saturated hydraulic conductivity on the flows delivered to the CSL.

RELATIONSHIP TO PREVIOUS WORK

This study combines and extends a number of previous studies. Way and Heneker (2007) provided the first attempt at quantifying volumes of water available to divert from the lower to the Upper South East, including a discussion on the water quality considerations. KBR (2009) provided an engineering investigation creating feasible flow-path options. AWE (2009a) produced a more detailed analysis of the diversion volumes, included the groundwater losses in the estimation and incorporated a number of climate change scenarios. Wood and Way (2011) developed daily time-step hydrological models of the South East catchments, which have been adopted in this study to provide estimates of the catchment yield available to be diverted. Further details on the differences between this study and the previous studies are provided in the remainder of this section.

STUDY PERIOD

As described by Wood and Way (2011), recorded flow data in South East catchments are varying in length. To overcome comparability issues in the hydrological model, the time period for model outputs were standardised for a 30-year period from 1971–2000. This period has been chosen for a number of reasons that are described later, while the study period in the AWE (2009a) report was defined by the restricted record downstream of Bool Lagoon (1986–2007).

RAINFALL RUNOFF RELATIONSHIPS

Way and Heneker (2007) and AWE (2009a) estimated the volume of water available for diversion using a simple relationship between the annual rainfall and corresponding runoff, to scale observed daily hydrographs. A significant improvement in the method provided by the current study is the use of a daily time-step hydrologic model developed by Wood and Way (2011) as part of the NWI Regional Flow Management Strategy Project to estimate the yield from the contributing catchments and route the resulting flow downstream, to account for storage, attenuation and travel time in the drainage network. The modelling was undertaken using WaterCRESS (Cresswell 2002) a PC-based water balance modelling platform which incorporates some of the most widely used models in Australia. The models were calibrated for gauged catchments with sufficient flow records using the Australian Water Balance Model (AWBM) available within the WaterCRESS platform.

The catchment boundaries adopted in the current study have been derived using Arc Hydro GIS extension based on the 10 m digital elevation model (DEM) of the region. AWE (2009a) reports that the catchment boundaries were derived manually based on contour lines produced from this DEM dataset. Hence, the catchment boundaries adopted by the current study are slightly different but likely to be more accurate.

GROUNDWATER INTERACTION

AWE (2009a) used saturated hydraulic conductivities in the groundwater loss estimation. In this study, weighted saturated hydraulic conductivity values based on the thickness of the soil and aquifer layers has been used to represent the expected soil layers.

The second order approximation to the head differential has been used in this work to represent the more expected relationship between the drain water level and groundwater level (e.g. Figure 17). This is contrasted with the study done by AWE (2009a), which assumed a linear profile between the two water levels.

The climate change scenarios adopted for rainfall and flow are the same as those adopted by AWE (2009a). However, the current study assumes that there will be no significant change in the groundwater levels due to a change in climate, as there is significant uncertainty in the potential changes in groundwater.

METHOD

The aim of this study has been to provide greater confidence in estimates of water volumes able to be diverted to the south lagoon of the Coorong. To do this, a range of modelling techniques has been used to replicate the processes of rainfall, runoff, losses and conveyance of water. The key modelling processes are described below:

- Hydraulic modelling of the flow-paths to provide estimates of width, depth and volume of floodways/drains for input to the water balance analysis and water surface elevation for input to the transmission loss analysis.
- Refinement and extension of the existing Department for Water hydrologic models of the South East to generate time-series of flows from runoff and diversions. Estimations of transmission losses for various flow-path reaches and flow rates.
- Water balance modelling (spreadsheet) to estimate annual yield volumes to the CSL. Diversion and runoff volumes from the hydrologic model and losses to groundwater from the transmission loss model used as inputs to the water balance.

These works are described in more detail in the following sections.

HYDRAULIC MODELLING

INPUTS TO TRANSMISSION LOSS AND WATER BALANCE

Hydraulic models were developed for all components of the flow-paths to provide meaningful inputs to the water balance model. Typical cross-sections of each modelled drains is provided in Appendix B. The parameters sought to be defined for each flow-path component were: typical channel profile (width, depth); volume of channel – particularly for 'fill to spill' situations; surface area of contained water; and longitudinal profile of water surface elevation.

Data used to develop the hydraulic models included the 2 m DEM of the South East, construction plans for existing drains including Taratap and Tilley Swamp Drain and conceptual channel profiles included in KBR's (2009) final report. Modelling was undertaken using HEC-RAS in its steady-state (constant flow rate) mode, with its companion tool HEC-GeoRAS used to define flow-paths and extract cross-sections in GIS.

For the Taratap and Tilley Swamp routes, KBR (2009) provides some general information on the floodway profile required to convey the design flow rate. However, it was found that the information contained within the report was insufficient to adequately define the floodway profile for the purposes of this analysis. Consequently, some conceptual design was undertaken to define the floodway, including determining appropriate grade, invert levels and width.

Based on the extracted cross-sections from the DEM, the modelled existing capacity of the Taratap and Tilley Swamp Drain has been identified as being less than 200 ML/day. Works are required to widen the drain to accommodate 1250 ML/day. For analysis purposes, a modified cross-section has been designed that involves construction of levees on the western side of the drain (which allows flow of water above ground) and then widening of the drain to the eastern side, maintaining the same invert as present.

The assumed roughness factor is 0.03 for both the channel and the overbank sections. A downstream water level in Morella Basin of 4.5 m AHD was applied as a downstream boundary condition. A varied channel width was used for hydraulic modelling, with water generally constrained 'in channel'. However, there was one location (shown in Figure 2) where the capacity of the drain would be severely restricted due to grade and flood-outs on the eastern side would be likely and due to increasing likelihood of flood-outs for large flows, drain capacities greater than 1250 ML/day have not been considered. A long-section of the natural surface of the Taratap and Tilley Swamp alignment is shown in Figure 3. The location referred to in Figure 2 is at approximate chainage 78 000.

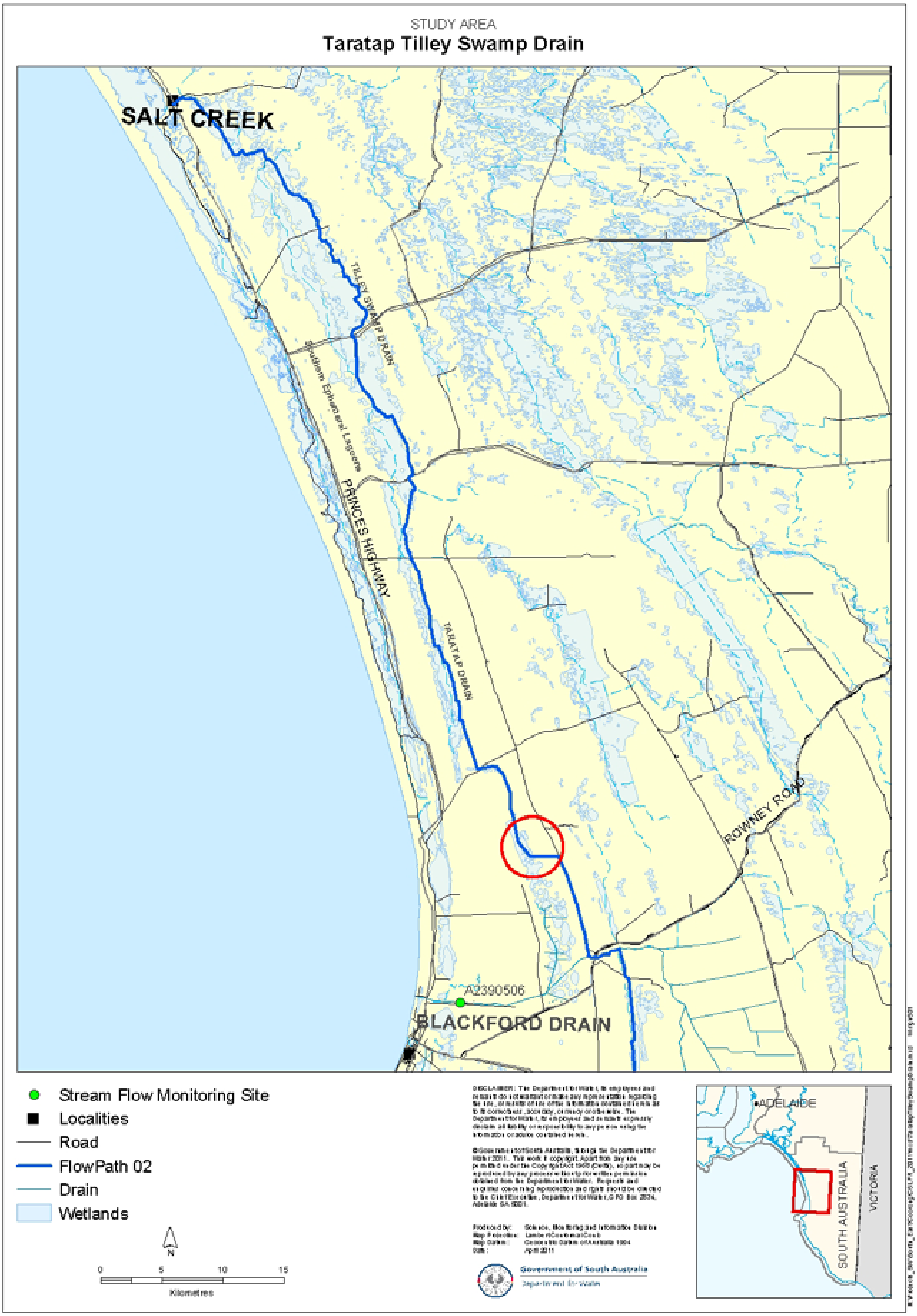


Figure 2 **Taratap and Tilley Swamp Drain—alignment and potential flood-out location**

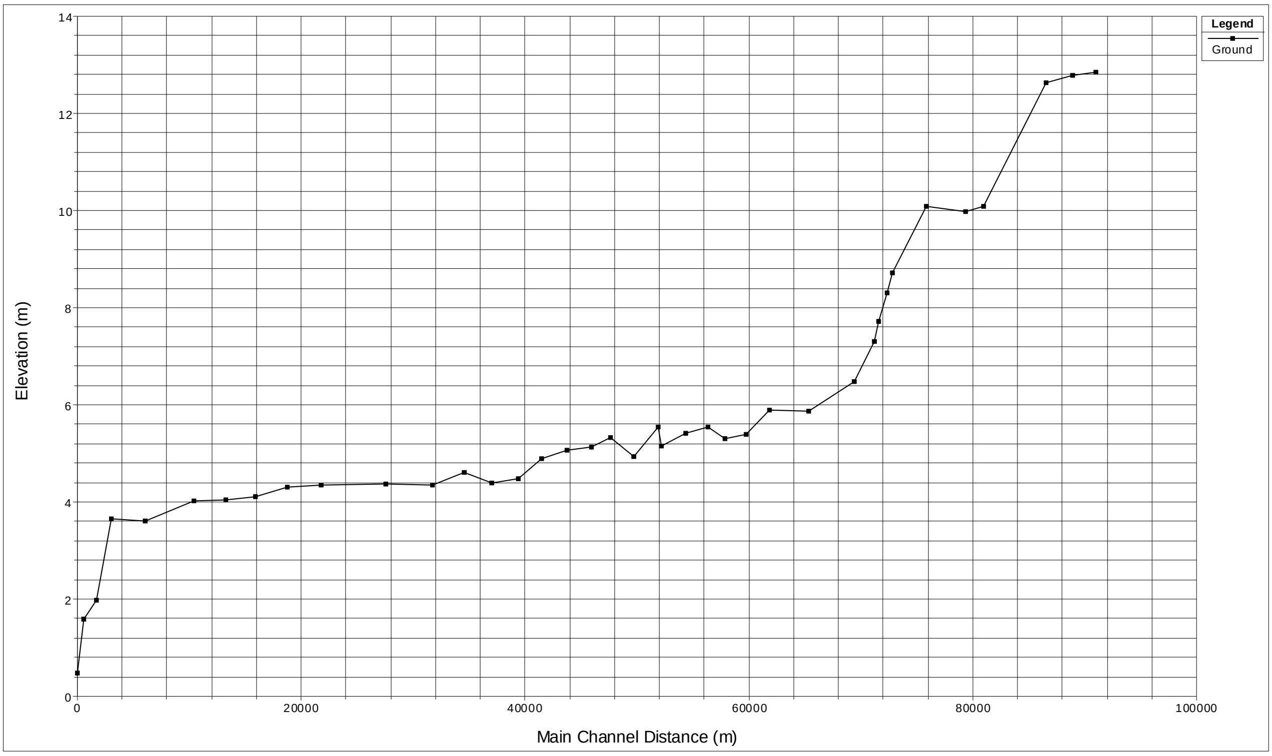


Figure 3 Taratap and Tilley Swamp Drain—natural ground profile

The preliminary conceptual modelling of the Reedy Creek Drain was based on adapting the existing cross-section to convey 2000 ML/day (note that this is greater than that required by the diversion limits recommended by this study). The cross-section adopted was a combination of excavated drain below natural surface and floodway above natural surface bounded by earthen levees on both sides. The water level is near ground level in most parts of the floodway to maintain existing drainage service to landholders. This design may not be appropriate in all locations, but was considered adequate for the requirements of this study.

It should be noted that any design study undertaken as part of this study to determine the required widths of flow-paths is of a conceptual nature only. Further detailed hydraulic modelling and civil design would be required to confirm the optimum channel configurations.

Extraction of cross-sections from the DEM for Blackford Drain confirmed that the capacity of the existing drain is greater than 2000 ML/day and there are no capacity issues for this drain.

CAPACITY OF SOUTHERN EPHEMERAL LAKES FLOW-PATH

The Southern Ephemeral Lakes is a component of Flow-path 03. Previous investigations by KBR (2009) have provided for a maximum daily diversion through the Southern Ephemeral Lakes of 2000 ML/day. However, it was recognised that several roads adjacent to the flow-path may be subject to inundation and a hydraulic analysis was recommended.

A hydraulic analysis was undertaken to determine the capacity of the Southern Ephemeral Lakes in their natural state. Further modelling was then undertaken to determine what engineering works were necessary to improve the overall capacity. An alternative Southern Ephemeral Lakes flow-path, whereby water is conveyed in a floodway for much of its length, is described in the following section.

The southern ephemerals flow route is characterised by a linear series of ephemeral lakes, situated between two parallel lines of dunes. Factors that constrain the hydraulic capacity of the flow-path include the extremely flat grade, the low elevation of the Princes Highway and other local roads and the elevation of high points of land (sills) between the individual lakes. There are anecdotal reports that the heights of the sills have increased due to human interference. Accordingly, the lowering of these sills is one of the engineering options considered.

The Southern Ephemeral Lakes flow-path was modelled using the software HEC-RAS. HEC-RAS's companion GIS tool, HEC-GeoRAS, was used for extracting cross-section data from the 2 m DEM, as well as for generating inundation maps. A one-dimensional, steady-state hydraulic model was developed, meaning the flow-path was represented by a branch with cross-sections along it and a constant flow rate was applied. The location and extent of the model is shown in Figure 4.

The modelled southern ephemerals reach is approximately 70 km long. It flows from south to north, starting at Blackford Drain near Kingston and terminating at the CSL near Salt Creek. The flow-path has been represented by greater than 100 cross-sections at intervals of approximately 500 m.

Two downstream water levels were modelled as boundary conditions to the model, representing current and future climate-change scenarios. Under current conditions, the typical water level within the CSL during winter is approximately 0.5 m AHD, with a possible additional 0.2 m due to wave set-up from north-westerly winds. Hence, a downstream water level of 0.7 m AHD was adopted for the current conditions model. A future climate change scenario was also modelled. The increase in mean sea level due to climate change was estimated by DENR to be 0.8 m (Matthews, 2005), resulting in a water level of 1.5 m AHD in the CSL.

In order to determine the potential existing and modified capacity of the flow-path, a range of flow rates were modelled. These were: 200, 400, 600, 1000, 1500 and 2000 ML/day, giving a total of 12 modelled scenarios (6 flow rates x 2 downstream boundary conditions).

Manning's roughness values were selected based on the aerial photographs. A value of 0.04 was assigned to areas of unvegetated ground, while 0.06 was assigned to areas covered by low vegetation.

Initially the model was run assuming no constriction from road crossings or access tracks. An additional study considered what crossing upgrade would be required for the Princes Highway; however, no other roads or access tracks were explicitly modelled. Given the flat grade of the flow-path, if crossings are required they will need to be designed to produce no afflux (increase in water level upstream of the crossing). Alternatively, low causeways could be constructed. Crossings are discussed in greater detail in the *Existing capacity* and *Modified capacity* sections below.

A major constraint to the maximum flow that can be diverted down the southern ephemerals flow-path is the water level adjacent to the Princes Highway. The Princes Highway runs adjacent to the southern ephemerals flow-path for almost its entire length. Between chainage 0 km (CSL) and chainage 53 km, the Princes Highway is on the eastern side of the flow-path, before crossing over to the western side of the flow-path from chainage 55–66 km. The section of the Princes Highway at most risk of flooding is at the crossing (chainage 53.3 km) and immediately upstream (south) of the crossing.

It is understood that there are no existing culverts at the Princes Highway crossing. Therefore, any diversion of water via the southern ephemerals flow-path will require works to provide culverts at the Princes Highway.

The upstream water level of the southern ephemerals flow-path at the diversion point from the Blackford Drain has not been considered to be a constraint in the analysis. It is believed that elevated water levels could be accommodated within that drain, as it passes through several drop-weir structures in that vicinity and these could be modified.

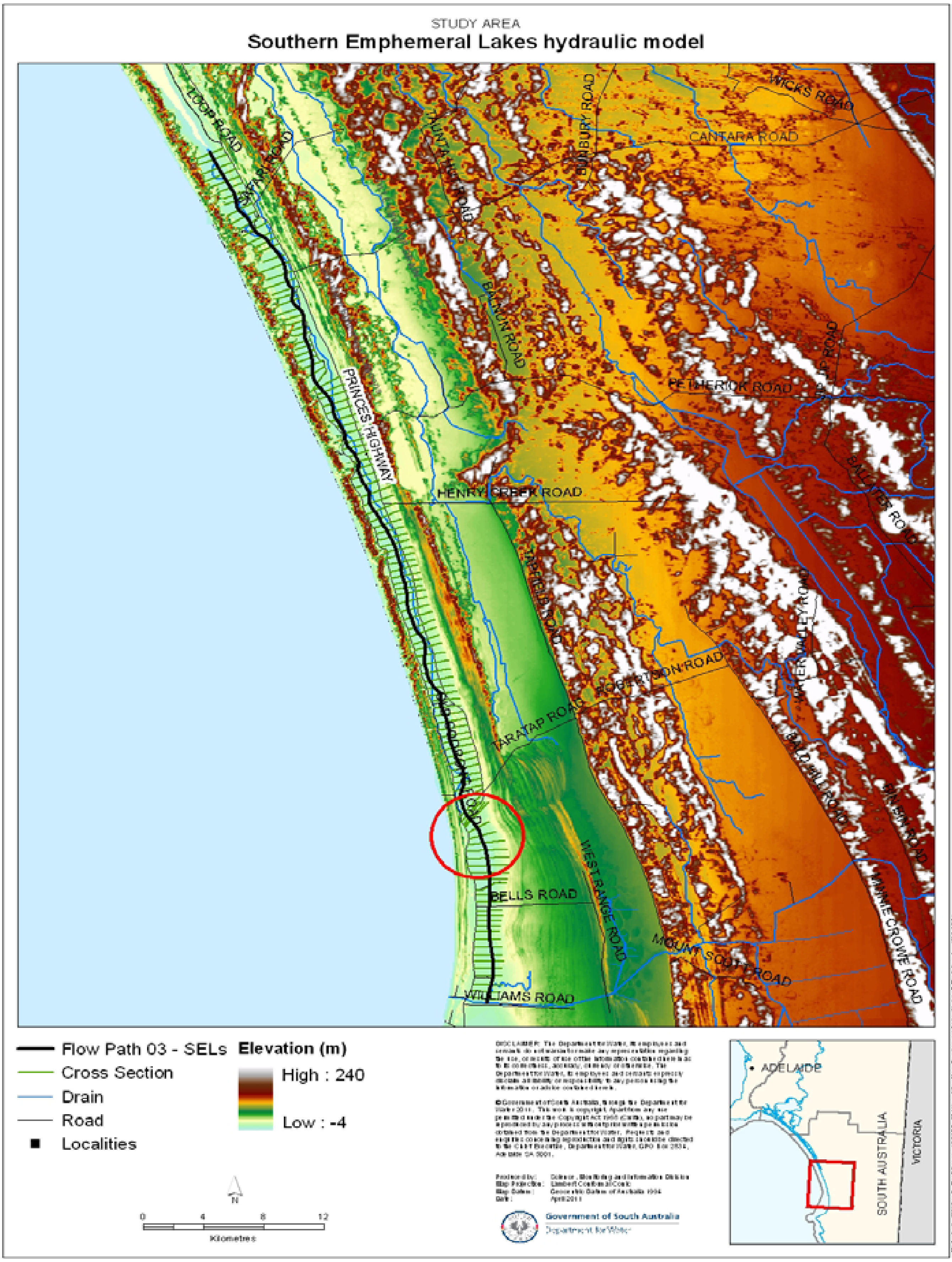


Figure 4 Southern Ephemeral Lakes hydraulic model

EXISTING CAPACITY

The existing channel was modelled to assess its capacity under the 12 flow and tailwater scenarios. The water profile for each scenario is shown in Figure 5. It can be seen that the 'sill' between the individual lakes act as the major influence on water level. It can also be seen that the effect of the increased tailwater (1.5 m AHD) under the climate change scenario is not transferred upstream beyond the first sill.

These initial calculations assume that there are no constraints at Princes Highway (chainage 53.3 km).

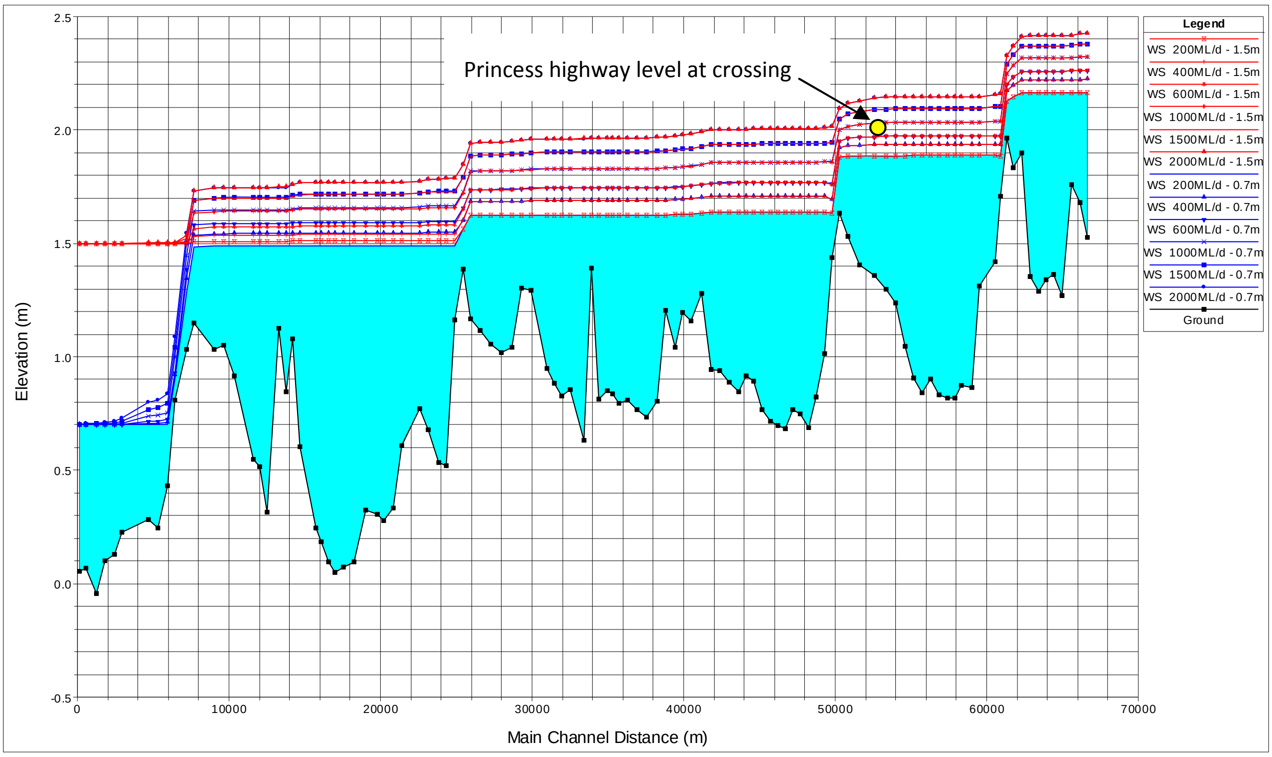


Figure 5 **Natural long-section of Southern Ephemeral Lakes**

The water level at Princes Highway is a key indicator of the existing capacity of the channel, since upgrade works at this location are likely to be very costly. The existing road crown level in the vicinity of the southern ephemeral crossing (chainage 53.3 km in the hydraulic model) is shown in Figure 6. These road levels have been extracted from the 2 m DEM. Given that the road is built up from the surrounding area, it is possible that the DEM slightly underestimates the true crest level. Nonetheless, there appears to be in excess of 1.2 km of highway where the crest level is approximately 2 m AHD. In its current state, the Princes Highway would be overtopped by flows of 600 ML/day. After allowing for a freeboard of 300 mm, the capacity is less than 200 ML/day. The construction of new culverts would still be required at the Princes Highway crossing irrespective of the diversion rate selected.

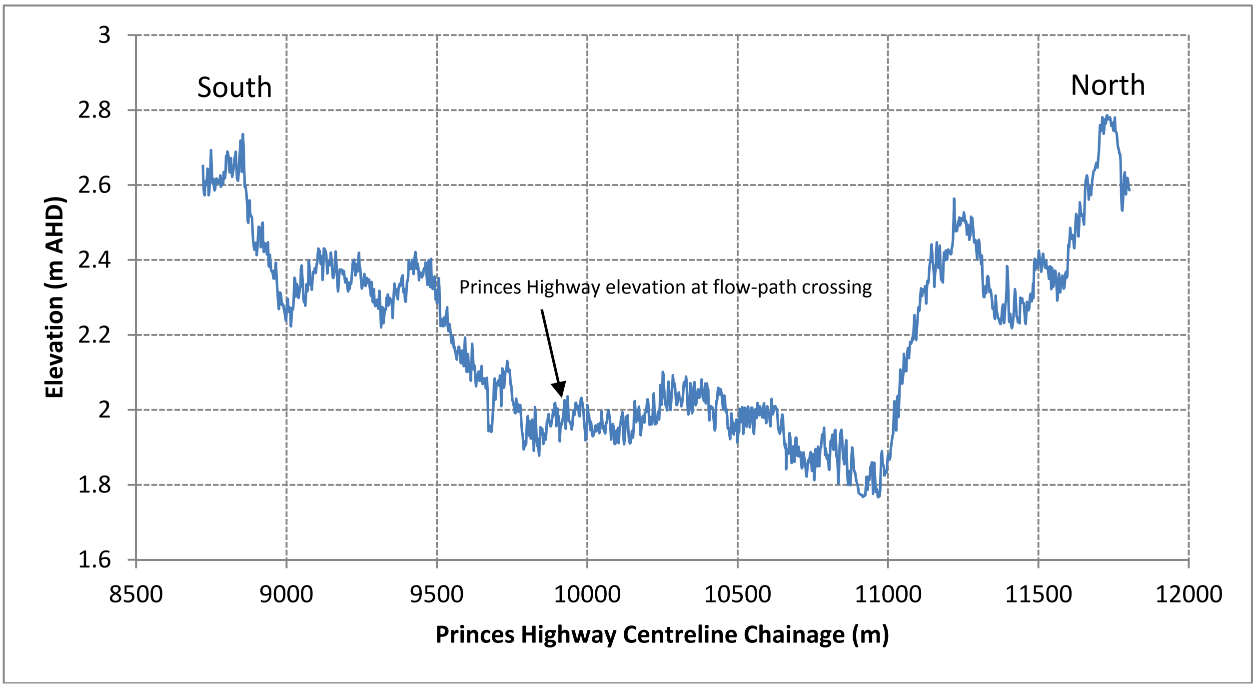


Figure 6 Princes Highway elevation at flow-path crossing

Flood inundation mapping was carried out using HEC-GeoRAS to provide an indication of the area of inundation and length of Princes Highway affected by a flow rate of 2000 ML/day down the southern ephemerals flow-path. The entire flow-path is shown in Figure 7. From these inundation maps, it has been estimated that in excess of 5 km of highway would need to be raised for 2000 ML/day to be conveyed via the southern ephemerals flow-paths in its existing state. Several other local roads and property accesses, such as the Old Coorong Road, would also need to be modified, but these have not been specifically addressed in this study.

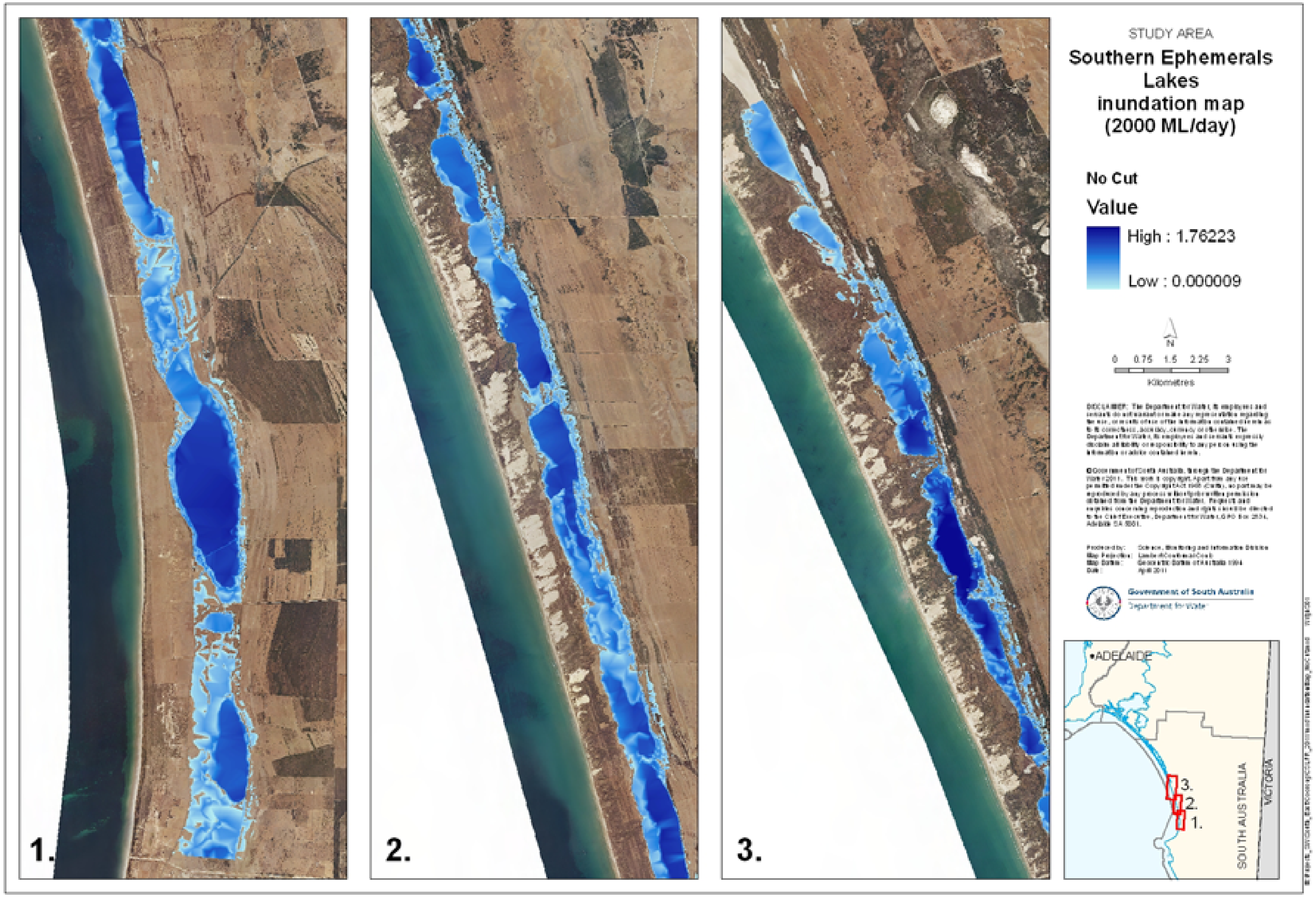


Figure 7 Southern ephemerals inundation map for 2000 ML/day

MODIFIED CAPACITY

Given the dominance of the sill levels on the modelled water level, lowering of the sills was trialled to assess the impact on the modelled water level along the flow-path, particularly at the Princes Highway crossing (chainage 53.3 km), where culvert and road raising works have the potential to be extensive and costly.

From inspection of the aerial photographs, it was judged that a 200 m wide channel could be excavated between individual lakes with the aim of increasing the overall capacity and reducing the maximum water level along the flow-path. Two cut depths were trialled, based on constant grade between upstream and downstream points of flow-path. The small cut has a maximum depth of 0.4 m, while the large cut has a maximum depth of 0.8 m. The effect that these excavations have on modelled water elevation is shown in Figure 8 and Figure 9.

It can be seen that with the sills lowered, there is a considerable difference in water levels between the two downstream water level scenarios. However, the difference is reduced further upstream the flow-path and is effectively zero at the location of the Princes Highway crossing (chainage 53.3 km). Therefore, it can be concluded that the assumed Coorong water level has no influence on infrastructure requirements at the highway crossing.

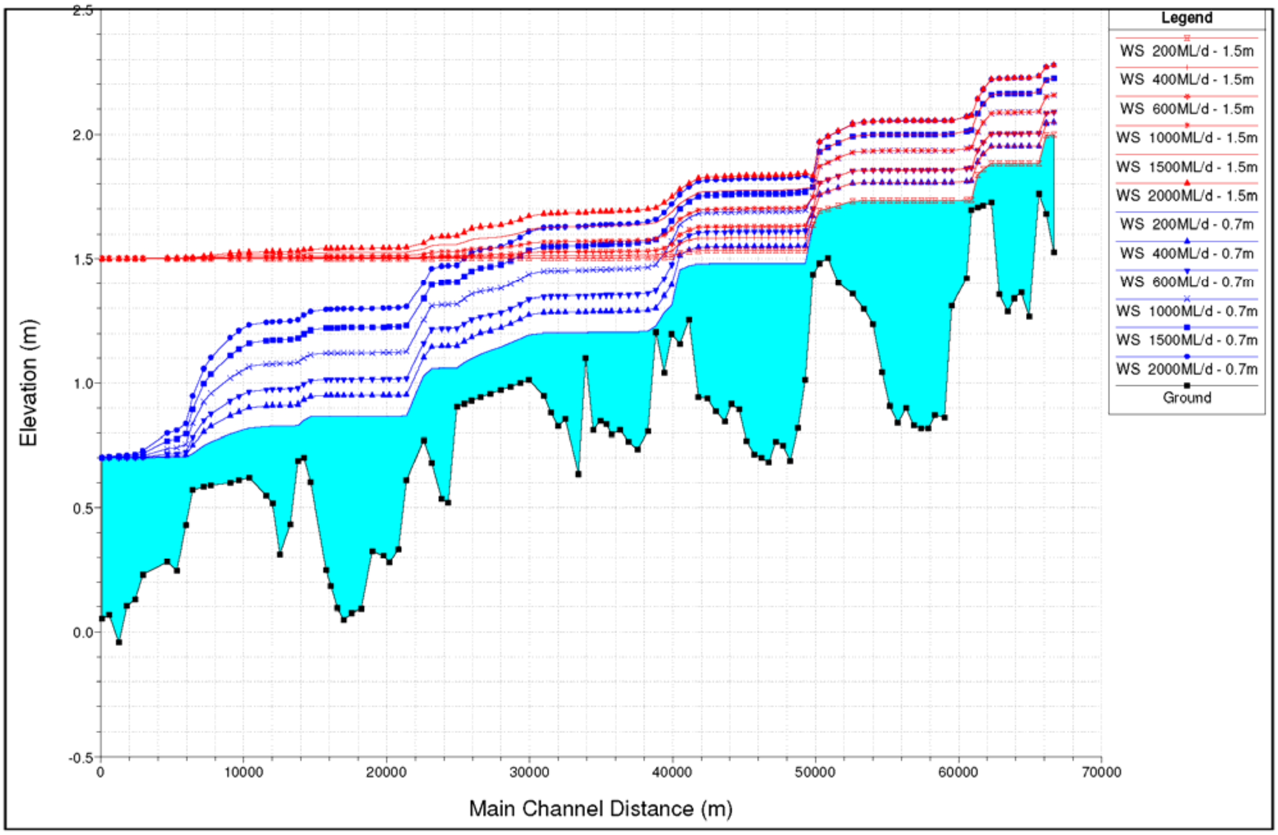


Figure 8 Long-section of Southern Ephemeral Lakes—small cut (maximum depth of 0.4 m)

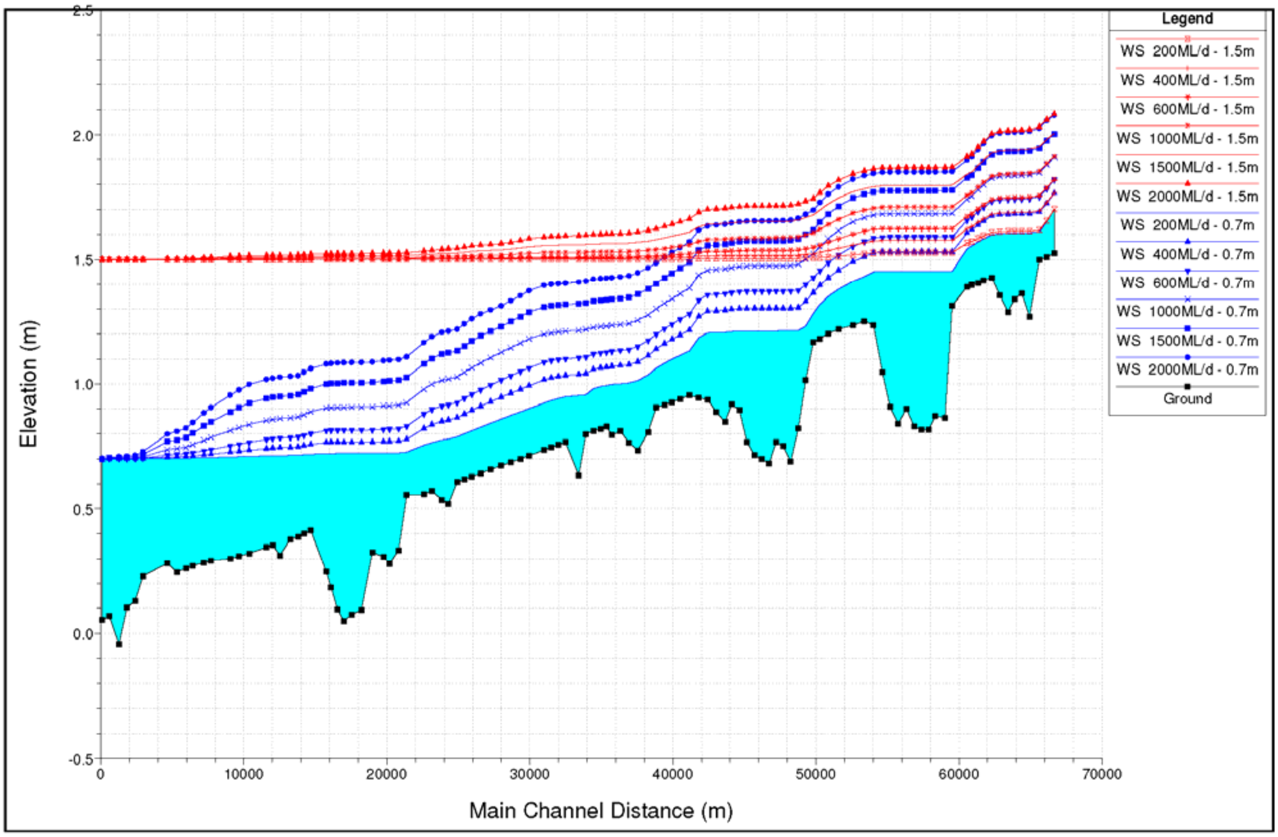


Figure 9 Long-section of Southern Ephemeral Lakes—big cut (maximum depth of 0.8 m)

The small cut option reduces the water level in the vicinity of the Princes Highway crossing by 0.1 to 0.15 m, while the large cut option reduces the water level by 0.3 to 0.45 m. Accordingly, the small cut option means that the highway is not inundated by a flow of 1500 ML/day, however its capacity would still be considered to be less than 200 ML/day when freeboard was taken into account. The large cut option mitigates highway inundation for 2000 ML/day, yet the capacity is 1000 ML/day when considering freeboard.

For a diverted flow of 2000 ML/day, the length of road raising required to prevent inundation of the Princes Highway is approximately 1.5 km for the small cut option and less than 500 m for the large cut option (considering freeboard). As discussed previously, these estimates have been made on the basis of a DEM only as no road plans were available. Consequently, these lengths should be considered as indicative only, since DEMs are limited, particularly for estimating crown levels of road embankments. Inundation maps for these two modelled scenarios are shown in Figure 10 and Figure 11. Approximate cut volumes were calculated for each option. These were estimated to be 1.16×10^6 m^3 for the small cut and 3.0×10^6 m^3 for the large cut option.

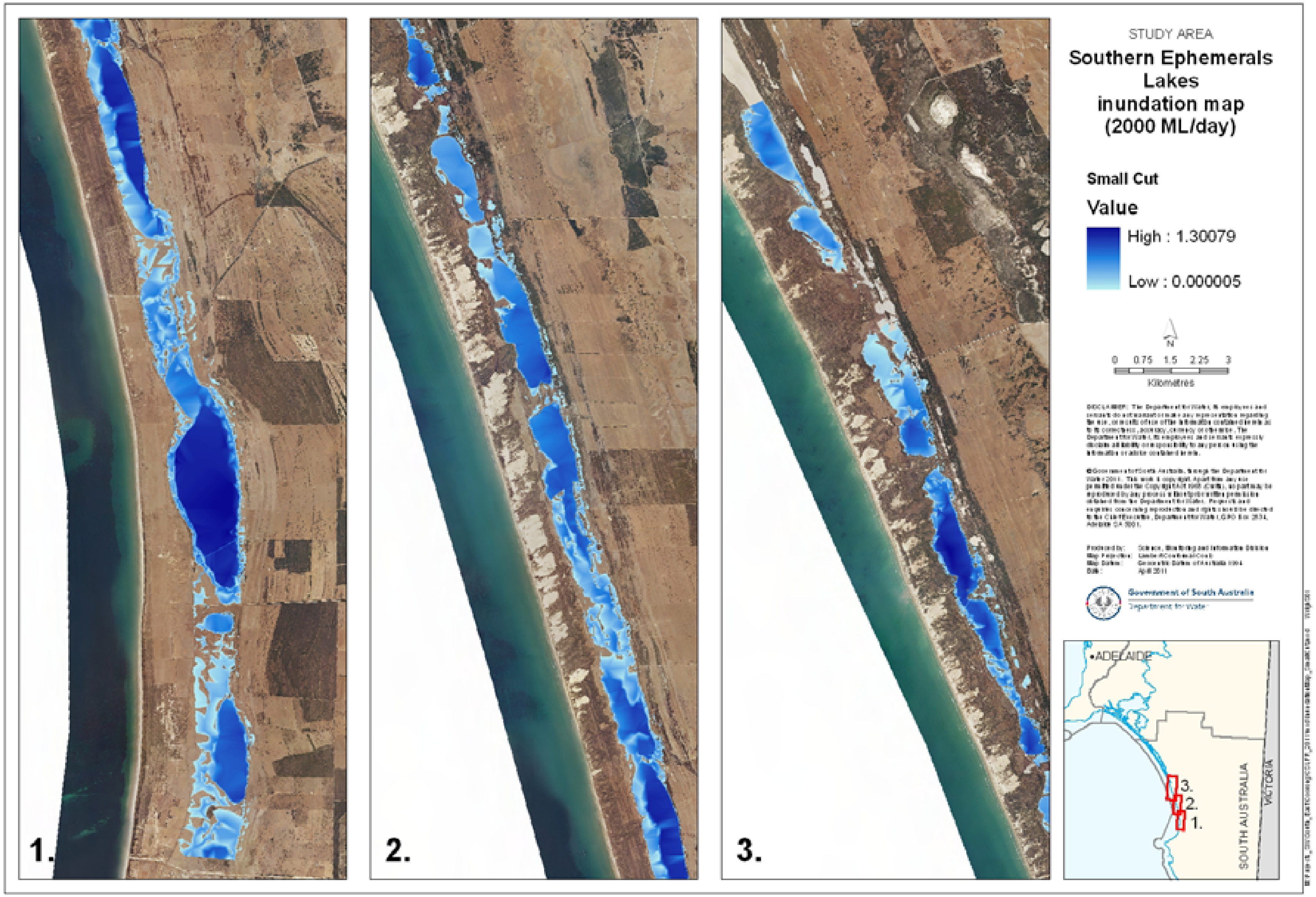


Figure 10 **Southern ephemerals inundation map for 2000 ML/day with small cut modification**

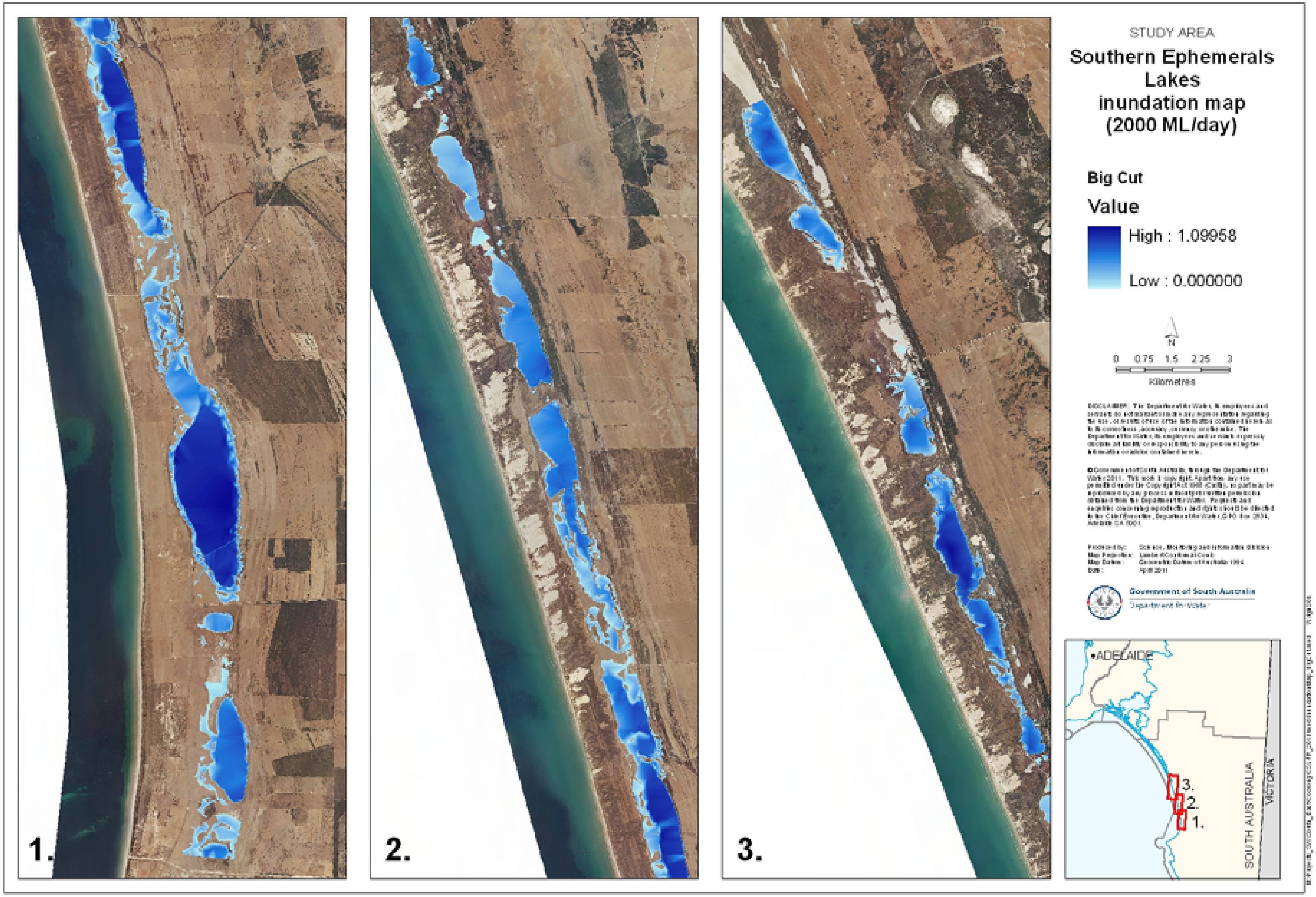


Figure 11 Southern ephemerals inundation map for 2000 ML/day with big cut modification

Preliminary culvert design was undertaken to estimate the scale of works required to upgrade the Princes Highway crossing to pass the diverted flows. This analysis was undertaken using HEC-RAS and based on the DEM only, with no plans or survey available of the road or watercourse.

Due to the very flat grade of the crossing and the flow-path in general, a large number of culverts are required to pass the flow without causing an increase in water level upstream of the crossing, also known as afflux. To provide an indication of the magnitude of civil works required at the highway crossing, a 'middle ground' set of conditions was modelled: a flow of 1500 ML/day in conjunction with a smaller cut through the lake sills.

Two culvert scenarios were trialled targeting low afflux and medium afflux upstream of the crossing. A lower afflux requires more culverts, however there is less need to raise the highway, both in terms of crest height and length. Conversely, culverts that result in a medium afflux upstream of the culverts require less culverts but there is more need for road raising. The low afflux case required raising the road level to a minimum of 2.3 m AHD (maximum water level 2.0 m AHD) and the medium afflux case required raising the road to a minimum of 2.5 m AHD (maximum water level 2.2 m AHD).

Hydraulic modelling resulted in the following culvert requirements:

- low afflux culverts: 25/3000 x 450 box culverts, total flow width 90 m
- medium afflux culverts: 8/3000 x 600 box culverts, total flow width 32 m.

It is difficult to suggest which of these would be the more practical and cost-effective option without detailed costings of civil works and further site information. However, it would be likely that the most cost effective option will combine both road raising and culverts.

Minimum energy loss (MEL) culverts were also considered, although not modelled. MEL culverts are particularly suitable for watercourses where the slope is relatively flat and afflux is undesirable and offer the advantage of a considerably reduced width compared to standard culverts. Preliminary analysis has shown that the culverts could be feasible for this application. However, because MEL culverts generally comprise a lowered barrel invert (that is, the culvert is set lower than the natural watercourse level), sedimentation is a risk that needs to be considered.

As stated previously, other required infrastructure upgrades along the flow-path were not specifically investigated, but it is likely that the Old Coorong Road and numerous other local roads and property accesses would require upgrades or new 'all weather' accesses to be constructed.

The proposal to cut channels through the sills separating the Southern Ephemeral Lakes would need further attention with respect to its potential environmental impacts, which have not been considered in this study.

MODELLING OF ALTERNATIVE SOUTHERN EPHEMERALS FLOODWAY

Following a presentation of the preliminary results of the hydraulic modelling of the southern ephemerals flow-path to the Project Steering Committee in October 2010, an alternative alignment through the Southern Ephemeral Lakes was requested for consideration. The intent of this route is to divert water from the Blackford Drain at a more inland (higher) point and thus take advantage of the steeper hydraulic grade available. The alignment was developed in consultation with local community members and derived using the 2 m DEM and construction plans of the Blackford Drain showing locations and heights of drop-weirs. The alignment and location of model cross-sections is shown in Figure 12. Note that the floodway terminates at the Old Coorong Road, which is approximately 30km south of the CSL.

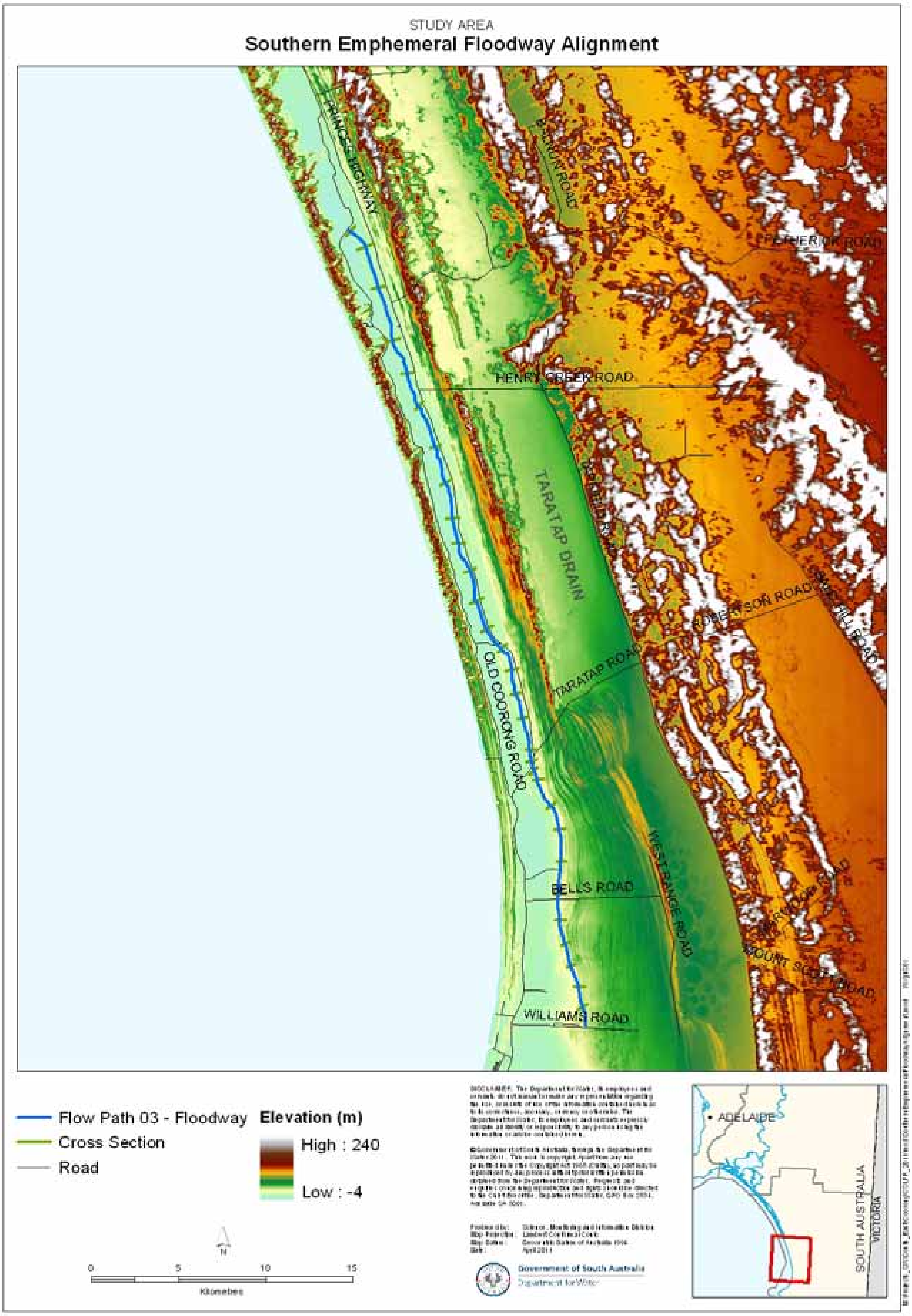


Figure 12 Southern ephemeral floodway alignment

The diversion point from the Blackford Drain is approximately 5.4 km inland from the coast. It is intended to raise the drop weir, located at chainage 3 M 1800’ on SEDB Plan 342, so that the water is elevated above natural surface level, similar to the water level of the next drop weir upstream. Spoil banks are situated on both sides of the Blackford Drain and minor works would be required to close off any access openings.

From this point the water will be diverted into a floodway which, as much as possible, follows the land contours as it falls towards the Princes Highway. The floodway would be two-sided, with the banks constructed from spoil pushed up from the central part of the channel. As a result, the channel invert will be slightly lower than the natural surface.

The floodway will pass beneath the Princes Highway immediately south of the intersection with Taratap Road. The highway would need to be elevated over the crossing. The length of raising would be limited to the width of the floodway itself, since the floodway is otherwise contained within banks upstream and downstream. Due to a range of uncertainties regarding location and elevation, the required culvert sizes were not modelled. However, it is expected that the required number of culverts would be significantly less than the highway crossing modelled in the previous section due to the steeper hydraulic grade of the channel and reduced need to minimise afflux upstream of the crossing.

After crossing the highway, the floodway would stay up-slope as far as possible, constrained by the location of the Princes Highway to the east. At approximately 8 km north of the highway crossing, the highway is quite close to the lakes and as a result, the floodway would also need to lose elevation so that it could be physically located between the highway and lakes. From this point onwards the floodway is much flatter.

It is proposed that the floodway would terminate just north of the Old Coorong Road (Cantara causeway). The crossing at this location would need to be upgraded to span the floodway. Also, a blocking bank would need to be constructed (or the existing road embankment adapted) so that diverted flows did not ‘back up’ southwards along the natural Southern Ephemeral Lakes and cause flooding problems. It is likely that several local road or property accesses would also require elevated crossings over the floodway which have not been specifically detailed in this study.

Where the floodway passes adjacent to the ephemeral lakes, it is possible that regulators could be incorporated to allow releases from the floodway into the lakes for environmental benefits.

Hydraulic modelling of the floodway alignment was undertaken using HEC-RAS to provide an indication of the required width and height of floodway, as well as providing water level and surface area data to the transmission loss and water balance analysis. Due to the fairly uniform cross-section of the floodway, cross-sections were defined at metre intervals. A long-section profile of the floodway is shown in Figure 13.

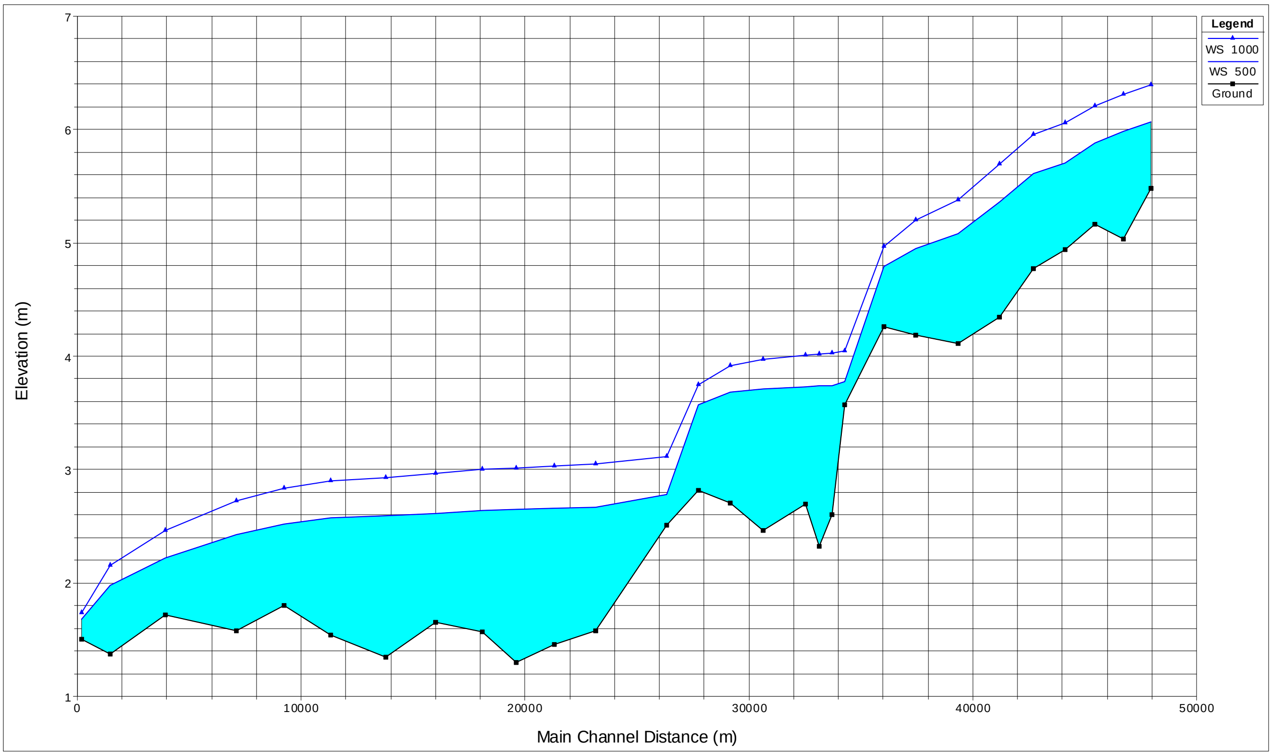


Figure 13 Ephemeral lakes floodway profile

The required floodway widths and bank heights have been derived from the hydraulic model. Note that the hydraulic model has assumed the floodway invert is at natural surface level, with vertical banks on either side. In practice, due to the need to excavate spoil for the banks, the invert of the floodway will be slightly lower than the natural surface and also the banks will be inclined. A reduced freeboard requirement was adopted to compensate for these approximations.

For a flow of 1250 ML/day, the required flow widths and heights are as follows:

- before Princess Highway crossing with average width of 40 m and average levee height of 1.0 m
- after Princess Highway crossing with average width of 60 m and average levee height of 1.5 m.

HYDROLOGIC ANALYSIS

The hydrologic analysis undertaken in this study consists of three components. The runoff expected from the majority of relevant contributing catchments was obtained from existing hydrologic models (Wood and Way 2011). Runoff from contributing catchments to ephemeral lagoons was estimated using a daily rainfall runoff model in this study and the loss to groundwater occurring along the flow-paths based on the hydraulic head produced by the difference between the water surface and the groundwater table was determined. The total yield expected along each reach of each flow-path is calculated using a water balance, including flow and rainfall inputs and groundwater and evapotranspiration outputs. Further details on the method used in the hydrologic analysis are provided in the remainder of this section.

RUNOFF ESTIMATION

For the first stage of hydrologic analysis, the potential runoff from every catchment contributing to proposed flow-paths depicted in Figure 1 has been simulated. In the remainder of this section the model structure adopted by Wood and Way (2011) is outlined. The calibration and validation of the model was also undertaken with existing flow data, the climate data used for both historic and climate change scenarios and the downstream flow requirements for each diversion point.

MODEL STRUCTURE AND CALIBRATION

Daily time-step rainfall runoff models have been used in the Wood and Way (2011) work. The model considers the soil moisture and storage processes occurring within the catchments to simulate the expected runoff. The commonly used AWBM model structure has been adopted within the WaterCRESS platform (Cresswell 2002). The AWBM rainfall runoff model processes rainfall and evaporation inputs to calculate the net rainfall input to a catchment node. This rainfall then serves to fill a number of soil stores (C1–C3) of variable areal extent (A1–A3) which are subject to evaporation before the excess becomes runoff. The total runoff is partitioned into surface runoff and sub surface storage by the use of the base flow recharge parameter, before the release of the sub surface (base flow) and surface runoff storages are routed by a recession coefficients to delay timing of flows to the downstream node. The process is repeated for each catchment node in the system. The structure of the AWBM model can be seen in Figure 14.

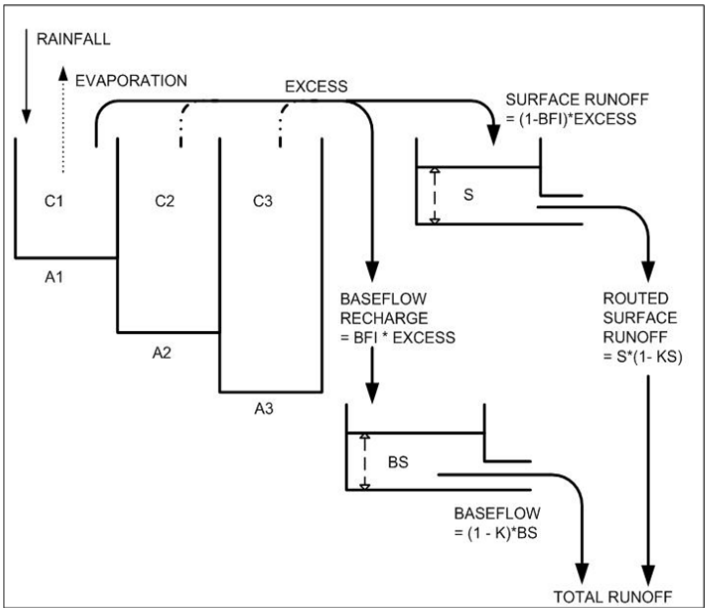


Figure 14 Schematic of AWBM rainfall runoff model structure (Podger 2004)

The rainfall runoff models developed as part of the National Water Initiative Regional Flow Management Strategy for the South East project (Wood and Way 2011) were extended for use in this study. The 2 m DEM available for the region was used to define the catchment boundaries (Figure. 3) as well as the depth–volume–area relationships developed for Southern Ephemeral Lakes to account for the storage and loss effects occurring in wetlands. There are a number of easterly catchments that are connected to the drainage network (and eventually the CSL), which have not been considered in this study and hence, are not highlighted in Figure 1. This includes the Didicoolum Drain and the Mount Charles Drain leading into the northern outlet. These catchments have not been considered due to very infrequent events where significant volumes of water are available to the flows paths considered as part of this study.

The models have been calibrated using the Nash–Sutcliffe Efficiency measure, as well as the bias in total volume estimation at locations where the available time series data are available at downstream points of the modelling catchments. The catchments that contribute to the proposed flood paths with data available for calibration are Bakers Range South (site A2390515), Callendale regulator (A2390514), Wilmot Drain (A2390527) and Drain L (A2390510). Details of model accuracy are provided in Wood and Way (2011). The calibrated model parameters obtained for these catchments, as well as other nearby catchments (such as for Bray Drain A2390504 and Drain L A2390505), were regionalised using a nearest catchment donor approach to develop models for the remainder of the contributing catchments, such as the ephemeral lagoon catchments. Where possible, the models were validated against short flow records that are available but unsuitable for model calibration (e.g. Kercoonda (A2391092)) and found to produce reliable estimates of expected runoff yields.

As suggested by Wood and Way (2011), the models have been developed for a standardised 30-year period of 1971–2000. This study period was chosen for a number of reasons:

- It is consistent with the 30-year rainfall surface developed by the Bureau of Meteorology for DWLBC, as described by Alcorn (2006).
- Daily evaporation data has been estimated at the SILO sites from 1969. Estimates for earlier years are based on monthly data, which is less suited to daily time-step modelling.
- It encompasses the longest of the available flow records in the region, which begin in 1971.
- It is of sufficient length to capture the recent historic variations in climate, therefore providing valid model outputs for policy development.
- The statistics generated, whether annual or monthly, are based on a sufficiently large sample size to be statistically valid.
- It is sufficiently long as to capture both wet and dry periods over the past 30 years and excludes the effects of the drought over the last decade.
- It largely excludes issues associated with land use change. For instance, the planting of blue gums in the Lower South East since 1998.

In addition, as can be seen in Figure 15 and Figure 16, the comparison of climate data over this 30-year period and silo data from 1900–2010 for gauging station M26070 shows that the standard 30-year period is consistent with the long term record.

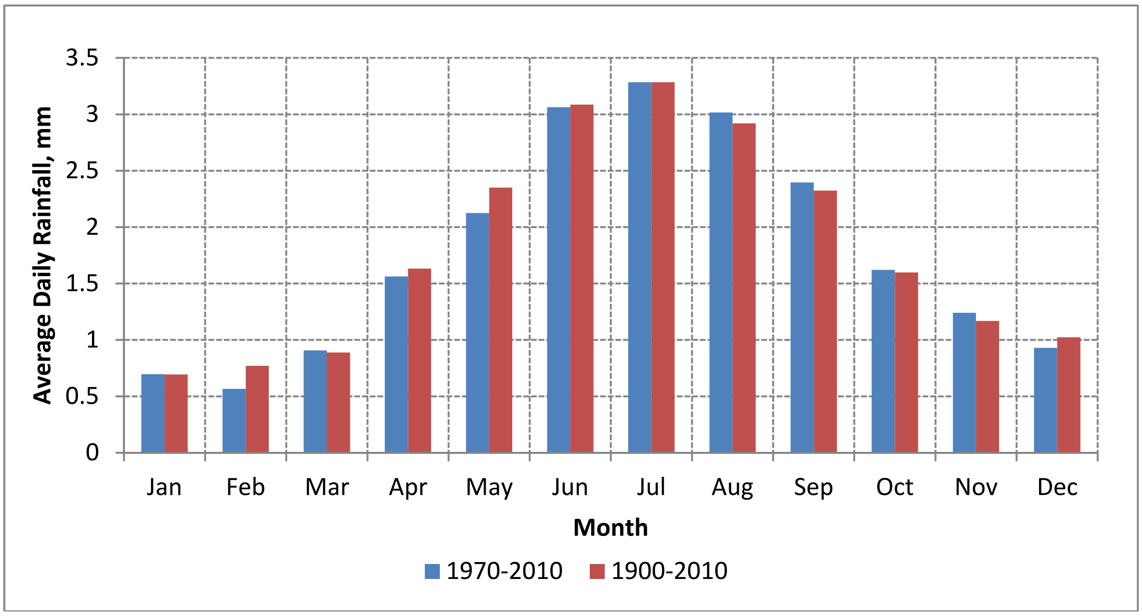


Figure 15 Comparison of average daily rainfall data for gauging station M26070

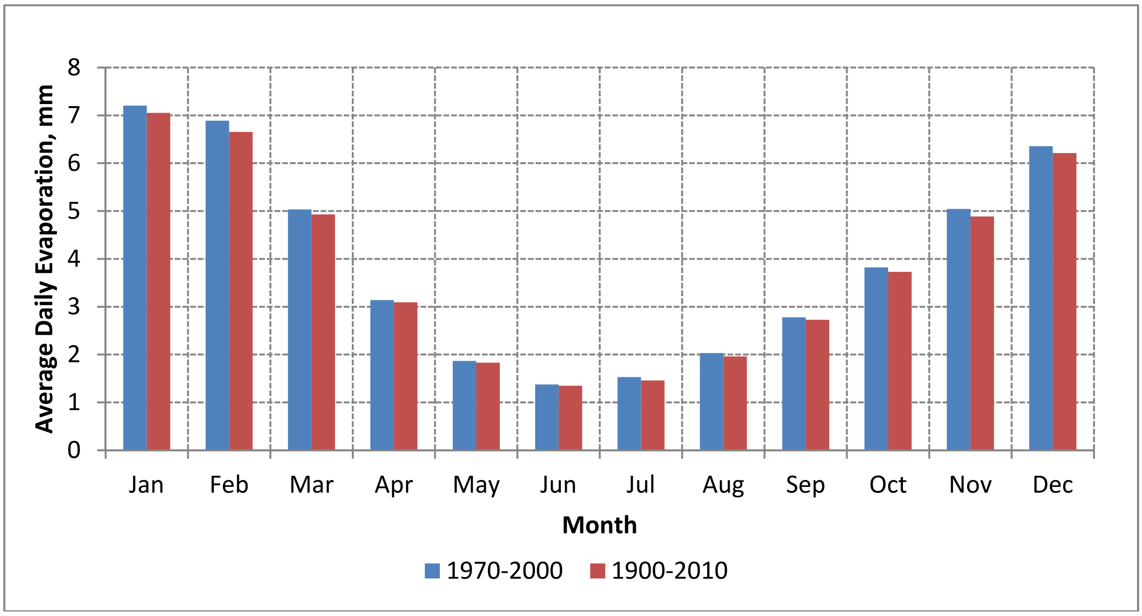


Figure 16 Comparison of average daily evaporation data for gauging station M26070

Table 3 Comparison of daily climate data

		1900–2010	1970–2000
Evaporation mm/day	Average	3.8	3.91
	Median	3.4	3.2
	Max	18.5	18.5
Rainfall mm/day	Average	1.8	1.81
	Median	0.00	0.10
	Max	72.60	72.60

The daily time-step models have been developed for all catchments contributing to the flow-paths considered (Figure 1), with the exception of the area upstream of the Callendale regulator on Drain M. For flow expected from this region, the historic flow record has been used directly. This approach was adopted for a number of reasons; firstly the flow record at this location encompassed the whole 30-year standard period and secondly, this approach removed the uncertainty involved in simulating catchments that extend into Victoria, as well as in the storage and release processes occurring at Bool Lagoon.

CLIMATE INPUTS

For the historic climate conditions, the rainfall and evaporation inputs required for the rainfall runoff model were derived from the Bureau of Meteorology Patched Point Datasets (Jeffrey et al. 2001). To consider possible changes in a future climate the projections adopted by AWE (2009a) for 2030 conditions have been used in this work. Scenarios to represent both a median and dry future climate for 2030 are considered, determined using information provided by Suppiah et al. (2006) and CSIRO and BoM (2007). Separate adjustments are applied for the wet and dry periods each year, with the wet period defined as the months of July to October inclusive and the remainder of the year defined as the dry period. The adjustments have been applied to historic rainfall series as input to the hydrologic model to generate the runoff, as well as adjustments to the historic flow records used to represent the flow at the Callendale regulator. Flow adjustments were provided based on modelled runoff reductions as a result of predicted rainfall reductions for monitoring site at Drain L by AWE (2009a).

The adjustments used are presented in Table 4.

Table 4 Climate change adjustments (AWE 2009a)

2030 climate	Season	Rainfall adjustment %	Flow predicted %
Median	Dry period	4.1	26
	Wet period	6.9	28
Dry	Dry period	10.4	37
	Wet period	13	54

DIVERSIONS

There are two cases to consider for diversions from the simulated runoff available in the region. The first are existing diversions that occur within the drainage network and secondly, the maximum and minimum diversion rates to be identified for the proposed diversion points (Figure 1).

REFLOWS diversions from Callendale are assumed to be active for this study. The diversion rates implemented were informed by the Upper South East Decision Support System (USE DSS), which has been developed to operate the regulators in the drainage network based on flow and water quality constraints. The minimum diversion rate at this location is 100 ML/day, to provide inflows for the terminal Lake George on Drain M. The maximum diversion rate is based on the capacity of the drainage channel at 1000 ML/day. Any flow occurring along Drain M within these limits has been considered to be diverted at the Callendale regulator, before it is available for the diversion point on Drain M considered for this study.

Any REFLOWS diversions, as well as runoff generated from the receiving mid-Bakers Range catchments, have not been considered to contribute to the flow-paths assessed in this study. It is assumed that any water available in this region will be used to sustain the local wetlands in the Upper South East and that there will be no further capacity from this region to support the CSL. However, this may not always be the case and hence, the runoff calculated may provide a conservative estimate of the potential yield from the Upper South East catchments.

Similarly, as advised by the USE DSS (Paul Masters [Business Analyst , Department for Water] pers. comm., 18 November 2010), all flows along the Blackford Drain from the Fairview system have been considered to be diverted northward along the Bald Hills Drain and, subject to maximum salinity constraints, will be delivered to the wetlands in the West Avenue watercourse. Based on the flow gauge at this location which commenced being recorded in 2003 (A2390569), an average yield of 5000 ML/year, or median yield of 6700 ML/year, is produced. However this record is influenced by diversions along the Fairview Drain and north along Bakers Range and does not include losses that will occur if this volume is diverted to the CSL. Further flows generated from the local catchment upstream of this diversion point are assumed to be available for diversion to the CSL, delivered to the flow-paths via Henry Creek.

Minimum and maximum diversion rates, similar to those used for the Callendale REFLOWS diversions, are also required for the diversion points considered in this study. The maximum diversion rates are dependent on the capacity of the receiving flow-path and have been subject to an optimisation study as part of this work. The results from this optimisation study and corresponding maximum diversion rates are presented in the *Results* section. The minimum diversion thresholds are determined based on the requirements of the receiving environment downstream of the diversion point. In this study the same thresholds as those determined by AWE (2009a) have been used, as summarised in Table 5.

Table 5 Minimum daily diversion rules

Diversion point	Downstream receiving environment	Minimum daily flow threshold rule
Drain M	Lake George	All flow below maximum daily diversion threshold once 30 GL has passed in a calendar year
Wilmot Drain	Lake Hawdon North	22 ML/day
Drain K	Lake Hawdon North	10 ML/day
Blackford Drain	None	0 ML/day

GROUNDWATER LOSSES

Morgan et al. (2011) reviewed the method implemented by AWE (2009a) to quantify stream losses to the groundwater system. As part of the review, the authors proposed three alternative cases for estimating transmission loss. The three cases are based on the potential physical conditions observed in the field (see Figure 17 for a conceptual summary of cases). All three methods proposed by Morgan et al. (2011) are simple analytical mathematical models, for one-dimensional flow under steady state conditions and assume the flow medium (soil/aquifer) is homogeneous and isotropic.

ASSESSMENT OF FIELD CONDITIONS AND APPLICATION OF MODELS

The three transmission loss cases proposed by Morgan et al. (2011) differ in their treatment of the channel elevation with respect to the aquifer and watertable. In all cases, it is assumed that a soil layer of relatively low permeability overlies the regional tertiary limestone aquifer. To determine the appropriate cases, the following tasks were carried out on each channel segment which was modelled:

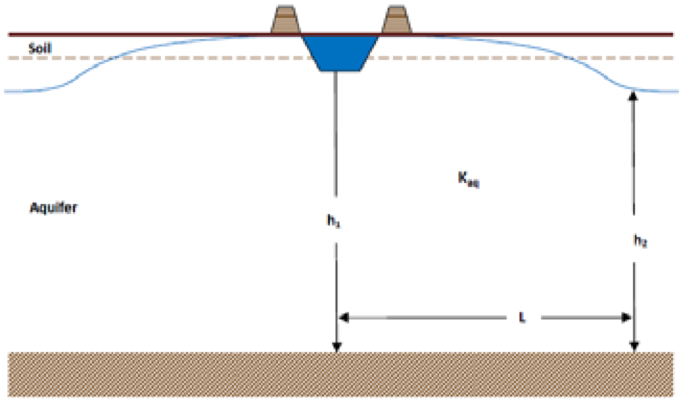
- The average elevation of groundwater (the watertable) in spring was identified at each location using ArcGIS. Groundwater levels were taken from an interpolated watertable map based on point observation data (Obswell data). The interpolation takes into account the most recent regional DEM (the LiDAR DEM). It is assumed that this interpolated watertable surface gives the most accurate depth to water information based on current data sets. Spring groundwater levels were used as they generally represent the watertable at its peak level, which is likely to correspond to times in which sufficient surface water flows are available to direct into the channels.
- Soil type, soil depth and soil hydraulic conductivity was identified at each segment. The soil type and depth information was taken from the South Australian Land and Soil Spatial Data (DWLBC 2007). This data set consists of spatially distributed polygons which identify all soil types likely to be present in an

area. In all cases, the dominant soil type was selected as representative. Soil hydraulic conductivity data was obtained from AWE (2009b).

- Thickness of the regional tertiary limestone aquifer was taken from the Department for Water's drillhole database (SA Geodata) and taken as the depth at which the regional aquitard was reported to occur. This data was not available for every channel segment, therefore aquifer thickness was assumed in many cases, based on available data.
- Hydraulic conductivity of the tertiary limestone aquifer was assumed to be 80 m/day in all segments, based on modelled values reported by Brown et al. (2000).

APPLICATION OF GROUNDWATER LOSS CASES

For each modelled flow-path, plots were made showing the elevation of the water level in the proposed drain (based on a particular flow scenario), the bottom elevation of the drain, the elevation of the watertable in spring and the bottom of the soil profile underlying the surface. An example of such a plot for Taratap and Tilley Swamp is provided in Figure 18. For all segments, Case 2 from Morgan et al. (2011) was identified as the most appropriate scenario. However, Case 1 and Case 2 are essentially equivalent, with the appropriate average hydraulic conductivity determined based on the relevant soil properties (as outlined below).

<table>
<tr><th>Transmission loss case</th><th>Conceptualisation</th></tr>
<tr><td>Case 1. Saturated flow: The channel intersects the aquifer and the watertable is shallow</td><td>
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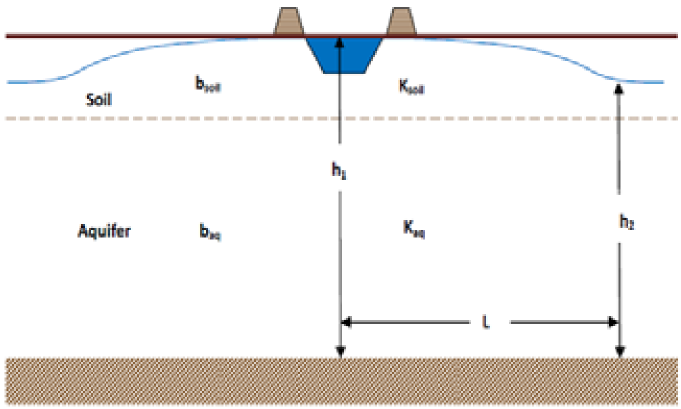
<tr><td>Case 2. Saturated flow: The channel sits within the soil layer and the watertable is in the soil layer</td><td>
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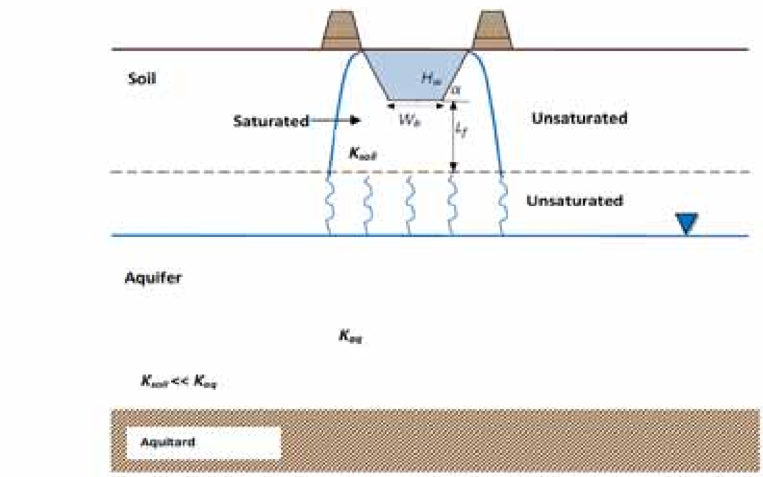
<tr><td>Case 3. Unsaturated flow: The channel sits within a low conductivity soil layer and is hydraulically disconnected from the watertable</td><td>
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Figure 17 Transmission loss cases developed by Morgan et al. (2011)

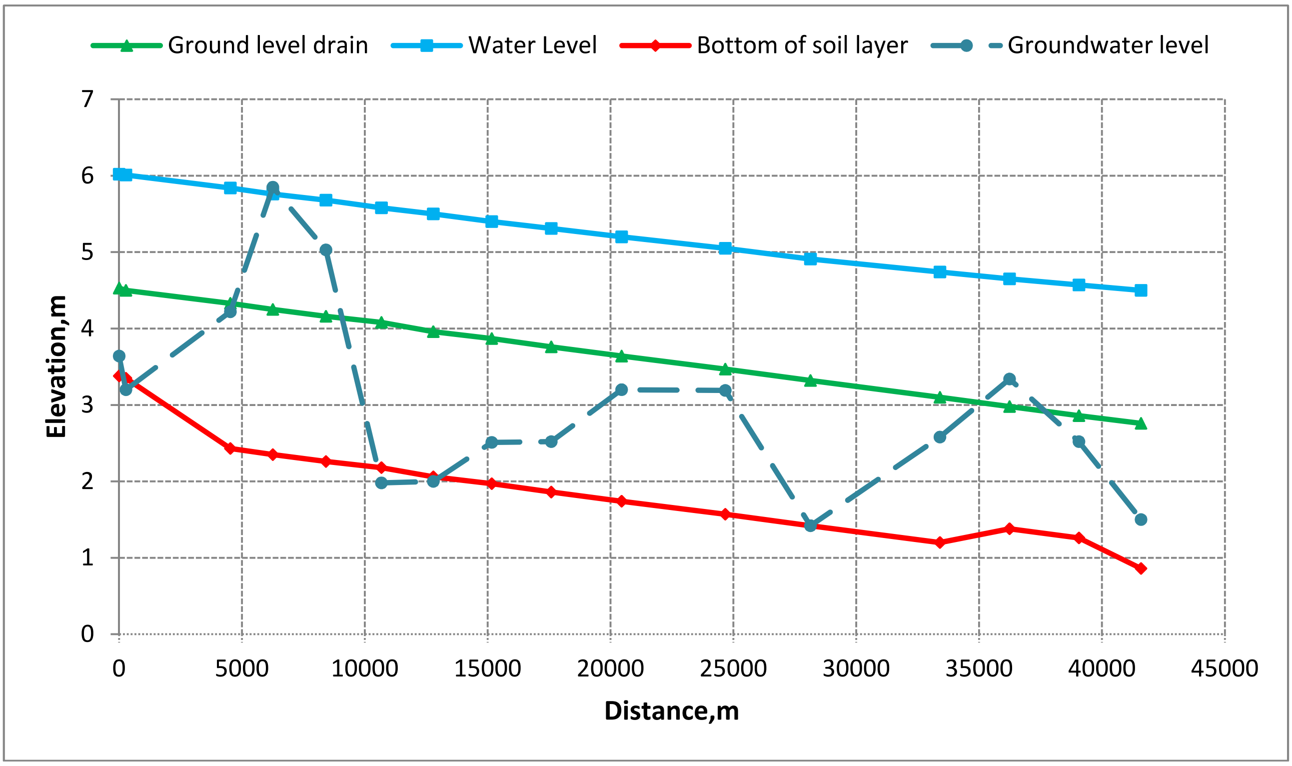

Figure 18 Elevations in the proposed Taratap and Tilley Swamp proposed flow channel, based on a 1500 ML/day flow

Figure 17 conceptualises Case 2 from Morgan et al. (2011). In this case, both the channel and the watertable sit within a low conductivity soil layer above the regional aquifer. At least 0.5 m of soil is present between the bottom of the channel and the top of the aquifer. The seepage from the channel into the aquifer may be calculated as:

$$Q = K_{ave}\frac{{h_1}^2 - {h_2}^2}{L}, \quad (1)$$

Where:

Q is the seepage per metre of channel

K_{ave} is the average weighted hydraulic conductivity of the soil and aquifer

h_1 is the elevation of water in the channel

h_2 is the elevation of the watertable

L is the distance from the channel where h_2 is measured.

In line with the assumptions used by AWE (2009a), as well as the spatial analysis performed in GIS, L was set at 250 m in all cases. The average hydraulic conductivity, K_{ave}, in a saturated, two-layer system, was calculated according to Equation 2 (Bear 1979, cited in Brunner et al., 2009):

$$K_{ave} = \left[\frac{1}{b_{soil} + b_{aq}} \times \left(\frac{b_{soil}}{K_{soil}} + \frac{b_{aq}}{K_{aq}}\right)\right]^{-1}, \quad (2)$$

Where:

K_{ave} is the average weighted hydraulic conductivity of the soil and aquifer

b_{soil} is the thickness of the soil layer (m)

b_{aq} is the thickness of the aquifer (m)

K_{soil} is the hydraulic conductivity of the soil (m/d)

K_{aq} is the hydraulic conductivity of the aquifer (m/d).

A spreadsheet was populated with all the data necessary to calculate Equation 1 and Equation 2 for each channel segment and transmission loss calculated. The transmission loss values for each segment were then incorporated into the water balance model for each reach, as detailed in the following section. Based on the thickness of the soil layer, depth of the groundwater table, depth of the drainage channel in relation to the soil layer and water level in the drain, it was concluded that transmission loss case 2 is the most suitable for the region. There are some reach segments where this is not always the case, for example where there is less than 0.5m of the soil layer between the drain invert and the tertiary limestone aquifer. However, these scenarios occur relatively infrequently and given the uncertainty in the soil thickness data and extrapolation of the groundwater level data, these reaches have not been treated differently and Case 2 has been applied for the whole region.

TREATMENT OF GAINING STREAM CONDITIONS

As seen in Figure 18, some segments of the flow-paths occurred in locations where the groundwater level was above the drain bottom elevation. In some of the low flow scenarios, groundwater levels were found to be higher than surface water levels. For these segments the Case 2 equation has been determined to be equally suitable to estimate gains to the drain as it is for estimating losses from the drain. As with the loss case, L = 250 m has been assumed for gaining conditions. This has allowed a net loss for each reach to be determined, considering the input estimate from segments where the groundwater table is above the water level in the drain. However, based on the surface water level in each drain and groundwater levels assumed, gaining conditions are rare over the region. This was found to be only in the Tilley Taratap - Tilley Swamp reach, and even then over short segments only.

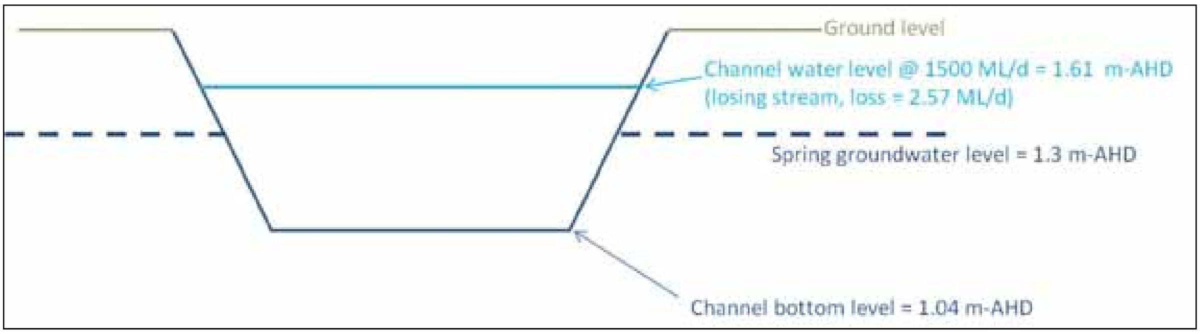

Figure 19 An example of a segment with losing stream

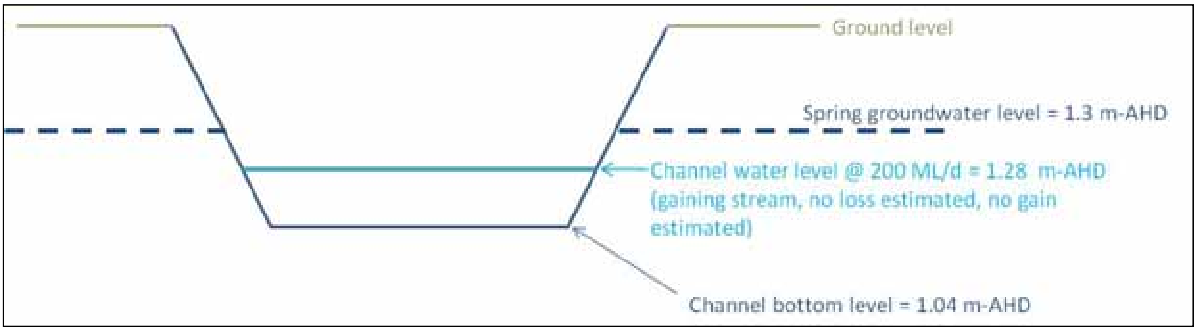

Figure 20 An example of a segment which may be gaining groundwater under low flow scenarios

Groundwater discharge is likely to be an important factor in the Coorong, however the volume of groundwater discharge is unknown and its significance remains speculative (Haese et al. 2008). While modelling could provide some indication of the influence of a seasonally fluctuating watertable on surface water levels in the southern ephemerals, it would require a more detailed transient numerical approach which is beyond the scope of this project (where an analytical steady state approach has been taken). In order to account for this phenomenon for the southern ephemeral lagoon paths, no groundwater losses are considered from the lagoons for the period from the start of June to the end of calendar year.

ESTIMATION OF SOIL HYDRAULIC CONDUCTIVITIES

Accurate estimation of saturated soil hydraulic conductivity suitable on a reach basis is difficult, as soil properties can vary considerably over short distances. AWE (2009b) undertook hydrogeological investigations to ground truth previously used (AWE, 2009a) soil hydraulic conductivity estimates used in the assessment of groundwater loss from the Reedy Creek channel alignment between Drain M and Drain K. The natural variability of soil hydraulic conductivity is evident in the two most common soil types investigated in the study, TNDXtC and FURXRC, where the conductivity ranged over two to three orders of magnitude for the same soil type. A plot of the frequency of occurrence of the range of K values for each Soil type can be seen in Figure 21. The lowest values for the TNDXtC soil type was actually 0.003 m/d, three orders of magnitude below the highest values of 2.7 m/d. As seen in Equation 1, the groundwater loss is directly proportional to the soil conductivity, indicating that the large uncertainty in suitable K values transfers directly to the groundwater loss estimates.

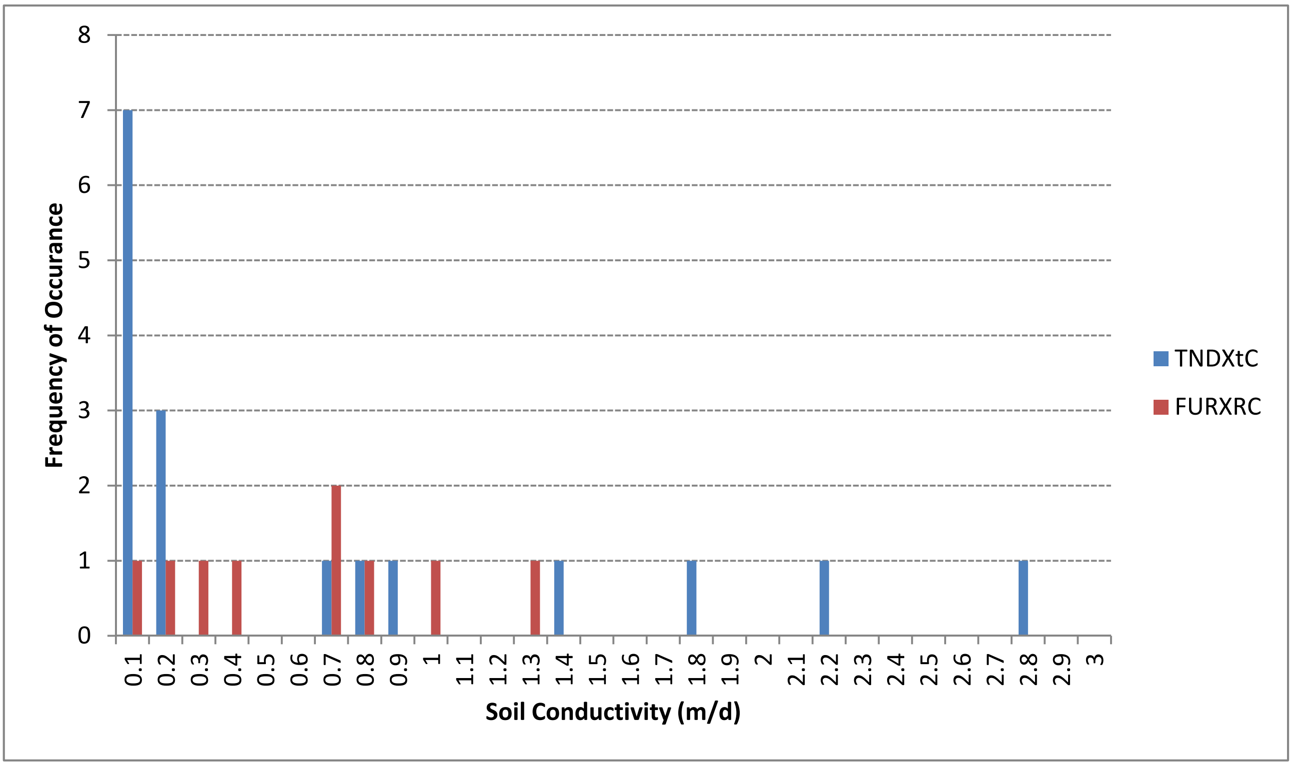

Figure 21 Range of saturated soil hydraulic conductivities for the two most commonly sampled soil types tested by AWE (2009b).

Due to the large range in values found through field testing, typical averaged values for the soil conductivity based on the soil type (Fetter, 2001) have also been considered. For the soil types present in the study area, the values considered based on the typical values (Fetter, 2001) and field studies (AWE, 2009b) can be seen in Table 6. For the majority of cases, the typical values are less than the field study values, which in turn leads to reduced groundwater losses.

Table 6 **Saturated Soil Hydraulic Conductivity (m/d) for different soil types, interpreted from different sources.**

Soil type	AWE (2009b)	Fetter (2001)
Black cracking clay	0.002	0.001
Bleached siliceous sand	2.52	0.5
Calcereous clay loam on marl	0.13	0.01
Gradational clay loam	0.046	0.01
Peat	0.570	0.05
Saline hydrosol	0.57	0.05
Saline soil	0.57	0.1
Sand over poorly structured clay	0.09	0.002[a]
Shallow calcareous loam on calcrete	0.137	0.05
Shallow dark clay loam on limestone	0.13	0.01
Shallow loam over clay on calcrete	0.137	0.0013[b]
Shallow sand on calcrete	0.35	0.01
Shallow sand over clay on calcrete	0.137	0.0013[c]
Thick sand over clay	0.09	0.0032[d]
Wet soil	0.57	0.05

[a] based on 1m sand (K=0.1) and 0.9m clay (K=0.001)
[b] based on 0.3m loam (K=0.1) and 0.9m clay (K=0.001)
[c] based on 0.3m sand (K=0.1) and 1.0m clay (K=0.001)
[d] based on 1m sand (K=0.1) and 0.45m clay (K=0.001)

To compare the impact of the different values of saturated soil hydraulic conductivity, the relationship between the flow rate, which drives the water level in the drain, and the transmission loss estimated has been investigated. The transmission losses estimated for the two most upstream reaches, from Drain M and the first reach along Ready Creek, can be seen in Figure 22 and Figure 23, respectively. The AWE (2009b) values, derived from site investigations, can be seen to be much higher in Table 6 than the values derived from the soil type from Fetter (2001). As the transmission loss is proportional to the hydraulic conductivity, the transmission losses presented in Figure 22 and Figure 23 are also much higher based on the site investigation values (AWE, 2009b) compared to the typical values (Fetter, 2001). This again highlights the difficulty in determining suitable quantitative values to represent soil properties at the reach, or reach segment scale.

The results indicate that based on the site investigation data, any flow of 200 ML/day or less for Drain M, and flows of 500 ML/day or less for Ready Creek, will be lost to transmission losses and not be seen at the end of the reach. In comparison, the Drain M losses from the values derived from the soil type range between 0 and 10 ML/day in Drain M, and between 50 and 105 ML/day in the first reach of Ready Creek. Over half of the first reach of Ready Creek is classified as Wet Soil or Saline Hydrosol, which has one of the highest soil hydraulic conductivity values (apart from bleached siliceous sand and saline soil), and hence the highest simulated loss. Recent site investigations and observations (Mark de Jong, Environmental Officer, South Eastern Water Conservation and Drainage Board, Department for Water, pers. comm. 11 August 2011) indicate that the groundwater losses estimated from the soil hydraulic conductivity values provided by AWE were unrealistically high and therefore the typical values based on the soil type (Fetter, 2001) have been adopted as the K values for this investigation.

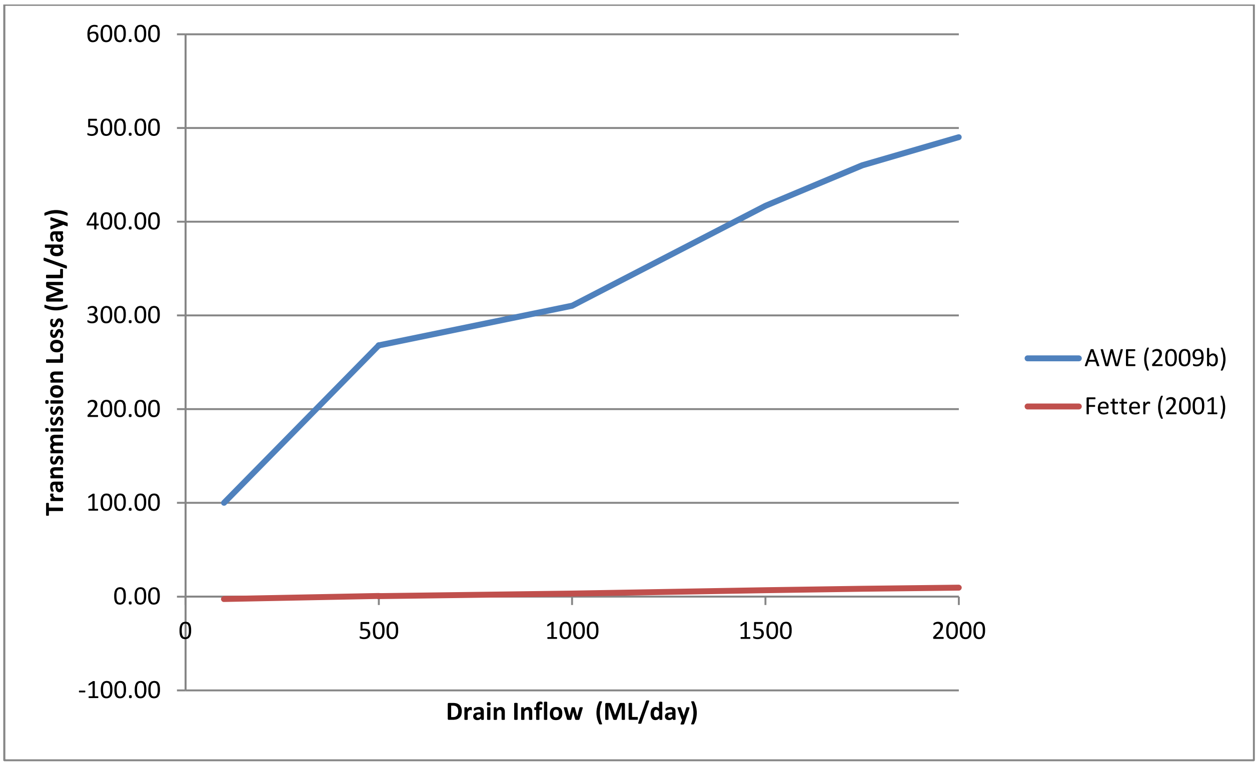

Figure 22 **Transmission losses based on different estimates of Saturated Soil Hydraulic Conductivity for Drain M. The length of this reach is 30.6 km.**

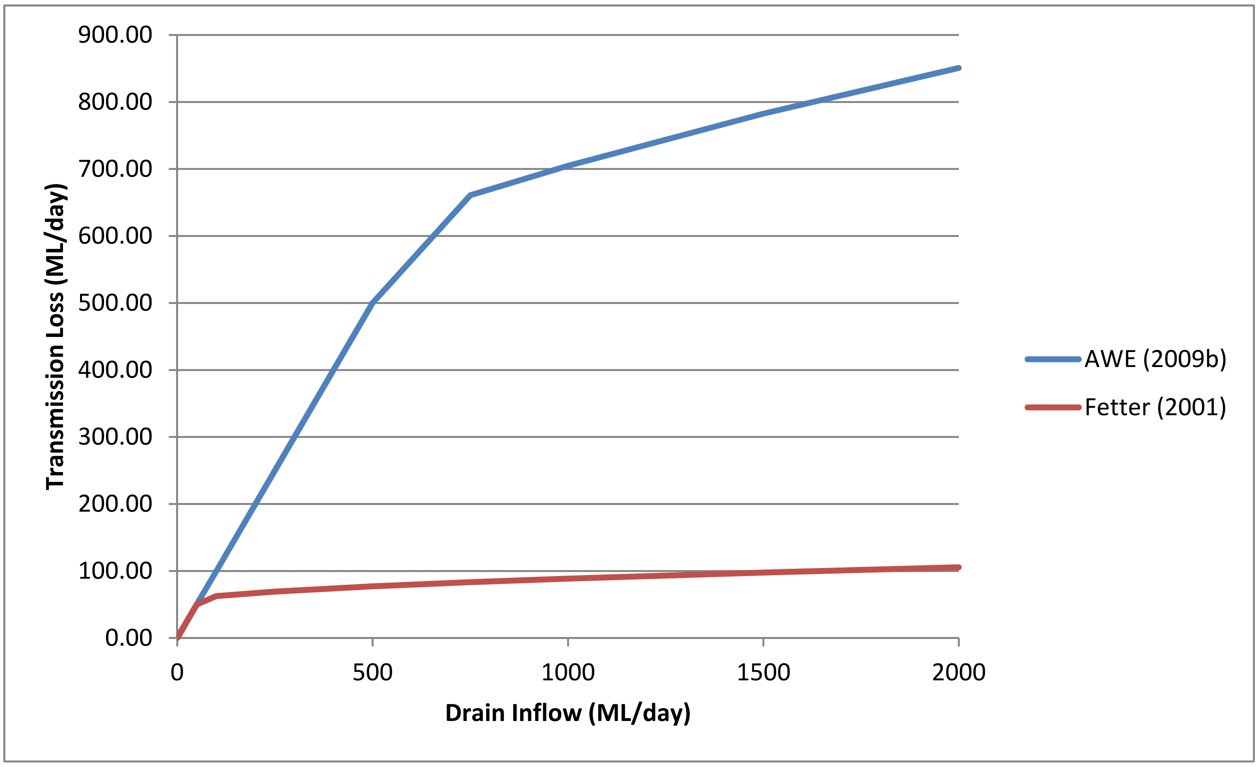

Figure 23 **Transmission losses based on different estimates of Saturated Soil Hydraulic Conductivity for the first reach of Ready Creek. The length of this reach is 70.5 km.**

VALIDATION OF GROUNDWATER LOSS ESTIMATES

The nature of surface water–groundwater interactions in the Upper South East is complex and varies both spatially and temporally. Processes are also generally poorly understood, largely owing to a lack of monitoring infrastructure specifically designed to investigate the process (both surface water and groundwater levels and salinity data in locations of interest). However, data collected as part of the Upper South East Program has provided a useful means of validating loss estimates in at least one location. Figure 24 presents the groundwater level and corresponding salinity in observation well NVL027—which is located adjacent to the Taratap and Tilley Swamp Drain. It shows the groundwater level fluctuating annually, with rising trends observed from winter to spring. The rise in groundwater level corresponds with a significant fall in groundwater salinity (decrease of over 12,000 µS/cm in 2009). This trend in salinity is not consistently observed in observation wells a further distance away from the drain (as seen in Figure 25, with the spatial location of the two observation wells seen in Figure 26) suggesting a process other than rainfall recharge is significantly diluting groundwater adjacent to the drain—most likely seepage of surface water from the Taratap and Tilley Swamp Drain. This observation correlates with assessments of drain efficiency in this location in recent years (Mark de Jong, Environmental Officer, South Eastern Water Conservation and Drainage Board, Department for Water, pers. comm.)

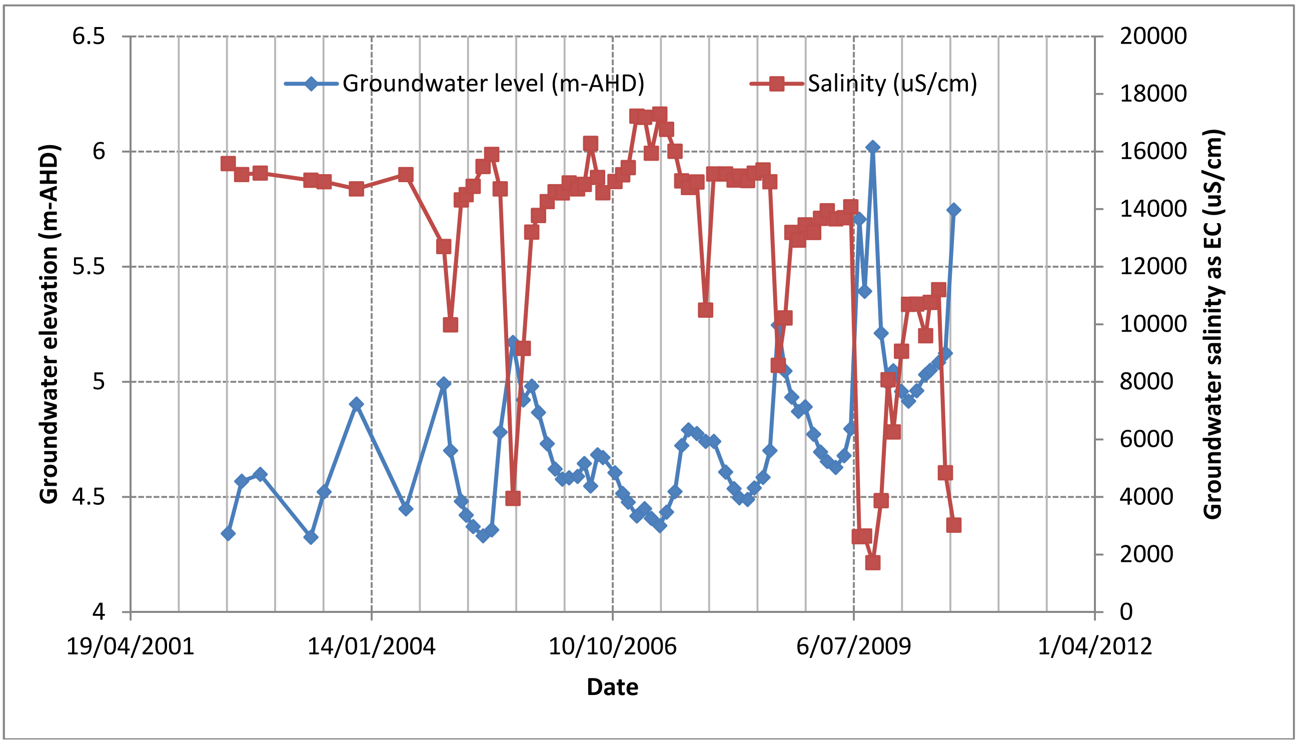

Figure 24 Groundwater level and salinity measured in observation well NVL027 (adjacent to Tilley Swamp Drain)

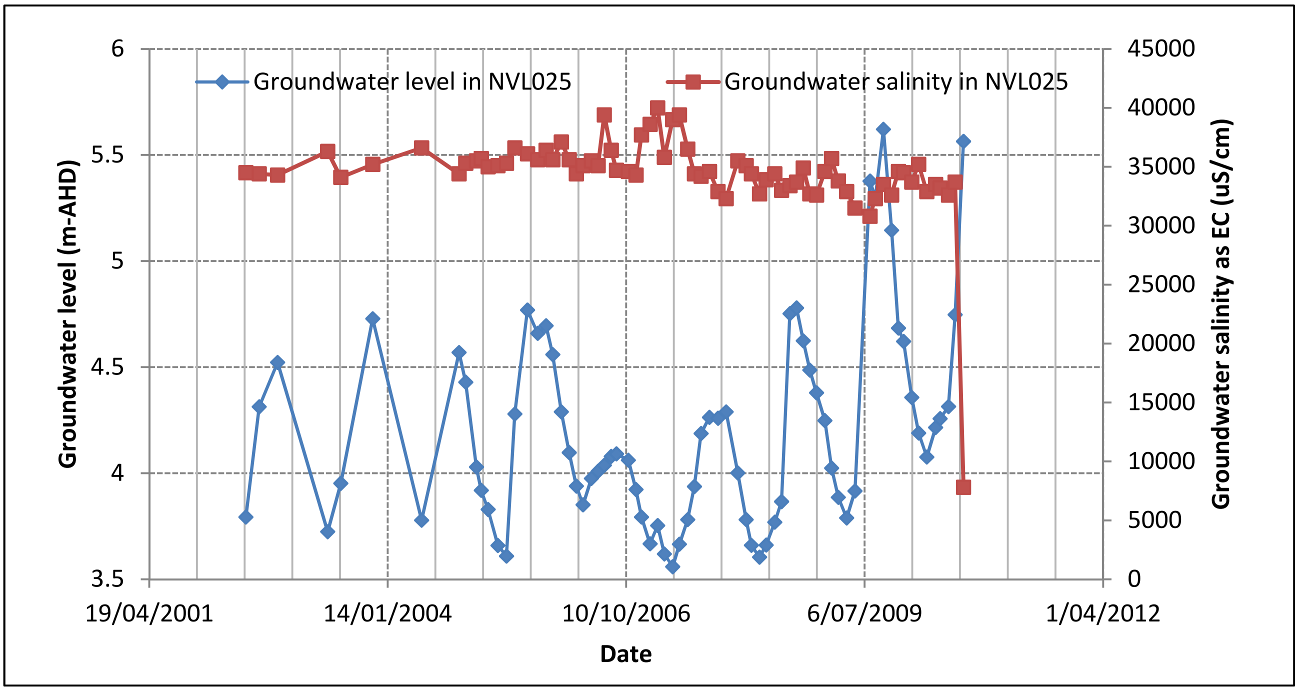

Figure 25 Groundwater level and salinity measured in observation well NVL025 (800 m further west from the Tilley Swamp Drain)

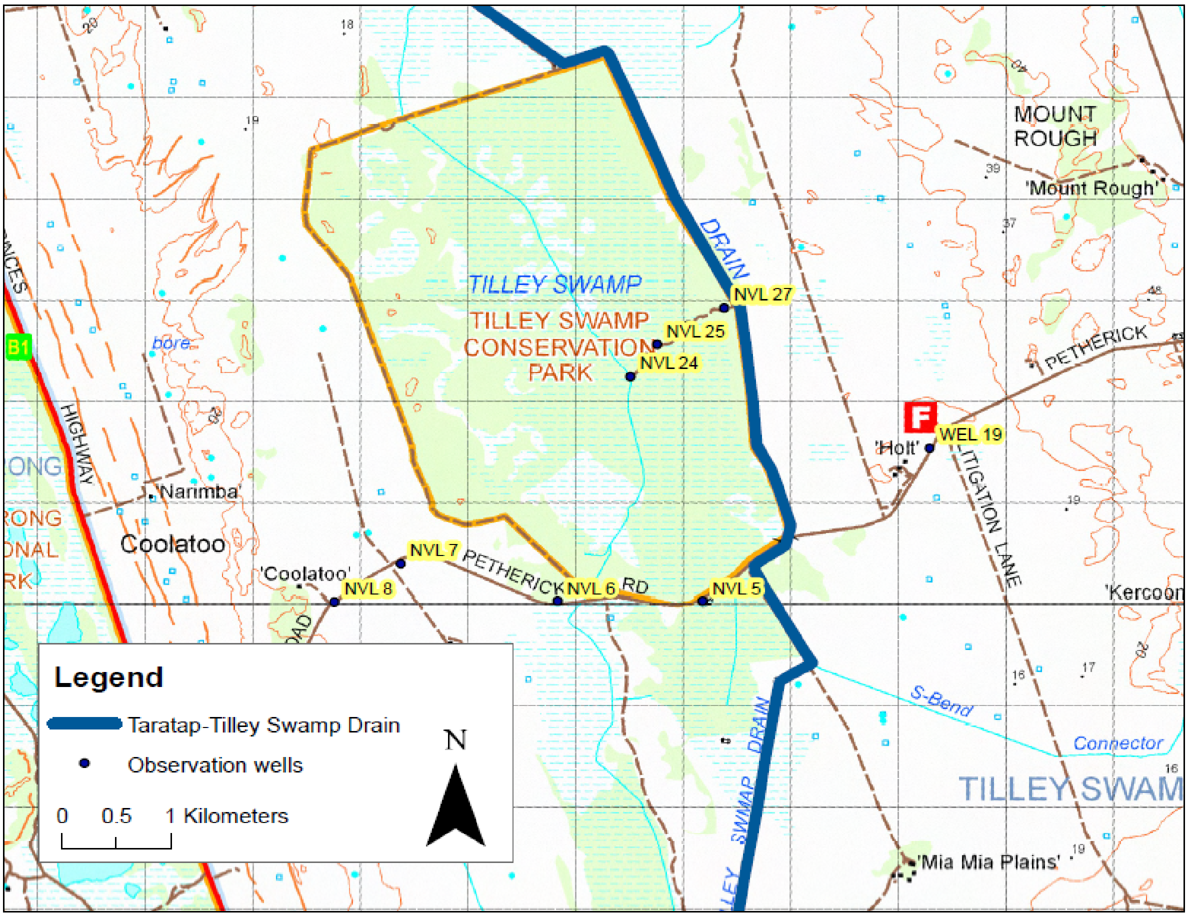

Figure 26 Location of Tilley Swamp Drain and observation wells NVL027 and NVL025

ASSUMPTIONS AND LIMITATIONS

While the approach taken to assess transmission loss in this study builds upon that undertaken by AWE (2009a; 2009b), it is still a relatively simple analytical method, involving a number of assumptions. The key assumptions and limitations associated with this method are as follows.

The effect of clogging on transmission loss is acknowledged to occur but has not been considered due to lack of data. Clogging is the process whereby the permeability of an infiltration surface (in this instance the soil lining the channel) may be reduced by accumulation of suspended solids (sediments, algae, sludge) delivered by the channel water (Bouwer, 2002). This would effectively result in a third layer to consider, with a thin, very low permeability layer sitting on top of the soil layer, reducing the transmission from the drainage network and hence the groundwater loss simulated from each reach.

The analysis of loss is based on groundwater levels measured in spring, typically when they are at their peak (and correlate with surface water flow events). Periods of intense rainfall may generate surface water flows at other times of the year, when the watertable is lower. In these instances, more transmission loss would be expected to occur because of the increased gradient between surface water and groundwater. This potential underestimate is a limitation in the current study.

Groundwater contributions are considered to some extent for the ephemeral lagoons, as the area of each lagoon below sea level is assumed to be maintained by groundwater at 1 June and no loss from July to the end of December each year. Gaining conditions in the drain are assumed to be driven by the regional groundwater table and hence are a separate source of water to rainfall driven interflow or baseflow. However, this may not always be the case, where rainfall leading to recharge and observed high groundwater tables may also be represented as a baseflow contribution in the runoff models. However, reaches simulated with the groundwater table intersecting the drainage network occurred infrequently, with short sections in the Tilley Taratap and Tilley Swamp reaches only. Hence, these gaining conditions do not add a significant volume to the yield delivered to the CSL.

The surface water level in the drain has been computed based on the inflow to the reach and has not been adjusted for the losses occurring within a reach. Hence, it is possible that transmission losses at segments at the end of longer reaches may be overestimated, as any losses occurring upstream within the reach will reduce the volume in the drain and hence, also the water level driving the groundwater loss. However, this influence has been taken into account for the start of a new reach, where all inflows are used to determine the water level.

UNCERTAINTIES

The significant natural variation in soil saturated hydraulic conductivities is evident from the large range in values determined from field studies, as seen in Figure 21. It is acknowledged that using low and high range parameter values demonstrates the large range of seepage loss estimates that are possible with the plausible range of field parameter values. It is important when these methods are applied that the sensitivity of the derived results to the parameter values is examined. By adopting the weighting equation seen in Equation 2, the least permeable layer, the soil layer, was found to have by far the largest impact on the weighted conductivity values used in the calculation of the groundwater loss for each reach segment. Hence, a range in the soil K value has been considered, where the low value has been determined by reducing the value by one order or magnitude (dividing by 10), while the high value has been estimated by increasing the value by an order of magnitude (multiplying by 10). This range in conductivities has been considered in the water balance modelling to provide a sensitivity analysis of the transmission losses involved for each path.

COMBINED WATER BALANCE WITH TRANSMISSION LOSS

The combined transmission loss analysis has been conducted in a spreadsheet format on a daily time step. Each reach has been considered separately, where a reach is defined by the presence of a diversion node or a controlling sill. The approach used to compute the daily water balance is outlined as follows:

- For each reach, the incoming flow is calculated based on the outflow from an upstream reach, from a diversion node and/or from any contributing catchments, as appropriate.
- Based on the incoming flow, the corresponding water level is determined based on the outputs from the hydraulic modelling. The corresponding water surface area is also estimated based on the water level and channel dimensions.
- The change in volume from the water body based on the difference between any rainfall input and evaporation output is then calculated.
- Groundwater losses are then applied based on the results derived from groundwater analysis, outlined in the previous section.
- After the losses have been applied, outflow is then calculated in each reach as the sum of the inflow to the reach plus the losses and gains outlined above.

More details on each components of the water balance are provided in the remainder of this section.

LOCAL CATCHMENT CONTRIBUTIONS

The local catchment contribution is used to account for the runoff generated from catchments that contribute directly to the reaches, as opposed to runoff that enters the flow-paths via diversions from the existing drainage network. Such catchments were defined by inspection of the catchment boundaries and flow-paths derived from the 2 m DEM. The resulting runoff has been calculated in the WaterCRESS platform using AWBM, as outlined in the *Runoff estimation* section. The contributing catchments to the flow-path and to the diversion points are illustrated in Figure 1.

RAINFALL DEFICIT

The volume of water lost or gained due to evaporation and rainfall has been termed rainfall deficit. Rainfall deficit is positive when rainfall is greater than evaporation (generally for the winter months) and negative when evaporation is greater than rainfall (often the case for the remainder of the year).

The same Patched Point Datasets used for the rainfall runoff modelling have been adopted to compute the daily rainfall deficit occurring at each reach. The surface water area has been determined from the channel dimensions and hydraulic modelling (to provide the necessary depth). Finally, the change in volume in each reach is determined by multiplying the surface water area by the difference between the rainfall and evaporation depths.

DISCRETE LAGOONS

The discrete lagoons boundaries and their commence-to-flow levels have been defined by inspection of the 2 m DEM of the region. The northern extent of the lagoons to be modelled is defined by the location of connected water bodies to Salt Creek, where the flow-path can discharge into the CSL. Four lagoons were identified and the boundary identified for each is presented in Figure 27.

Each lagoon is assumed to begin at empty at the start of the 30-year water balance simulation. This has been deemed to be a valid assumption based on the regular drying pattern that occurs and that the initial conditions will have little influence after a short period of running the water balance model. It has also been assumed that, on 1 June each year, the groundwater table will intersect the southern ephemeral lagoons and they will be naturally filled and maintained at a target winter level. The target winter level and corresponding storage volume has been determined by identifying the area in each lagoon below mean sea level (0 m AHD), defined by inspection of 2 m DEM and confirmed by previous observations. Given the assumption that groundwater is supporting the water level in each lagoon, no groundwater losses are applied in the lagoons for the period from the start of June to the end of December.

For each of the four lagoons, the target winter level and corresponding volume, as well as the sill level and corresponding commence-to-flow volume, are presented in Table 7. A scenario has been considered to reduce the losses occurring through the lagoon flow-paths, where the sill heights are reduced by 400 mm and therefore the corresponding commence-to-flow volumes are also reduced. The adjusted sill levels and reduced fill volumes for each of the lagoons are also presented in Table 7.

It should be noted that in this study the reasonable cut depth of 400 mm derived by hydraulic analysis has been considered for water balance calculation and to assess the effect of cuts through the sills on deliverable water at CSL, a series of different cut depths can be considered. In addition, sensitivity analysis on the effect of different winter target levels at each discrete lagoon on deliverable water at CSL can be done for further investigations.

Table 7 Characteristics of lagoons in Flow-path 03—considering ephemeral lakes

	Lagoon 1	Lagoon 2	Lagoon 3	Lagoon 4
Target winter water level, m	1.4	1.25	0.6	1
Target winter volume, ML	23.31	4808.43	989.21	726.39
Sill elevation, m (natural)	2.30	2.00	1.80	1.70
Commence-to-flow volume, ML	3518.88	24101.7	11031.51	4704.74
Sill elevation, m (after cut)	1.90	1.6	1.40	1.30
Commence-to-flow volume, ML	1159.05	11662.59	6240.72	1887.84

Flow-path 03—Floodway involves bypassing the first two lagoons, as well as a significant proportion of the third lagoon. The boundary for the third lagoon for this version of Flow-path 03 is shown in red in Figure 27. The lagoon characteristics for the floodway version of Flow-path 03 are presented in Table 8, where the significant reduction in the commence-to-flow volume of lagoon 3 can be seen.

Table 8 Characteristics of lagoons in Flow-path 03—considering floodway

	Lagoon 3	Lagoon 4
Target winter water level, m	0.6	1
Target winter volume, ML	843.95	726.39
Sill elevation, m (natural)	1.80	1.70
Commence-to-flow volume, ML	5595.63	4704.74
Sill elevation, m (after cut)	1.40	1.30
Commence-to-flow volume, ML	3717.53	1887.84

Flow-path 02 terminates at Morella Basin before flow can be discharged along Salt Creek to the CSL. Based on rules defined by the USE DSS and confirmed with the South Eastern Water Conservation and Drainage

Board, a winter target level of 4.5 m AHD in the basin has been assumed, with all surpluses above this level during 1 May to 30 September being discharged along Salt Creek to the CSL. The target level in the basin is reduced to 3.1 m AHD in October, where any necessary drawdown can be achieved by further discharging flow to the CSL. The depth–area–volume relationship used for Morella Basin in this study was developed by AWE (2006) and is summarised in Table 9.

Table 9 Morella Basin depth–area–volume relationship (AWE 2006)

Water level m AHD	Volume ML	Surface area ha
2.3	0	0
3	30	42
4	5920	824.5
4.2	7600	855.7
4.4	9340	882.5
4.6	11130	904.2
4.8	12950	92.3
5	14810	935.5
5.1	15750	941.3
5.2	16690	946.5
5.3	17640	951.1
5.4	18600	955.6

Figure 27 Discrete lagoons in Flow-path 03

RESULTS

The results are presented in a number of sections, in the order as listed below:

- Results from the maximum diversion rate optimisation.
- The total yield produced at the CSL for the full flow-path investment, both on average and as a probability distribution.
- The components of loss that make up that yield to represent the benefits obtained from a staged investment of the flow delivery system.
- The three flow-paths considered as part of this study and comparison of their ability to supply significant volumes to the CSL.

DIVERSION OPTIMISATION

There is a direct trade-off between providing the capacity to divert larger volumes of water to the Coorong and the costs involved in providing the increased capacity, including financial costs as well as potentially environmental and aesthetic costs. Hence, optimum maximum diversion rates have been estimated to identify the point at which the benefit of increasing the diversion capacity is significantly reduced. The water available for diversion at the Blackford Drain is dependent on the volume diverted at the upstream points, hence these upstream diversion sites have been considered before the Blackford Drain has been considered. All results presented in this section are based on historic climate conditions.

The average annual flow diverted for increasing maximum diversion rates is presented in Figure 28 at each of the three upstream locations. It can be seen that the optimal diversion rate for the Wilmot Drain is 500 ML/day, where any rate greater than this does not yield considerable gains in average annual volume. For Drain K, the optimal diversion rate has been determined to be 250 ML/day, as the value of an extra approximately 1.3 GL/year on average from a 500 ML/day diversion has not been considered to be worthwhile. These two optimal diversion rates are illustrated by yellow points in Figure 28.

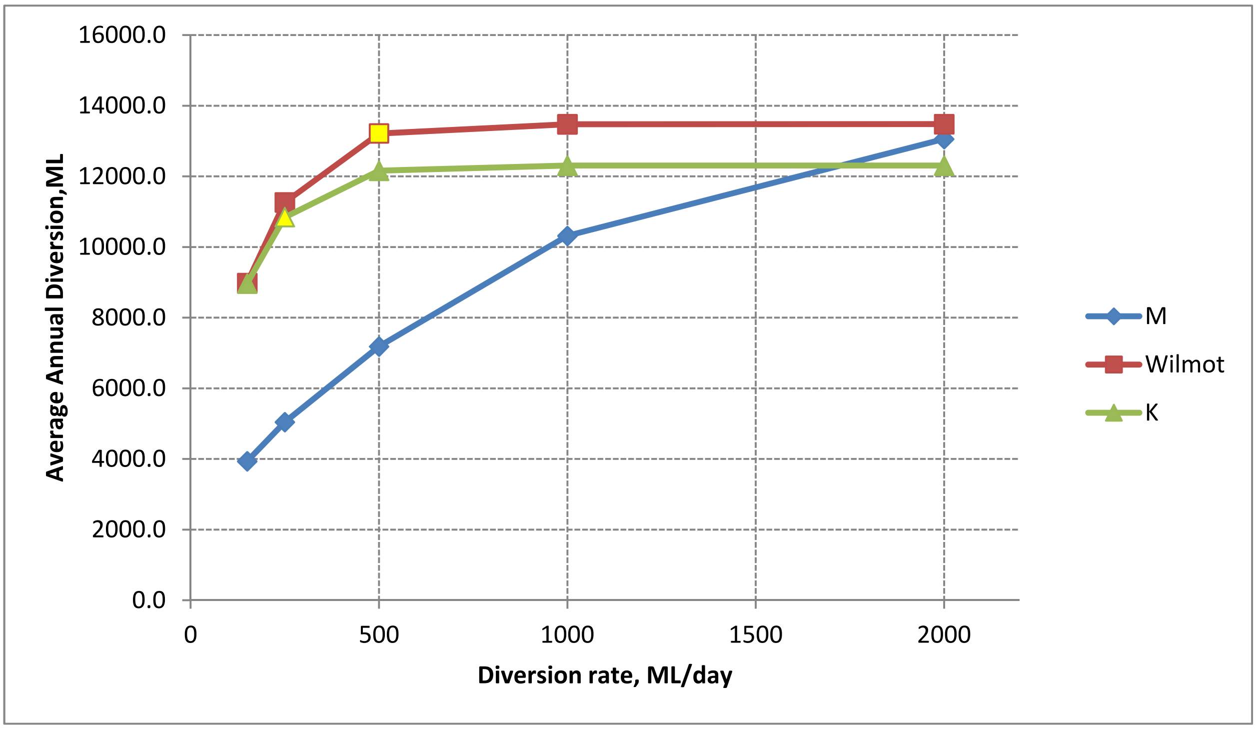

Figure 28 Average annual diversion volume for a range of maximum daily diversion rate

From Figure 28 there does not appear to be an optimal rate for diversion from Drain M, as the average annual diversion continues to increase with the increasing maximum daily diversion rate. However, due to the REFLOWS project upstream on Drain M and the requirements of Lake George downstream, the flow available for diversion for the Coorong South Lagoon Flow Restoration Project occur relatively infrequently. Hence, the annual average diversion rate does not provide the most reliable information on the water availability at this location. To gain a greater understanding of the frequency of yields from the Drain M diversion point for a range of diversion rates, the probability of total volumes diverted at this location occurring for different diversion rates are presented in Figure 29. It can be seen that diversions only occur for over 50% of years, irrespective of the diversion limits, and therefore the median diversion from Drain M is close to 0 ML/day. Hence, diversions from Drain M are only likely to occur in wetter years, with approximately 7 and 11 GL/year yielded for a two in five year event (40%) and between 11 and 25 GL/year for a one in five year event (20%), depending on the maximum diversion capacity. For comparison, the flows available for different recurrence interval events from Wilmot Drain and Drain K (at the optimal diversion rates) are presented in Figure 30. For the same one in five year event, approximately 20 GL/year is expected to be available from each of the Wilmot and Drain L catchments.

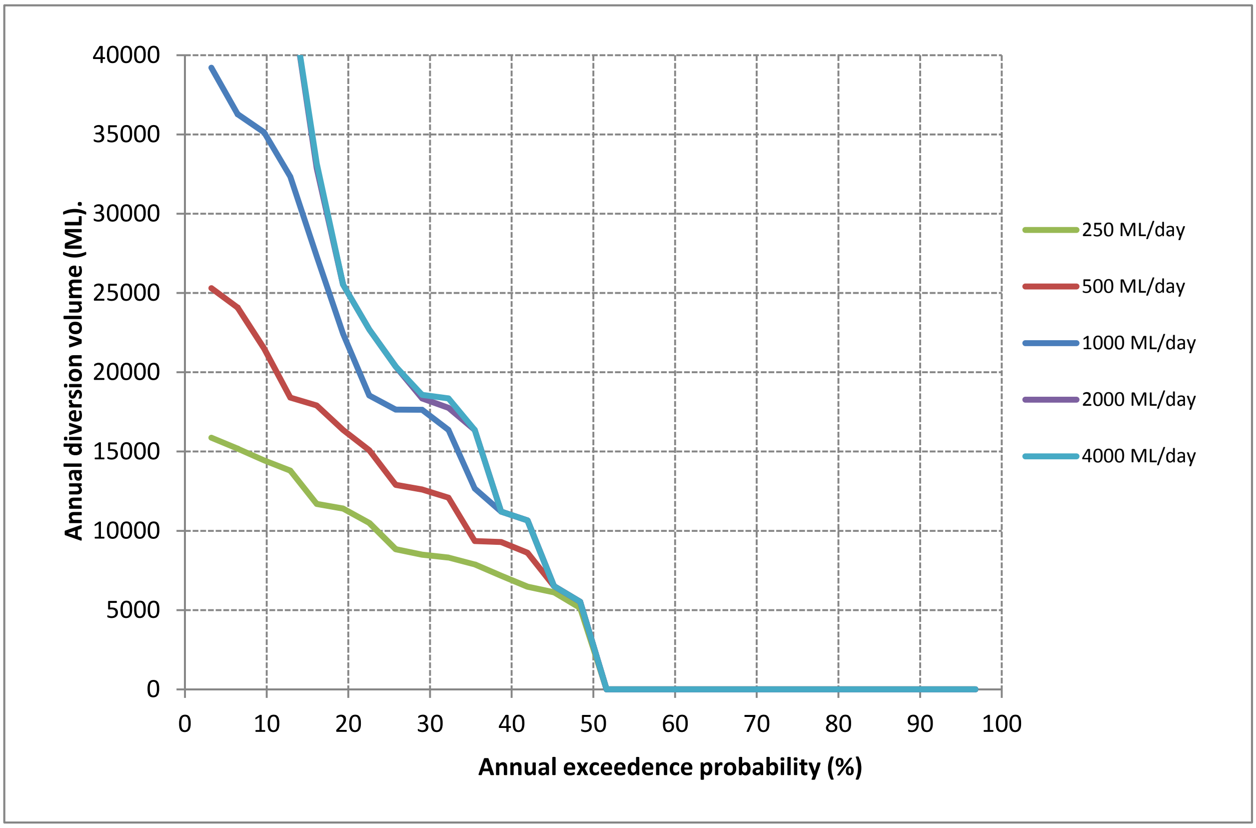

Figure 29 Annual exceedance probability of annual diversion from Drain M

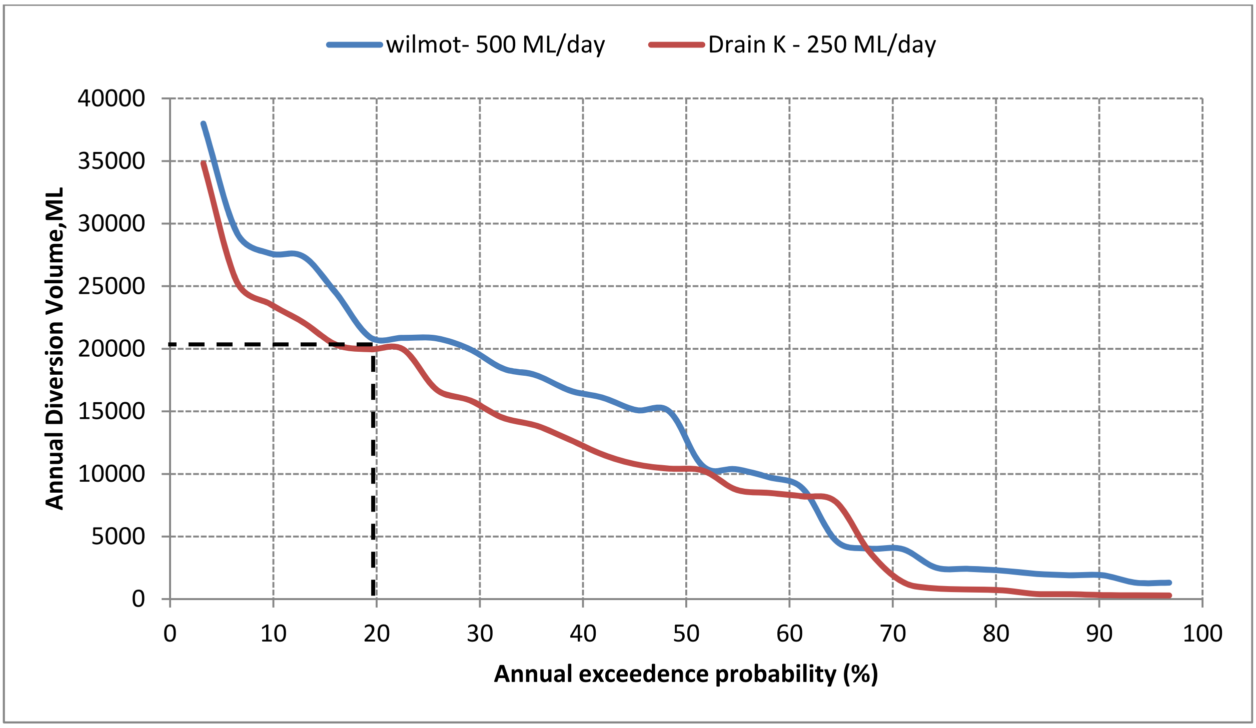

Figure 30 **Annual exceedance probability of annual diversion from Drain K and Wilmot Drain diversion points**

In order to determine an optimal diversion rate for Drain M, both the Drain M diversion rates and diversion rates from the Blackford Drain, including all upstream catchments, have been considered in conjunction. The Drain K and Wilmot Drain diversions have been fixed at the identified optimal limits of 250 and 500 ML/day, respectively. All contributing areas and channel losses have been considered to produce the total volume diverted from the Blackford Drain, as presented in Figure 31.

There is a distinct break in the annual diversion volume from the Blackford Drain at approximately 1000 ML/day, irrespective of the maximum daily diversion from Drain M. Given the few events that are available to divert from Drain M, it is unlikely that the infrastructure required to divert 1000 ML/day or more will be a worthwhile investment. Also, AWE (2009a) found that there was limited additional benefit in increasing the maximum daily diversion threshold to this level.

The cumulative distribution of total annual diversion volumes from the Blackford Drain for different diversion rates is presented in Figure 32 and Figure 33. In Figure 32, a maximum diversion rate of 250 ML/day from Drain M is assumed and in Figure 33, a maximum diversion rate of 500 ML/day from Drain M is assumed. From Figure 32 and Figure 33, again it can be seen that there is little benefit in diverting more than 1000 ML/day from the Blackford Drain for Drain M diversions of either 250 ML/day or 500 ML/day. Hence, the optimal diversion rate from the Blackford Drain has been determined to be 1000 ML/day.

There is also little difference between Figure 32 and Figure 33 in the total volumes diverted, with the diversion rate from Drain M only influencing the most infrequent events. For the annual flows occurring between 10 – 30% of the time, a diversion rate of 500 ML/day (Figure 33) generally produces the total volume diverted from the Blackford Drain approximately 2–5 GL/year more than that for a 250 ML/day diversion capacity (Figure 32), however, for the majority of the time the total volume yielded from the Blackford Drain is very similar for both Drain M diversion limits. It is these rarer events (probability of occurrence of less than 40%) that produce the difference in the annual average diversion rates presented in Figure 31, where the larger events produce an extra 6% on average when increasing the diversion rate from 250 ML/day to 500 ML/day. Given the limited benefit of the larger capacity diversion from Drain M, the diversion rate of 250 ML/day has been deemed optimal for this study.

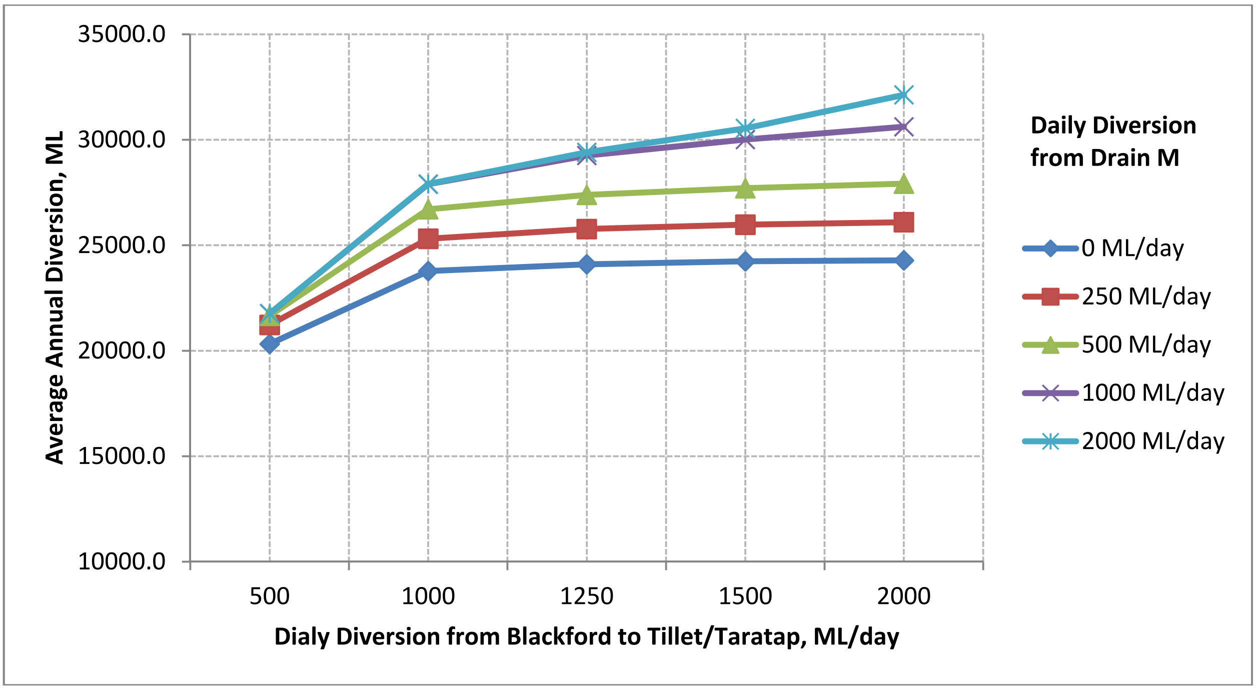

Figure 31 Variation of average annual diversion from Blackford with maximum daily diversion rate from Drain M

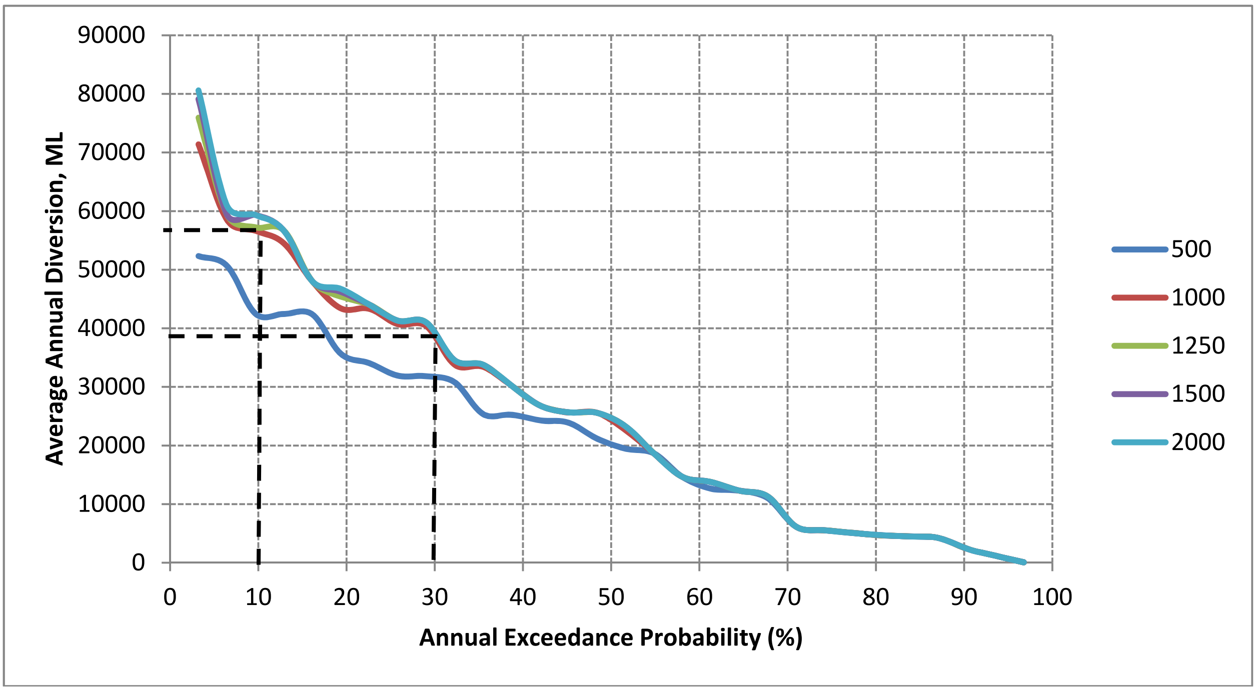

Figure 32 Annual exceedance probability of annual diversion from Blackford Drain (Drain M: 250 ML/day; Wilmot Drain: 500 ML/day; Drain K: 250 ML/day)

The local catchment contributing to the Blackford Drain (Figure 34) has been considered in the total diversion volumes from the Blackford Drain presented in Figure 32 and Figure 33. This area is expected to generate a median volume of 15 GL/year for Flow-path 02 and 17GL/year for Flow-path 03, as the diversion point for Flow-path 03 has a slightly larger contributing area. To provide a basis for comparison to the daily diversion rates, the exceedance probability curve of daily flows generated from the local catchment contributing to the Blackford Drain is presented in Figure 34.

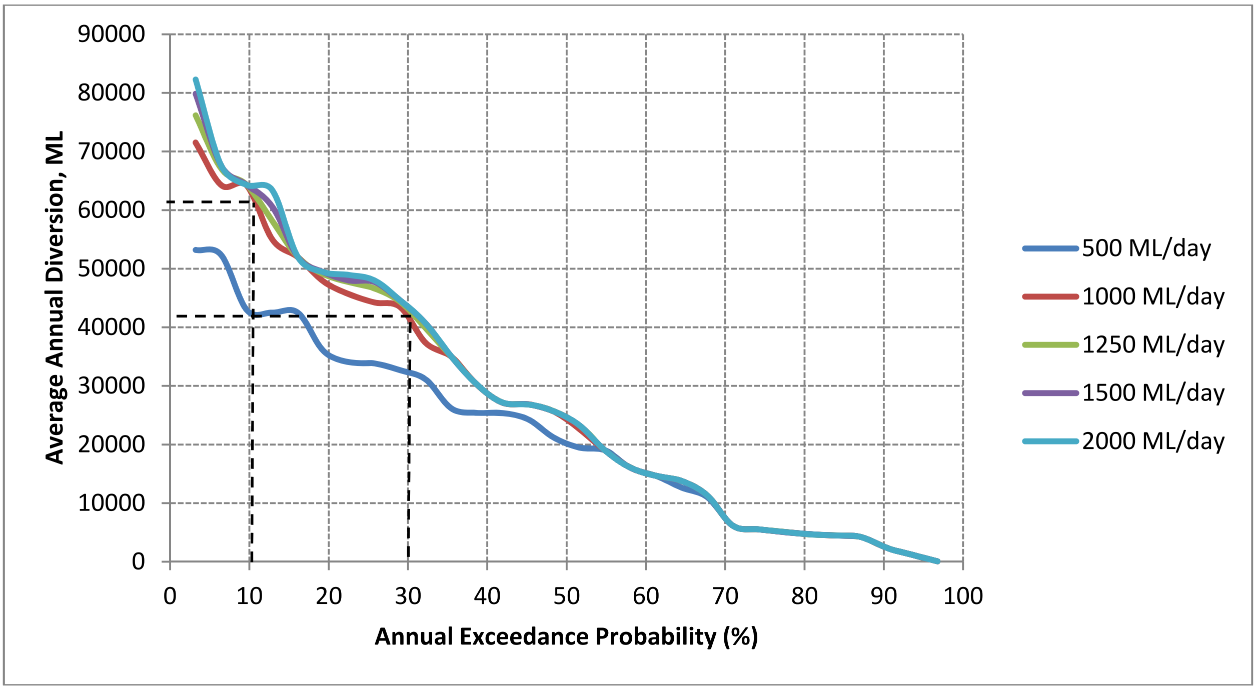

Figure 33 **Annual exceedance probability of annual diversion from Blackford Drain (Drain M: 500 ML/day; Wilmot Drain:500 ML/day; Drain K: 250 ML/day)**

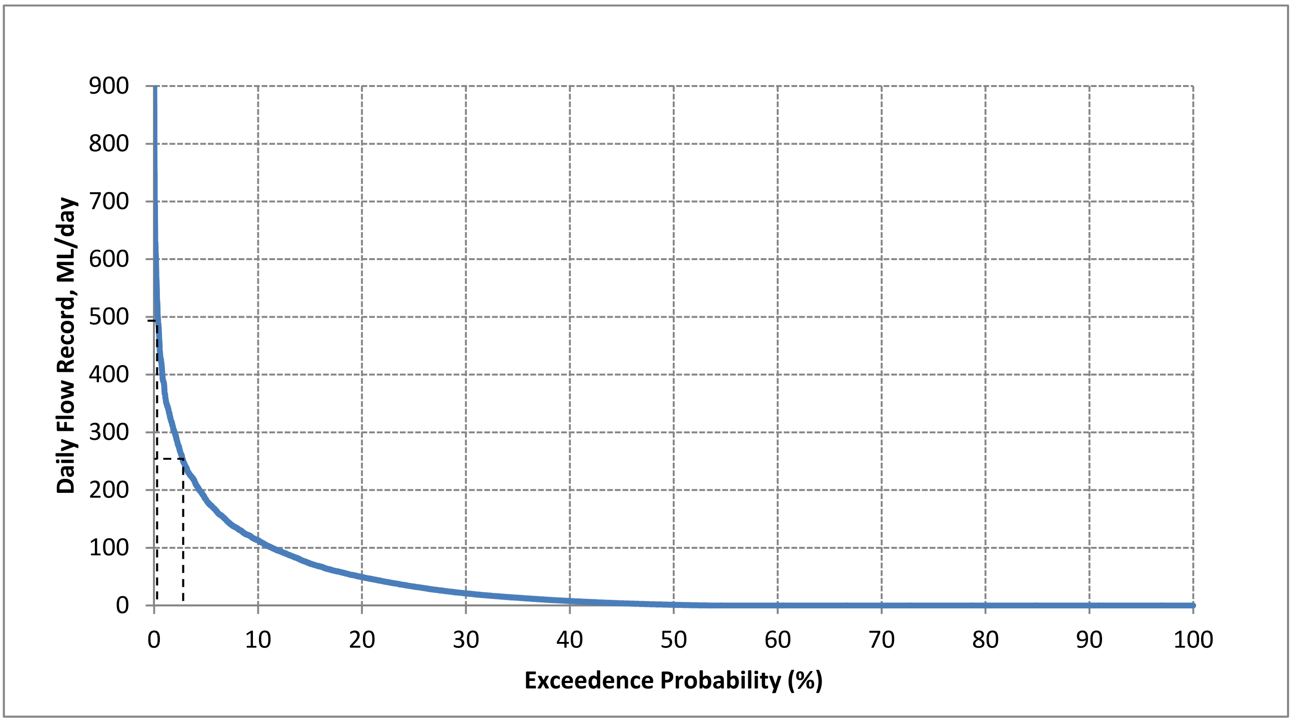

Figure 34 **Exceedance probability of daily flow yield for the local catchment contributing to the Blackford Drain diversion point for Flow-path 02**

A diversion rate for these flows has not been identified independently, as these flows will be collected in the drainage system irrespective of the drain operation and cannot be 'diverted' as such. Therefore, the total diversion from the Blackford Drain is dependent on the combined flows from this local contributing catchment, as well as any flow diverted from further south.

The results presented in this section have identified the optimal diversion rates based on probability of flow events occurring once downstream requirements have been met. The optimal diversion rates were identified as the flow rates at which the benefit of increasing the diversion capacity is considerably reduced. The rates are based on different probabilities of occurrence, for example it can be seen from Figure 34 that there is a less than 3% change of receiving more than 250ML/day from the Blackford Drain local catchment and less than 0.5% chance of more than 500 ML/day. The method adopted has considered this aspect by analysing the total contribution to the Blackford Drain from all catchments for different return periods. As the focus of this study has been on the diversion rates required for simulation of yields to the CSL, individual channel capacities required should be the focus of further engineering analysis. The optimal diversion rate from the Blackford Drain (1000 ML/day) is slightly less than the sum of the optimal diversion rates upstream (250 ML/day from Drain K, 250 ML/day from Drain M and 500 ML/day from the Wilmot Drain) and the volume expected to be generated from the local contributing catchment. This is due to the infrequent flows from Drain M, as well as the channel losses expected along the drainage network. The final optimal diversion limits determined are summarised in Table 10.

Table 10 Optimal diversion rates

Diversion point	Optimal diversion rate ML/day
Drain M	250
Wilmot Drain	500
Drain K	250
Blackford Drain	1000

YIELD AT THE COORONG SOUTH LAGOON

Based on the maximum diversion limits determined in the previous section, the yield delivered to the CSL has been presented in a number of forms. For all results presented, the diversion rates identified in the previous section have been used and all lagoons have been considered to have sill levels reduced by 400 mm. In the following section, annual median and average volumes for the different flow-paths (considering all catchments to Drain M) and climate scenarios are presented, as well as a sensitivity analysis on the affect of the soil transmissivity on the volumes delivered. This is followed by the probability of occurrence of different yields expected for the different flow-paths, which highlights the major difference between the drainage network and lagoon flow-paths. Finally, the yield expected from each diversion point to represent different stages of the flow restoration project are presented, to provide an insight into the benefit of collecting runoff from catchments further and further upstream.

ANNUAL MEDIAN AND AVERAGE YIELDS

Both the median and average annual yield expected for historic and climate change rainfall scenarios are presented in Table 11. It can be seen that the largest volumes are delivered by Flow-path 02, as it has the least losses in comparison to the other flow-paths and also a significantly larger local catchment contribution.

The yields presented in Table 11 for Flow-path 03—SELs is that expected from the path along all four lagoons. The yield can be seen to be less than one third of that of Flow-path 02, mostly due to the loss of local catchment contributions from the east to the Taratap and Tilley Swamp Drain highlighted in Figure 35. Flow-path 03—Floodway bypasses the first two discrete lagoons, before falling into the top of the third lagoon and then following the same path as Flow-path 03—SELs. The decline in the yield expected from this path compared to Flow-path 03—SEL is due to greater transmission losses to groundwater. The floodway adopted for this path is on average more than 2 m above the watertable and hence, a large proportion of the runoff captured by this path is lost for the majority of years. Conversely, the SELs route for Flow-path 03 has been assumed to be supported by groundwater from June to the end of December each year and hence, the groundwater losses are significantly reduced along this path. However, the larger rainfall deficit loss for the SELs route results in similar median and average annual yields for both Flow-path 03 options.

The impacts of the climate change scenarios considered are also presented in Table 11, where the projected reduction in rainfall can be seen to significantly reduce the yield expected for all cases. The climate change median scenario (CCM) reduces the median annual volumes delivered to the Coorong for Flow-path 02 and Flow-path 03—SELs in the order of 35 and 70% respectively, while the climate change dry (CCD) reduces volumes at Coorong for Flow-path 02 and Flow-path 03—SELs by 55 and 100% respectively. Further information on the impact of reduced rainfall on the yield expected is provided in the following section, which presents the yield as a function of the probability of that yield occurring.

Table 11 Average and median annual volume from proposed flow-paths

	Median Annual, ML			Average Annual, ML		
Climate Scenario	Historic	CCM	CCD	Historic	CCM	CCD
FlowPath 02	58095	37834	26192	53200	38093	26498
FlowPath 03 - SELs	15387	4634	0	19475	10297	4577
Existing Network	29358	20498	15377	29224	20418	14860
Total	44745	25132	15377	48699	30715	19437
FlowPath 03 - floodway	13205	4079	0	16031	8352	3862
Existing Network	29358	20498	15377	29224	20418	14860
Total	42563	24577	15377	45255	28770	18722

As mentioned above, the most significant factor for the difference between Flow-path 02 and both of the Flow-path 03 routes is the contribution of the local catchments from the east to the Taratap and Tilley Swamp Drain. The contribution from these catchments represents the current 'as is' state of the drainage system in the region, where flows from the Kercoonda and S-Bend Drain make their way along the existing system to Morella Basin and then along Salt Creek to the CSL. The median and annual average yield expected from this existing system, for both historic and climate change scenarios, is presented in Table 12. The yield from this existing system can effectively be combined with the Flow-path 03 yields presented in Table 11 to provide a fair comparison with Flow-path 02. The inclusion of this existing flow contribution to the CSL brings the total yield expected from Flow-path 03—SELs much closer to that expected from Flow-path 02, approximately 14 GL (23%) less for a median year and 4.5GL (8%) less on average.

Table 12 Average and median annual volume from existing drainage network (K=80 m/day)

	Median annual ML			Average annual ML		
Climate scenario	Historic	CCM	CCD	Historic	CCM	CCD
Kercoonda—S-Bend Drain	29358	20498	15377	29224	20418	14860

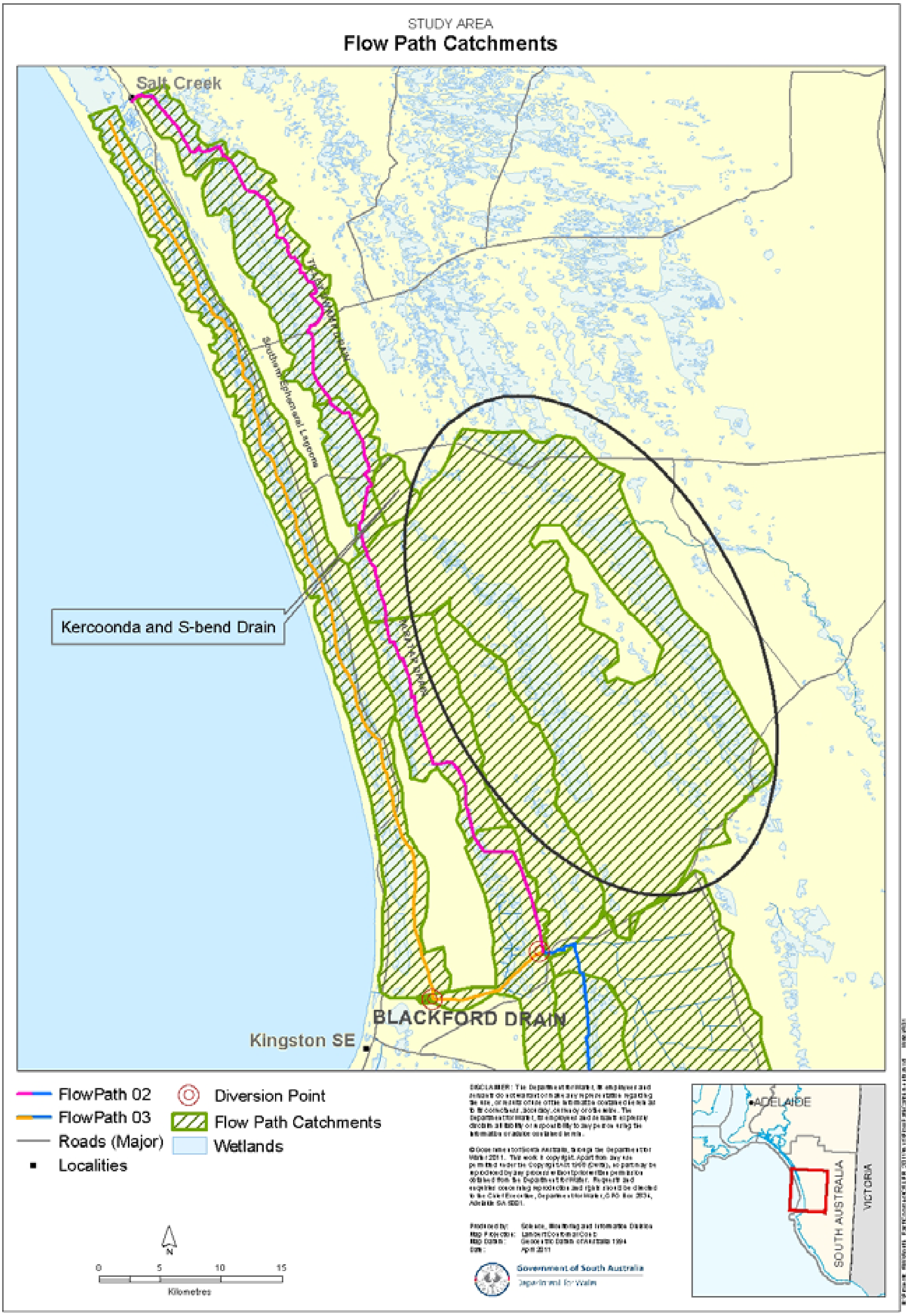

Figure 35 **Contributing catchments to existing drainage network**

Given the uncertainty involved in the surface water–groundwater processes occurring in the region, the sensitivity of yield delivered to the Coorong based on the soil hydraulic conductivity has been assessed. The soil hydraulic conductivity values have been considered one order of magnitude higher and lower (multiply or divide by 10) to represent the natural variability observed in this parameter. No change to the aquifer conductivity has been considered, as the less permeable soil layer was found to dominate the weighted conductivity adopted, as defined by Equation 2. The results for the sensitivity analysis for the average and median volume delivered to the CSL are summarised in Table 13 and Table 14. The impact of changing the soil conductivity can be seen to be relatively linear, with both the median and annual yield reduced by approximately half when increasing the conductivity by an order of magnitude (comparing Table 11 and Table 13) and increasing by approximately half when reducing the soil conductivity by an order of magnitude (comparing Table 11 and Table 14). The scenario considering the reduction in the groundwater loss (Table 14) has resulted in the FlowPath 03 – floodway path producing slightly more yield to the CSL compared to the FlowPath 03 – SELs path, where in this case the increased evaporation from the open ephemeral lagoons resulted in more loss from the system than the reduced groundwater loss simulated for the floodway option.

From the results presented in this section, it is clear that the soil hydraulic conductivity has a significant influence on the groundwater losses simulated and in turn, the volume delivered to the CSL. After undertaking hydrological investigations along Reedy Creek, AWE (2009b) noted that the observed natural variability in the hydraulic conductivity indicates that transmission loss estimates to groundwater are indicative only. The groundwater loss is directly proportional to the hydraulic conductivity (Equation 1), hence if the conductivity value is largely uncertain, then so is the groundwater loss calculated. AWE (2009b) concluded that there is likely to be limited value in further geotechnical type investigations to better refine conductivity estimates, due to the observed variation.

Table 13 Average and median annual volume at CSL for high groundwater loss (K order of magnitude higher)

	Median Annual, ML			Average Annual, ML		
Climate Scenario	Historic	CCM	CCD	Historic	CCM	CCD
FlowPath 02	39951	29413	21356	36975	28159	20172
FlowPath 03 - SELs	8233	3625	0	9786	5869	2813
Existing Network	21711	15210	11151	20257	14427	9910
Total	29944	18835	11151	30043	20296	12723
FlowPath 03 - floodway	0	0	0	94	31	7
Existing Network	21711	15210	11151	20257	14427	9910
Total	21711	15210	11151	20351	14458	9917

Table 14 Average and median annual volume at CSL for low groundwater loss (K order of magnitude lower)

	Median Annual, ML			Average Annual, ML		
Climate Scenario	Historic	CCM	CCD	Historic	CCM	CCD
FlowPath 02	72732	49554	34875	71463	52041	36487
FlowPath 03 - SELs	30454	15607	5742	35219	21744	12303
Existing Network	28960	21521	16302	28156	21405	15777
Total	59414	37128	22044	63375	43149	28080
FlowPath 03 - floodway	35253	22039	13310	39442	26200	16540
Existing Network	28960	21521	16302	28156	21405	15777
Total	64213	43560	29612	67598	47605	32317

YIELD PROBABILITY OF OCCURRENCE

The average and median volumes presented in the previous section provide a useful overview of the yield expected from the different flow-paths considered. However, the annual variability in the expected yield is also of interest and highlights the significant difference between the flow-path options. The annual exceedance probability has been computed for each of the scenarios considered, where the annual exceedance probability is the probability of the annual volume being exceeded in any one year, as was the case in Way and Heneker (2007) and AWE (2009a). Figure 36 presents the annual volume diverted to the CSL for different exceedance probabilities for Flow-path 02. As an example, Figure 36 can be interpreted as 80% of the years will produce flow of 13800 ML to be diverted to the Coorong under the historic climate condition and the median values presented in Table 11 can be seen as the diversion volume corresponding to the 50% exceedance probability. From Figure 36, Flow-path 02 can be seen to be relatively reliable, with all years expected to deliver at least some flow to the CSL and a relatively linear increase in the flow diverted with the probability of occurrence up to 112 GL for a one in ten year event (10%). The reduction in yield expected due to the different climate scenarios considered can also be seen in Figure 36.

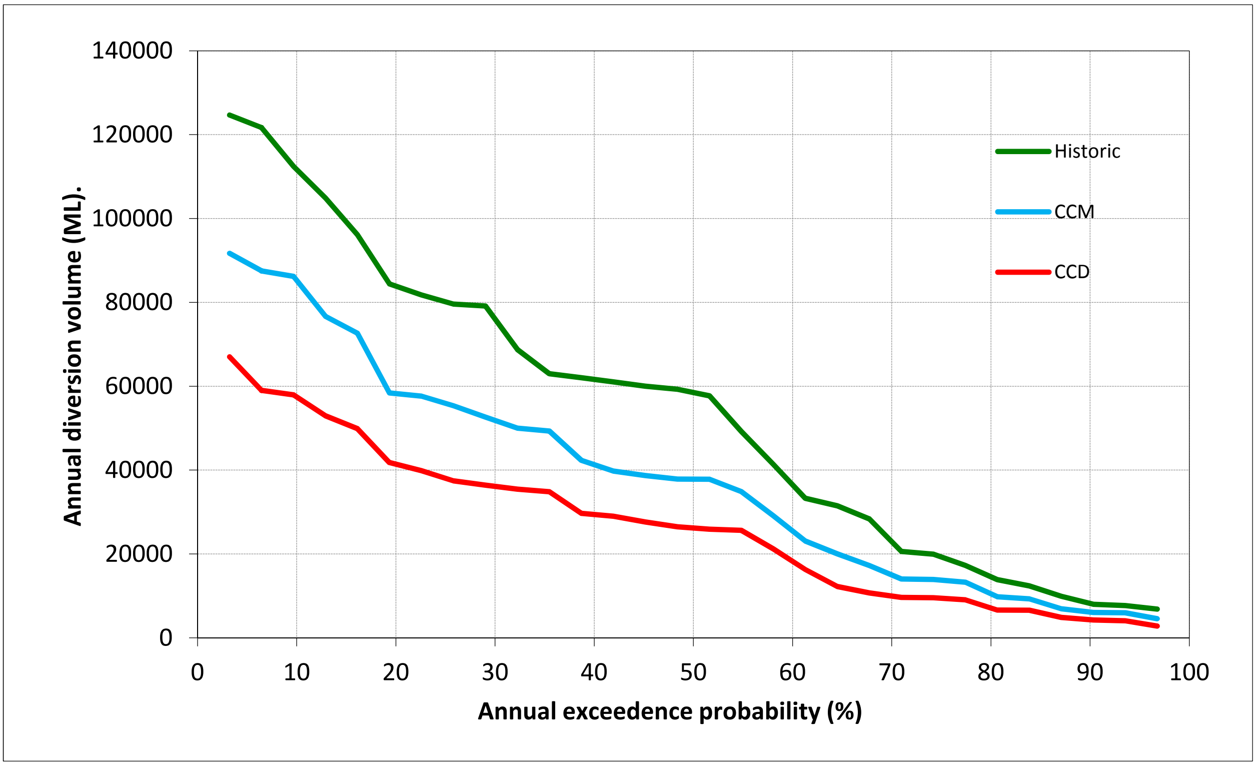

Figure 36 Annual exceedance probability of annual volume at CSL from Flow-path 02

The same information is presented in Figure 37 for the Flow-path 03—SELs. Along with slightly less total volume diverted for events with the same probability of occurrence, the reliability of flows from this path is also reduced, with some flow expected 70% of the time under historic conditions, reducing to 55% and only 40% for the median and dry climate change scenarios respectively. For the Flow-path 03—Floodway option there are slightly greater groundwater losses through this path compared to the path through the SELs. Figure 38 indicates that the expected occurrence of flow events is very similar for both Flow-path 03 routes, however the yield expected from the floodway route is slightly below that through the SELs.

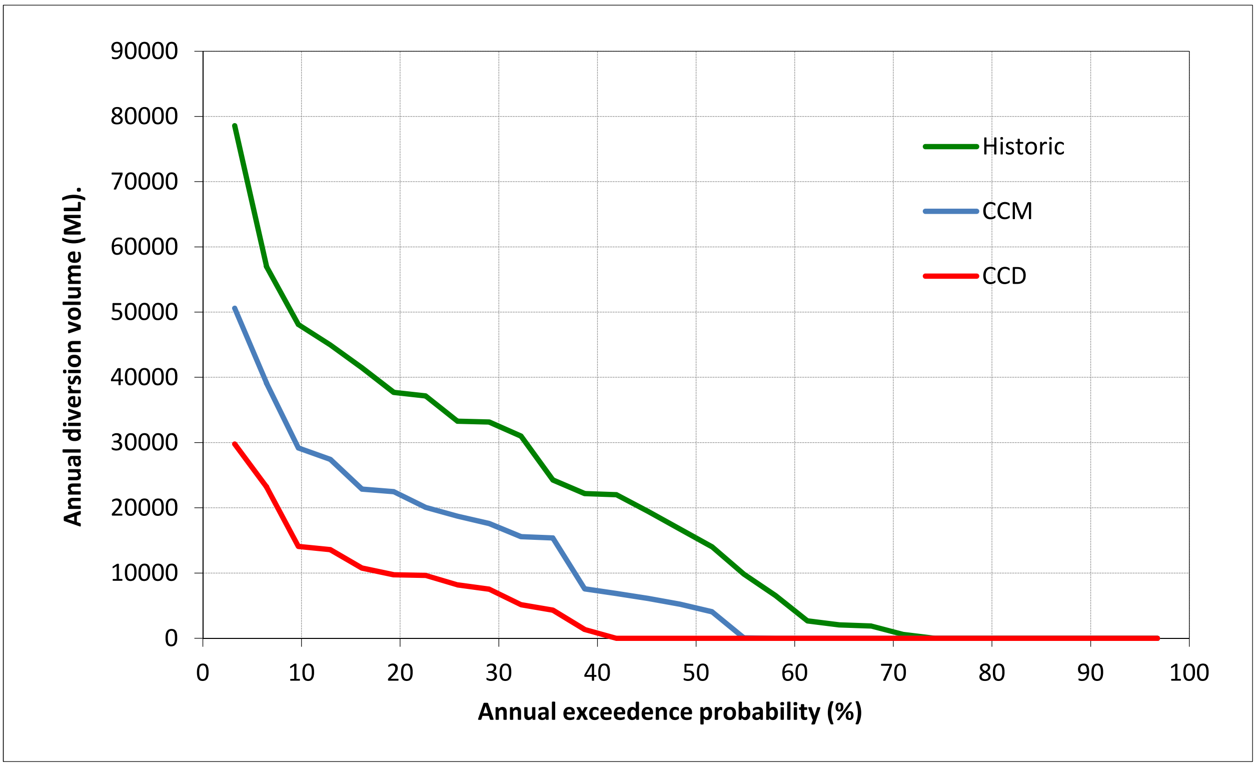

Figure 37 Annual exceedance probability of annual volume at CSL from Flow-path 03—SEL

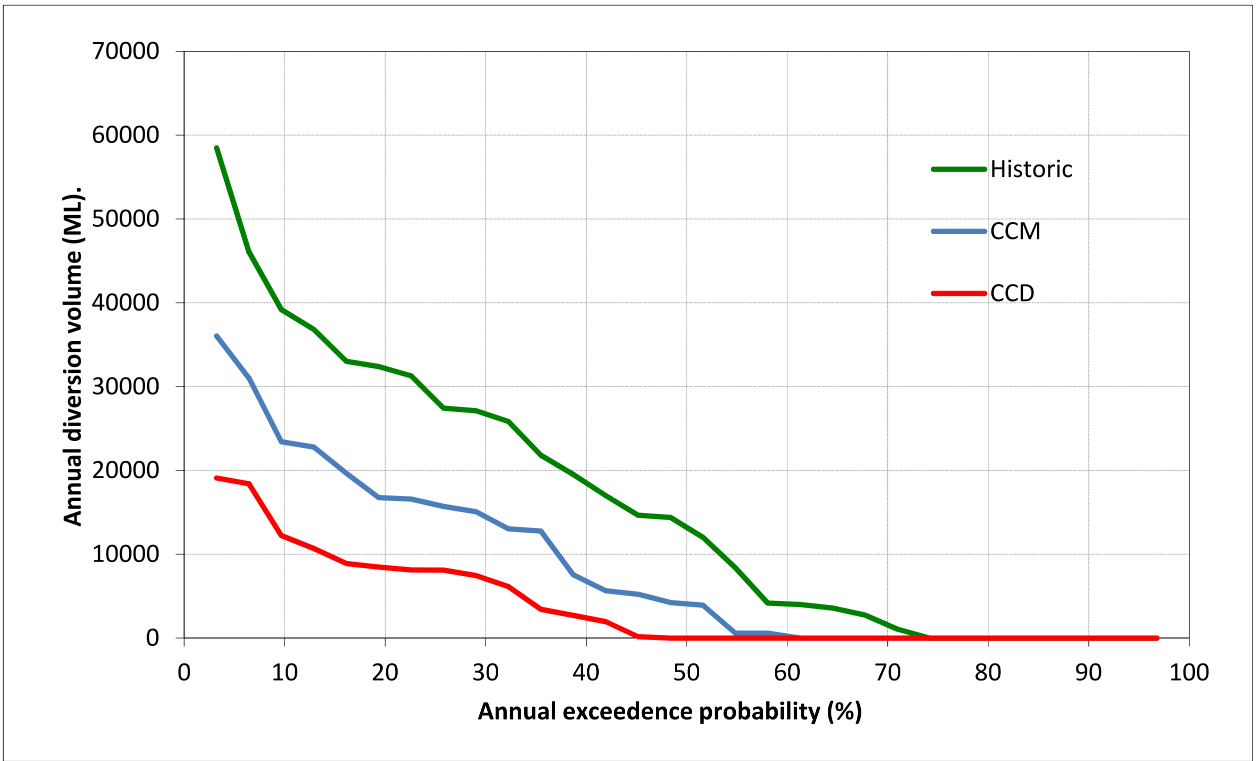

Figure 38 Annual exceedance probability of annual volume at CSL from Flow-path 03—Floodway

The likelihood of different diversion volumes reaching the CSL occurring via the three flow-paths considered for historic, median and dry climate scenarios are also presented in Table 15, Table 16 and Table 17 respectively. The number of years that are expected to exceed certain volumes (accumulated into 15 GL ranges) in the 30-year period considered in this study are included in the tables, as well as this occurrence presented as the frequency expected to occur in a ten-year period, on average. For the historic climate, presented in Table 15, the frequency of events greater than 15 GL occurring are eight and five in ten years for Flow-path 02 and Flow-path 03—SEL, respectively. For the larger events considered, that are 30 GL or greater, the expected frequency of events delivered by Flow-path 02 is approximately double that of Flow-path 03—SELs. As expected for Southern Australia, the climate change scenarios considered lead to a reduction in the frequency of large flow events occurring and few yields of greater than 30 GL are expected for the dry climate scenario that from any of the options considered, and only from Flow-path 02 (Table 17).

Table 15 Probability of exceedance in tabular form at SCL—historic climate condition

FlowPath	Volume (>ML)	No. Years	Frequency in 10 years
FlowPath 02	15000	24	8
	30000	20	7
	45000	17	6
	60000	14	5
	75000	9	3
	90000	5	2
FlowPath 03-SELs	15000	15	5
	30000	10	4
	45000	3	1
	60000	1	1
	75000	1	1
	90000	0	0
FlowPath 03-Floodway	15000	13	4.3
	30000	7	2.3
	45000	2	0.6
	60000	0	0
	75000	0	0
	90000	0	0

Table 16 Probability of exceedance in tabular form at SCL—climate change median

FlowPath	Volume (>ML)	No. Years	Frequency in 10 years
FlowPath 02	15000	21	7
	30000	17	6
	45000	11	4
	60000	5	2
	75000	4	2
	90000	1	1
FlowPath 03-SELs	15000	11	4
	30000	2	1
	45000	1	1
	60000	0	0
	75000	0	0
	90000	0	0
FlowPath 03-Floodway	15000	9	3
	30000	2	0.6
	45000	0	0
	60000	0	0
	75000	0	0
	90000	0	0

Table 17 Probability of exceedance in tabular form at SCL—climate change dry

FlowPath	Volume (>ML)	No. Years	Frequency in 10 years
FlowPath 02	15000	19	7
	30000	11	4
	45000	5	2
	60000	1	1
	75000	0	0
	90000	0	0
FlowPath 03-SELs	15000	2	1
	30000	0	0
	45000	0	0
	60000	0	0
	75000	0	0
	90000	0	0
FlowPath 03-Floodway	15000	2	0.6
	30000	0	0
	45000	0	0
	60000	0	0
	75000	0	0
	90000	0	0

STAGED DELIVERY OF YIELDS

The results presented in this section provide an insight into the benefit of extending the flow restoration project to intercept flows from the diversion points considered further and further upstream. The historical climate scenario exceedance curves, presented in Figure 36–Figure 38, have been broken down to indicate the cumulative effect of each diversion point. The results for Flow-path 02 are presented in Figure 39, with the diversion volumes expected from the existing Kercoonda and S-Bend Drain, or existing drainage network (EDN), as the lower line. This diversion exceedance curve is also applicable to the Flow-path 03 results; however, the flow is delivered via Morella Basin and Salt Creek, as opposed to the SEL flow-path and therefore has not been included in the relevant Flow-path 03 figures. The benefits of combining this existing volume (EDN) with that from the diversion on the Blackford Drain, capturing the local contributing catchments only, can be seen from the line EDN + BF. For exceedance probabilities of 50% and greater, at least an extra 14 GL/year is expected to be provided to the CSL from just these catchments (as the difference between the EDN and EDN + BF lines). Similarly, the benefit gained by extending the route to intercept Drain K can be seen as line EDN + BF + K and again to Wilmot Drain (EDN + BF + K + W) can also be seen from Figure 39, where the combination of Drain K and Wilmot Drain provides a slightly lower yield to the CSL as that obtained from the Blackford Drain local catchments, after considering drainage losses in transferring runoff from Drain K and Wilmot Drain to the CSL. Finally, the benefit by completing the route to intercept Drain M can be seen to be extremely limited (EDN + BF + K + W + M), with 1–5 GL gained from Drain M in wet years only (probability of exceedance of 35% or less). However, for this case, over 60 GL are derived from the upstream diversion points, limiting the benefit of this final stage of the flow restoration project to intercept Drain M.

Similar staged yield delivery results are presented in Figure 42 for Flow-path 03—SEL. Again, the contribution from the local catchments that contribute to the Blackford Drain for increasing exceedance probability is presented, which can be seen to be similar (although slightly more) than that expected from Drain K and Wilmot Drain. As was the case for Flow-path 02, the benefit gained by extending the route to include Drain M is limited, with small further diversions (1 -5 GL) expected for the wetter years, where the diversion volume from the upstream catchments is already relatively large. The staged diversion volume contributions for the final case considered, Flow-path 03—Floodway is presented in Figure 45. The volumes expected are slightly lower than those for Flow-path 03—SEL for each exceedance probability and the relationship between the volumes gained by the different diversion points is again similar.

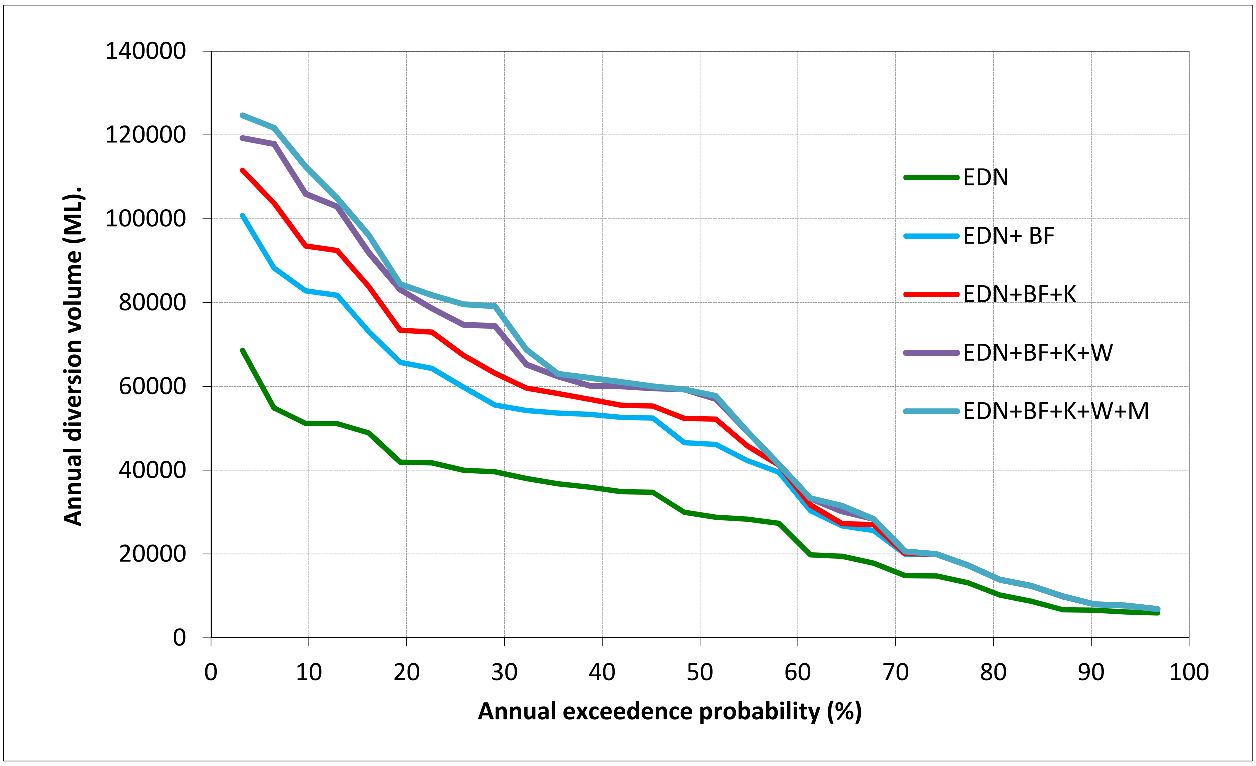

Figure 39 Annual exceedance probability of cumulative diversion volume: Flow-path 02 — historic climate condition

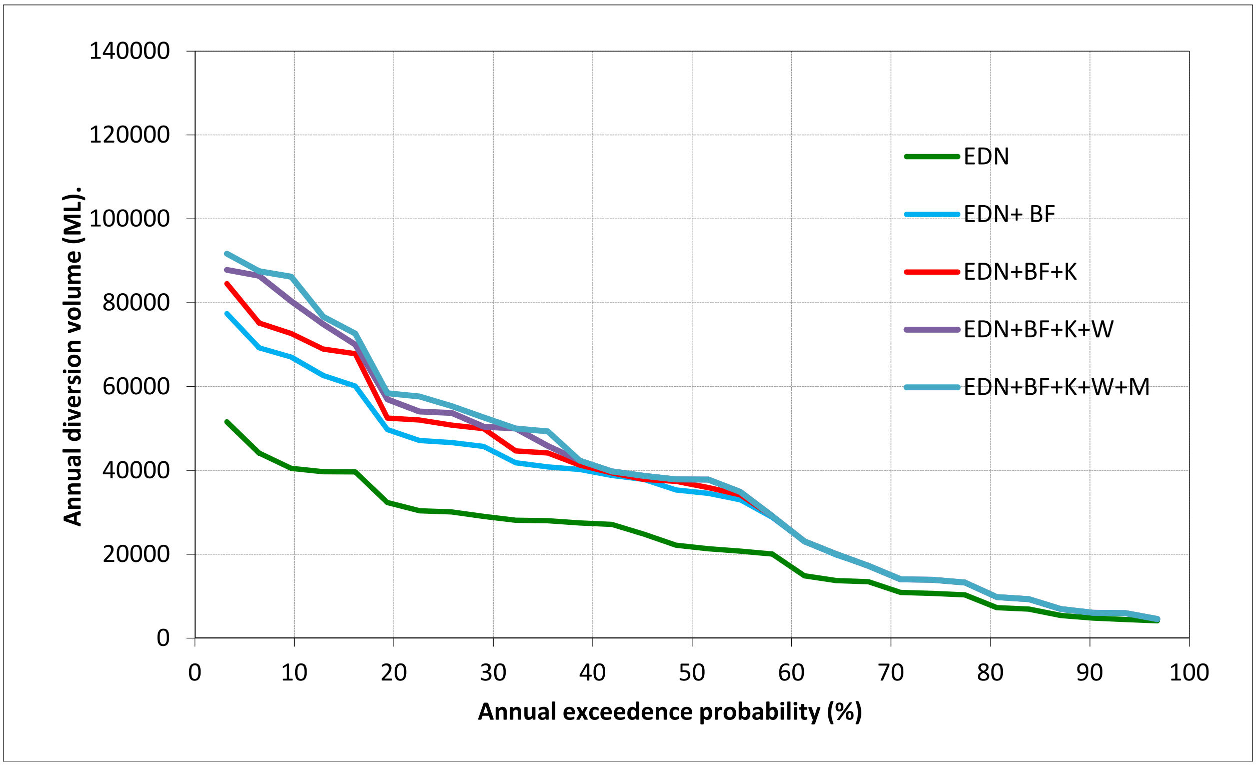

Figure 40 Annual exceedance probability of cumulative diversion volume: Flow-path 02 — climate change median

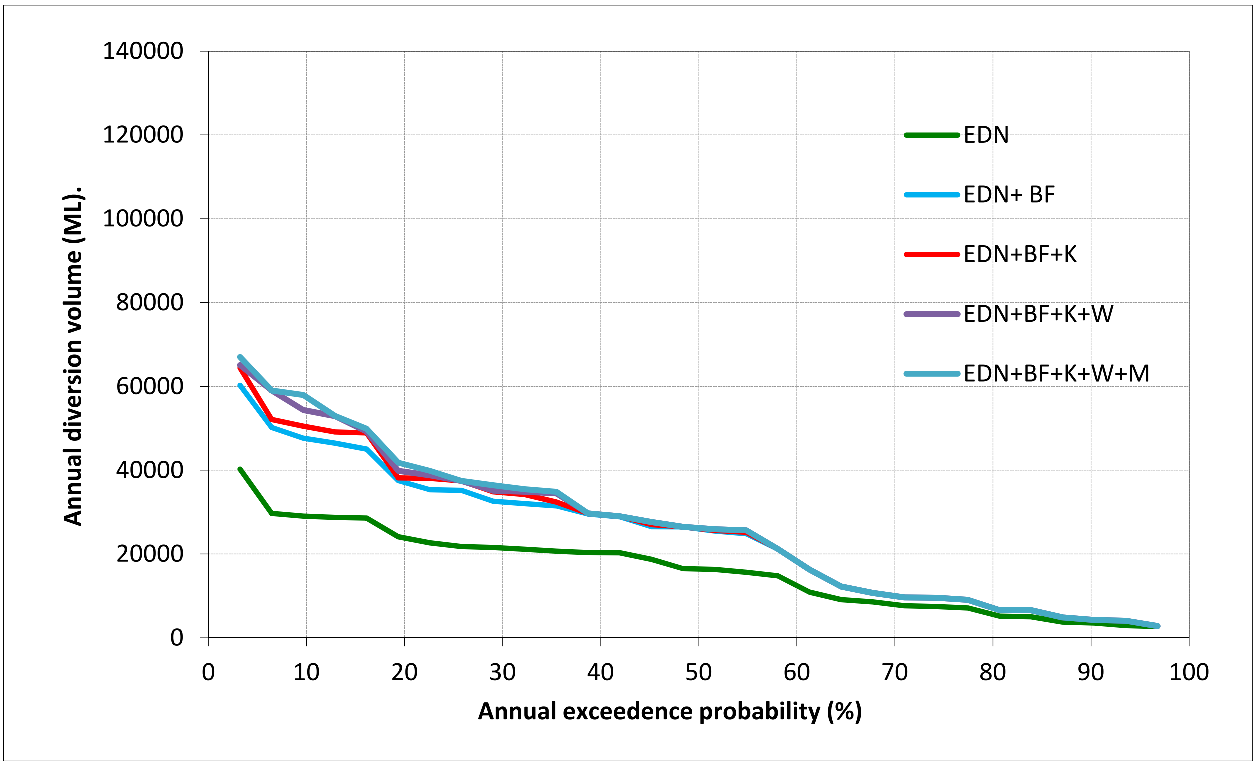

Figure 41 Annual exceedance probability of cumulative diversion volume: Flow-path 02 — climate change dry

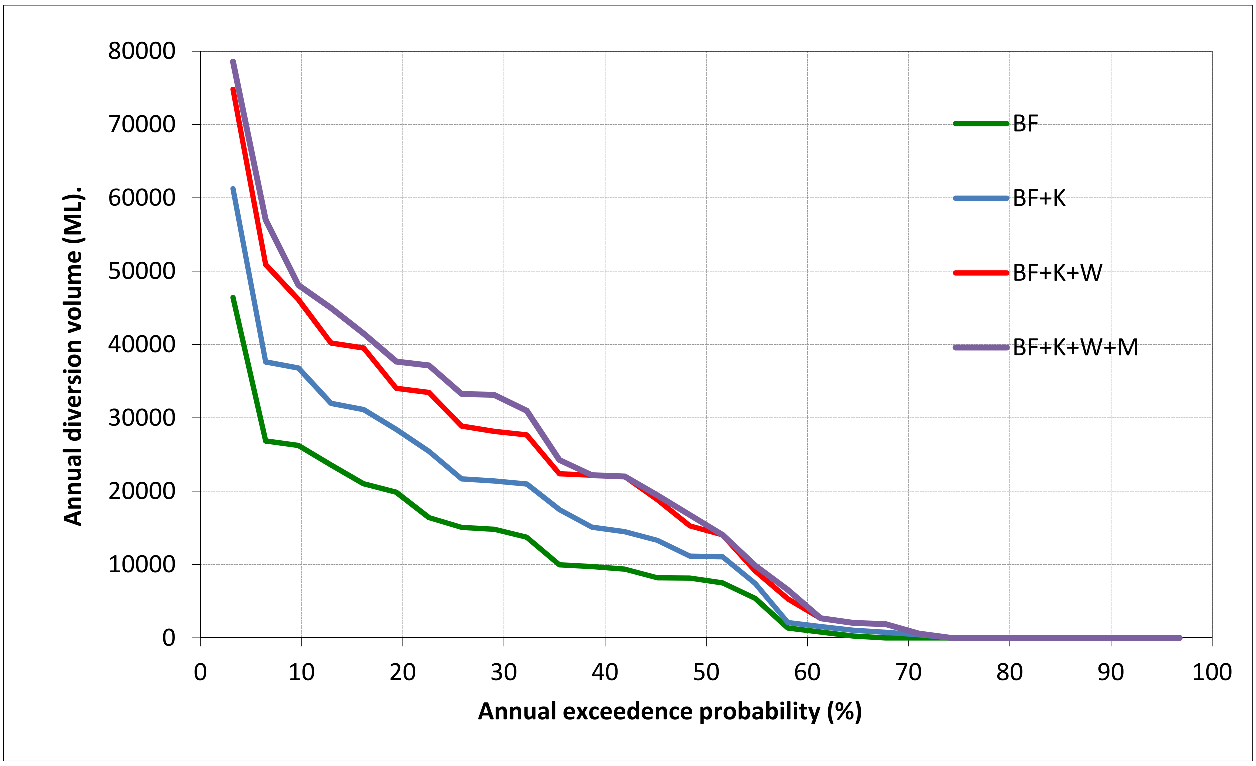

Figure 42 Annual exceedance probability of cumulative diversion volume: Flow-path 03—SELs — historic climate condition

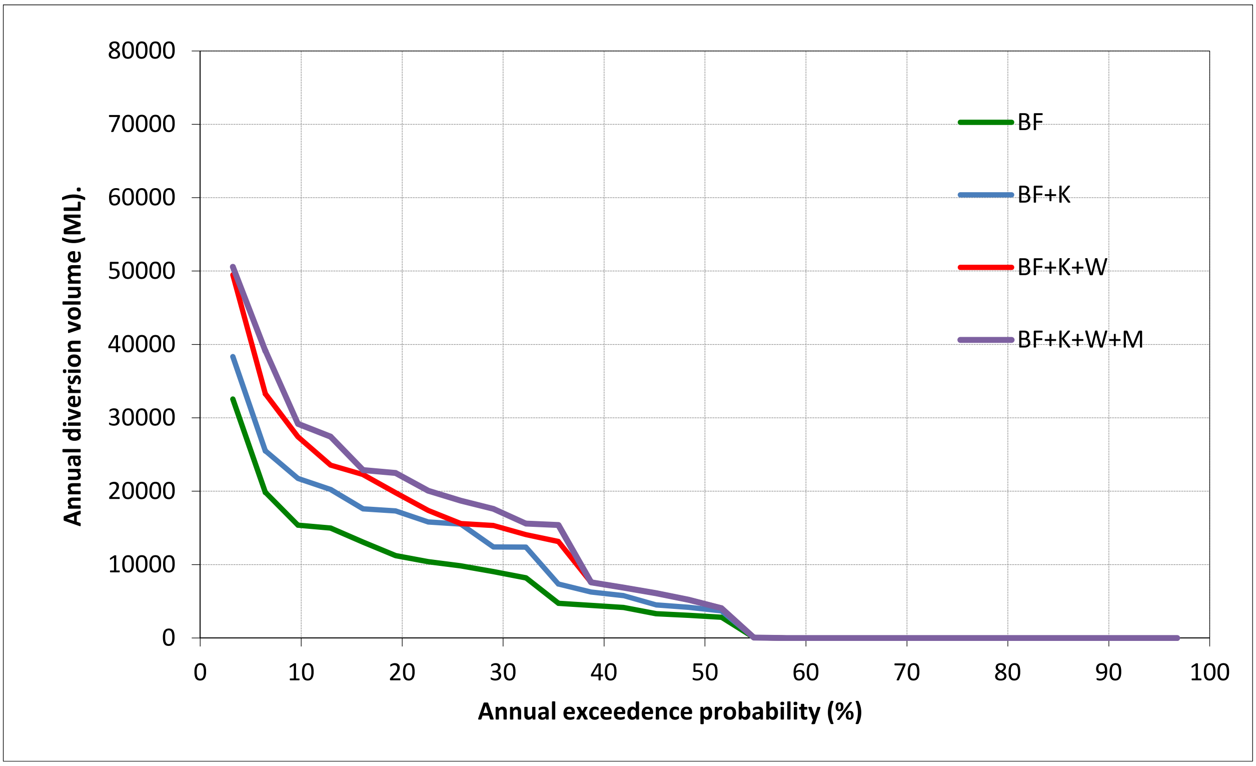

Figure 43 Annual exceedance probability of cumulative diversion volume: Flow-path 03—SELs — climate change median

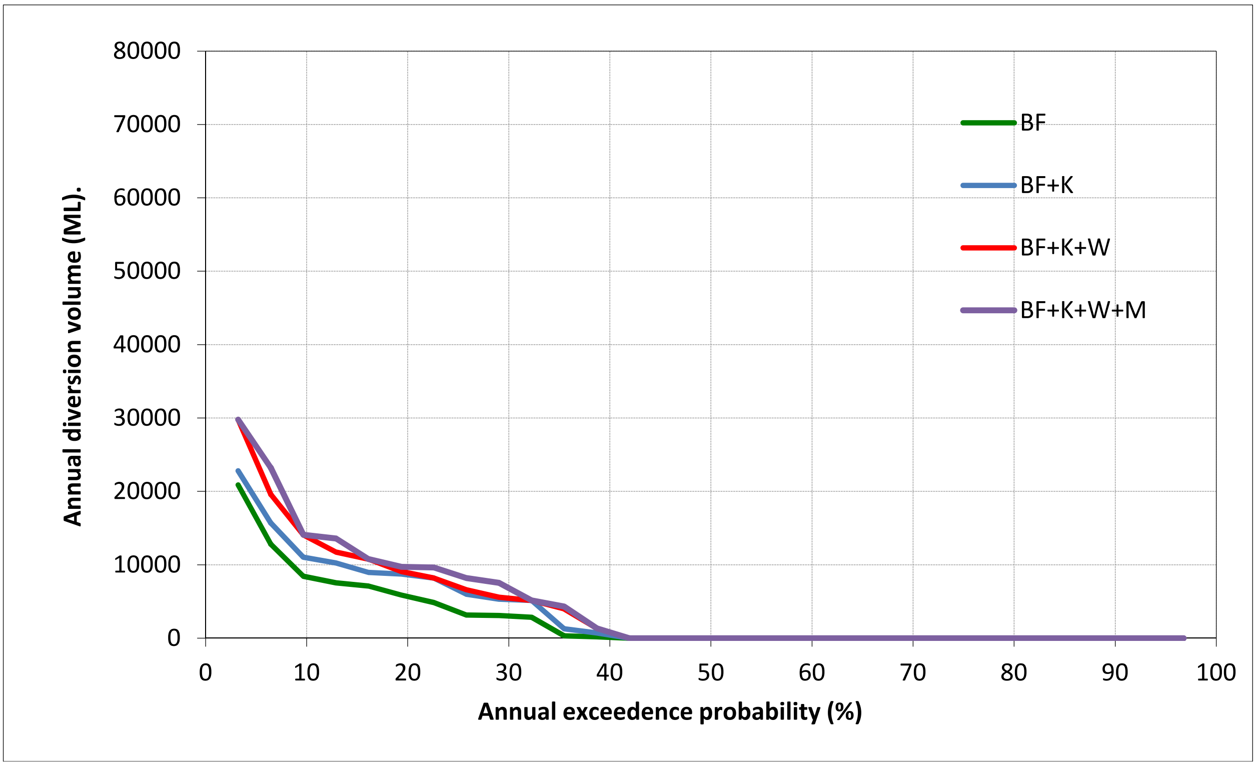

Figure 44 Annual exceedance probability of cumulative diversion volume: Flow-path 03—SELs — climate change dry

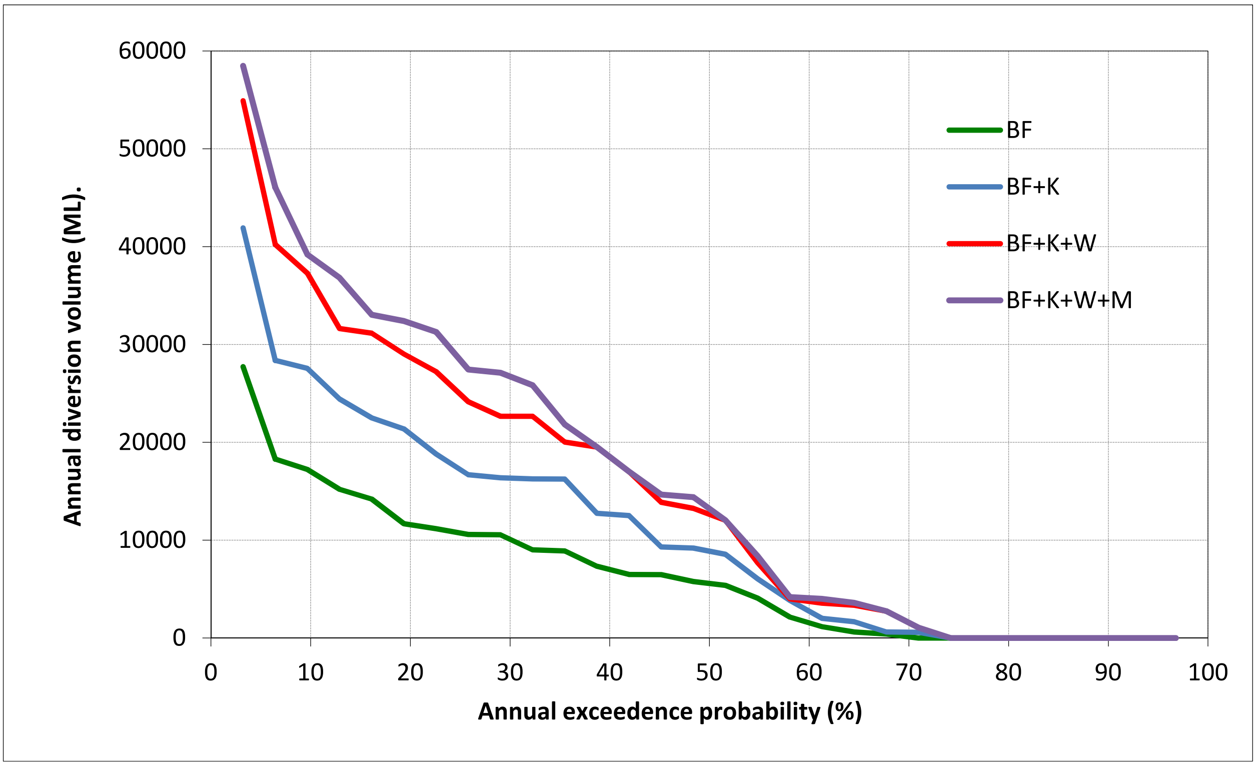

Figure 45 Annual exeedance probability of cumulative diversion volume: Flow-path 03—Floodway — historic climate condition

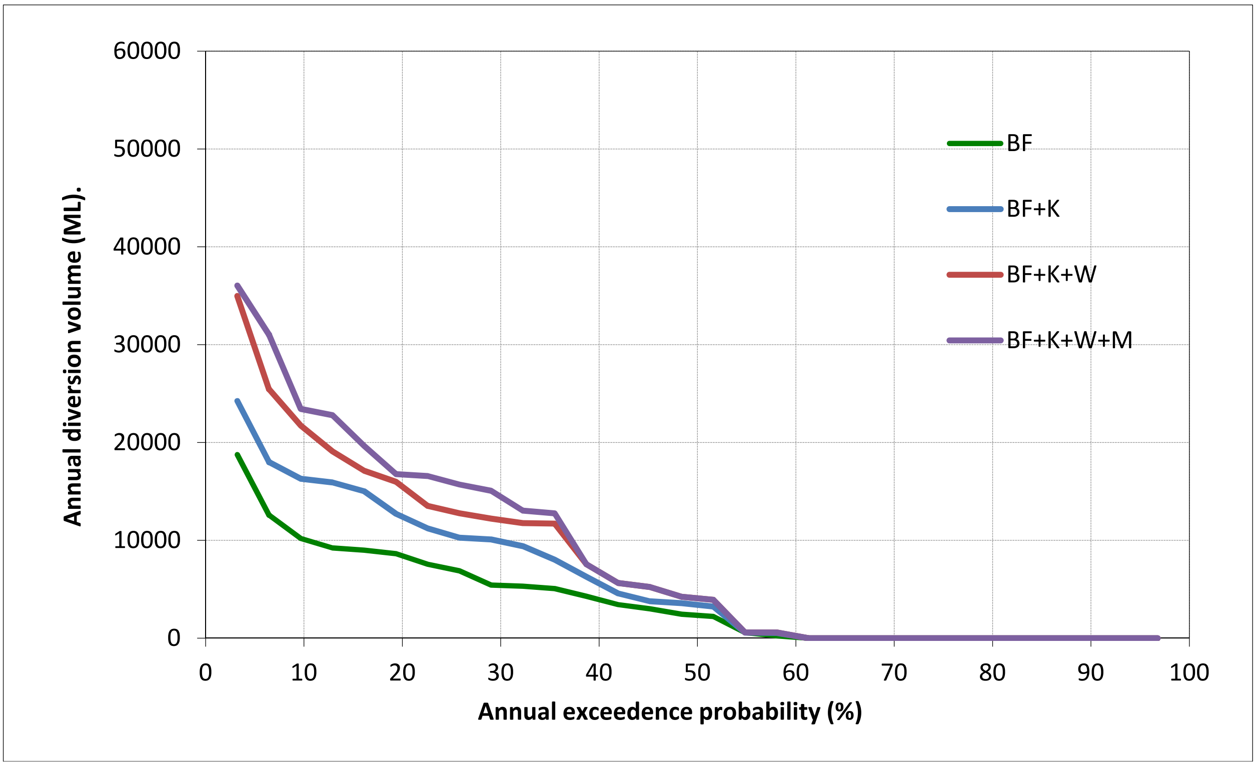

Figure 46 Annual exceedance probability of cumulative diversion volume: Flow-path 03—Floodway — climate condition median

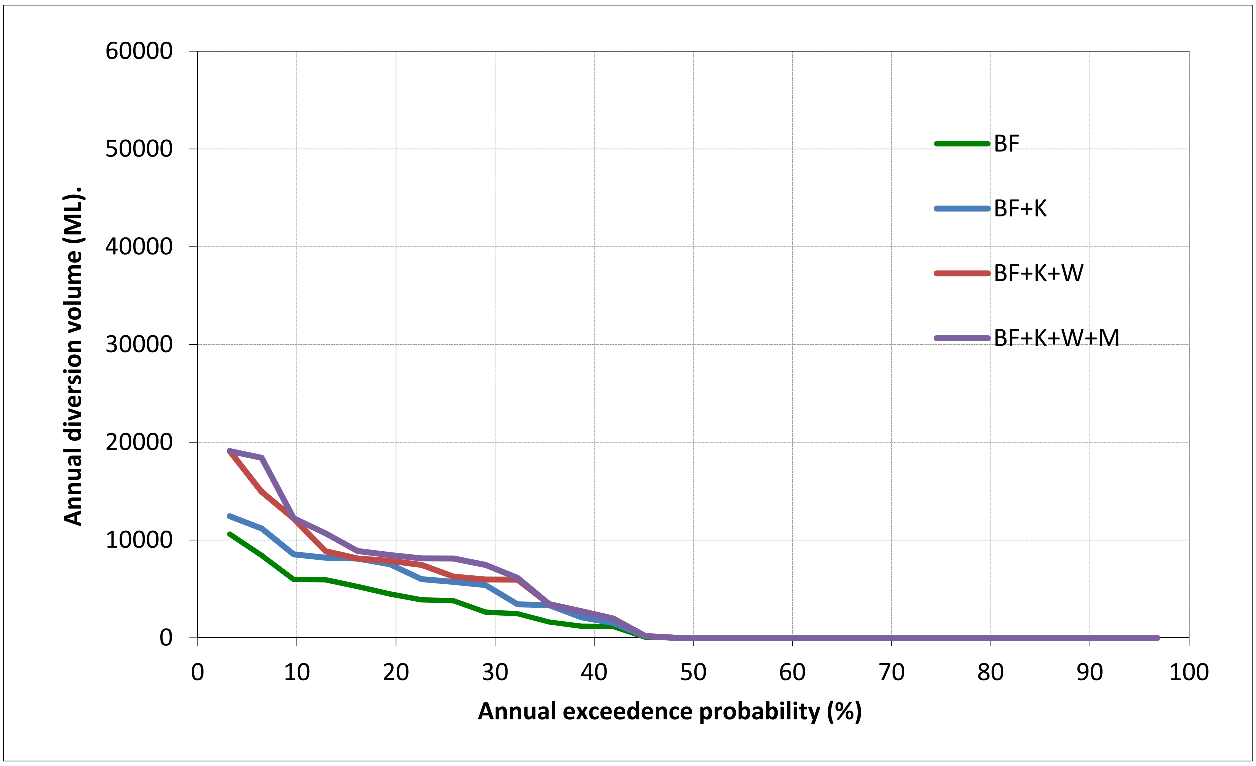

Figure 47 Annual exceedance probability of cumulative diversion volume: Flow-path 03—Floodway — climate condition dry

In addition to the plots of staged delivery of yield for the three flow-paths and three climate change scenarios considered (Figure 39 to Figure 47), similar staged delivery yield results (including the volume expected from the existing drainage network for the Flow-path 03) routes are presented in Table 18, Table 19 and Table 20 in order to provide an equivalent comparison for the proposed flow-paths for each climate scenario.

Table 18 Median total volume delivered to CSL—historic climate condition

Diversion	FlowPath 02		FlowPath 03 - SELs		FlowPath 03 - Floodway	
	Median	Mean	Median	Mean	Median	Mean
Existing Drainage Network (EDN)	29,358	29,224	29,358	29,224	29,358	29,224
EDN + BF	46,348	43,701	37,182	38,711	34,927	35,701
EDN + BF + K	52,278	48,033	40,459	42,974	38,229	39,808
EDN + BF + K + W	58,144	52,371	44,005	47,227	41,989	43,856
EDN + BF + K + W + M	58,496	53,893	44,746	48,710	42,564	45,255

Table 19 Median total volume delivered to CSL—climate change median

Diversion	FlowPath 02		FlowPath 03 - SELs		FlowPath 03 - Floodway	
	Median	Mean	Median	Mean	Median	Mean
Existing Drainage Network (EDN)	21,736	22,140	21,736	22,140	21,736	22,140
EDN + BF	34,947	33,364	24,699	27,711	24,069	25,966
EDN + BF + K	36,647	35,416	25,675	29,763	25,143	27,929
EDN + BF + K + W	37,834	37,172	26,371	31,514	25,816	29,607
EDN + BF + K + W + M	37,834	38,093	26,371	32,437	25,816	30,492

Table 20 Median total volume delivered to CSL—climate change dry

Diversion	FlowPath 02		FlowPath 03 - SELs		FlowPath 03 - Floodway	
	Median	Mean	Median	Mean	Median	Mean
Existing Drainage Network (EDN)	16,422	16,159	16,422	16,159	16,422	16,159
EDN + BF	25,996	24,447	16,422	18,520	16,422	17,903
EDN + BF + K	26,062	25,371	16,422	19,377	16,422	18,741
EDN + BF + K + W	26,192	26,116	16,422	19,889	16,422	19,241
EDN + BF + K + W + M	26,192	26,499	16,422	20,104	16,422	19,446

COMPONENTS OF LOSS

The separate components of loss along each of the flow-paths considered are presented in this section and the schematic of each scenario is illustrated in Appendix A. This allows for the magnitude of the different losses to be compared for each of the flow-paths and the inclusion of the climate scenarios allows for this comparison to occur based on the effects of climate change.

LOCAL CATCHMENT CONTRIBUTION

The local catchment contribution is significant for the reaches between Drain K and the Blackford Drain and the Blackford Drain to the downstream diversion point. As the diversion point is slightly further downstream along the Blackford Drain for the two Flow-path 03 options, the yield expected from this catchment is slightly higher in Table 24 and Table 27 compared to the yield presented in Table 21 for Flow-path 02.

The large yield expected for Flow-path 02 in the Tilley Swamp–Salt Creek (TS–SC) reach, as seen in Table 21 and Figure 49, is the contribution expected from the Kercoonda Drain before any losses are applied in delivering that water to the Coorong, via Morella Basin and Salt Creek.

Due to the reduction in rainfall implemented for the climate change scenarios, there is a corresponding reduction in the local catchment contribution. For the median climate change scenario, the 6.9% reduction for the wet period rainfall results in a 23% reduction in the runoff yield on average. For the dry climate change scenario, the 13% reduction in the wet period rainfall leads to a 42% reduction in the expected runoff yield. These results are in line with the general rule observed for catchments in a similar climate, where a 10% reduction in rainfall often leads to approximately a 30% reduction in runoff.

RAINFALL DEFICIT

The rainfall deficit provides an insight into the timing of the flow along the reach, as well as the surface area involved. Based on the PAN evaporation station at Penola and a PAN factor of 0.7, the months where rainfall will exceed evaporation are May to September inclusive. Hence, the few reaches that provide a positive rainfall deficit are those that are mainly in use for this period only. Generally, from Table 21, for Flow-path 02 with limited large open storages within the flow-path (with the exception of the TS–SC reach which includes Morella Basin), it can be seen that the further north the reach is, the larger the rainfall deficit loss is. This indicates that the flow is continuing later into the year when evaporation will begin to exceed rainfall. The exceptions to this are the Drain M to Wilmot Drain reach, which flows inconsistently and the Blackford to Taratap and Tilley Swamp Drain, which is very short at approximately 3 km in length.

Similar results are not as clear for Flow-path 03 due to the effects of the surface area of the storages in the ephemeral lagoons. Lagoon 2 is the largest (as seen in Figure 27) and therefore, has the largest loss in terms of total volume in Table 27. The net loss from the system for most reaches for the Flow-path 03 options indicates that there is still water in the lagoons after September, when the monthly evaporation will exceed the incident rainfall. The impact of climate change on the rainfall deficit is relatively small, with a 13% increase in the rainfall deficit for the median scenario, most likely due to a reduction in the duration in the flows remaining in the system for the warmer months. A 32% reduction in the rainfall deficit is observed on average for the dry climate scenario due to the reduction in rainfall falling on each reach in the flow-paths.

GROUNDWATER LOSS

As seen in Figure 48 to Figure 56, groundwater loss is generally the largest component of loss. The Groundwater loss along Reedy Creek, from Drain M to the Blackford Drain, is the same for all flow-paths. The groundwater losses along these first three reaches can be broken down into the groundwater loss per day that there is flow entering the reach, where the average loss in each of the three reaches considered along Reedy Creek was found to be between 1.4 - 6.2 ML/day/km. These values are similar to that presented in AWE (2009a), which reported 1–4 ML/day/km of groundwater loss along Reedy Creek. These results are comparable considering the uncertainty in the understanding of the hydrogeology (both hydraulic conductivities and head difference between the water level in the drain and the groundwater level) and the differences in the way the water level in the drain or lagoon has been computed.

The groundwater loss presented for the lagoons in Table 24 to Table 29 has only been simulated to occur for the period from January to May, inclusive, representing the drying out of these systems. No groundwater loss is simulated between June and December, as the lagoons are assumed to be supported by the groundwater system for this period. Hence, the groundwater losses reported for the lagoons for Flow-path 03 and the Tilley Swamp to Salt Creek reach for Flow-path 02 generally represent the volume lost when the storage in the water bodies dries out in the summer months. This generally corresponds to the time when flow from the contributing catchments has ceased, representing the drying out of the storage in the lagoon that must be filled before spilling occurs along the flow-path. The groundwater loss is not the only process driving the drying out of the lagoons. Evaporation is also simulated, which is evident in the negative rainfall deficit seen for all lagoons in Flow-path 02 and the Tilly Swamp to Salt Creek reach of Flow-path 02.

The loss along the floodway reach of Flow-path 03, seen in Table 27, is due to the large difference between the surface water level expected and the groundwater table. On average along this reach with a 1000 ML/day diversion limit, the surface water level is expected to be 4 m AHD, compared to a groundwater level of 1.86 m AHD. Given this difference of over 2 m, there are significant groundwater losses along this reach. However, the groundwater loss along the floodway path is only slightly greater than the rainfall deficit, or evaporation, occurring in the Lagoon 1 and 2 reaches of Flow-path 03 – SELs, resulting in these two paths having similar total yield delivered to the CSL. As seen from the soil hydraulic conductivity sensitivity analysis presented earlier in this section, if the conductivity is reduced by an order of magnitude and hence also the groundwater loss, the evaporation from Lagoon 1 and 2 becomes a greater loss term than the groundwater loss from the floodway path.

For some scenarios of Flow-path 03 there is a positive groundwater contribution reported for some of the lagoons, for example the floodway route for Flow-path 03 with historic climate conditions (Table 24 and Figure 51). This is produced by the assumption that at the start of June the water level in each lagoon is at mean sea level, which results in some storage in the lagoon, as seen in Table 7. If a lagoon dries out before the end of the December, when groundwater losses first occur, the volume in the lagoon has been lost via evaporation, represented as rainfall deficit in the results. Hence, in this case there has been a gain from groundwater in the overall water balance and is reported as such in the results presented in this section. This is clear from Table 24 to Table 29 where for each case there is a positive groundwater loss, the volume lost via the rainfall deficit is greater, which incorporates this initial groundwater contribution.

As the catchment yield is expected to reduce for the climate change scenarios, the corresponding water level along the flow-path will also be reduced. Therefore, the difference between the water level and groundwater table is also reduced, decreasing the groundwater losses. If the losses along the Drain M to Wilmot Drain are ignored (due to the small and infrequent flows involved along this reach), the groundwater losses are reduced by 25% for the median climate scenario on average and 48% for the dry climate scenario.

Table 21 Average annual loss and gain along Flow-path 02, ML — historic climate condition

Reach	M–Wilmot	Wilmot–K	K–BF	BF–TT	TT-TS	TS–SC
Local catchment contribution	**0**	**0**	**5205**	**15045**	**1535**	**29520**
Rainfall deficit	**-55**	**42**	**-173**	**-8**	**-720**	**-1240**
Groundwater loss	**-2355**	**-8565**	**-12253**	**-1**	**-24**	**-1231**

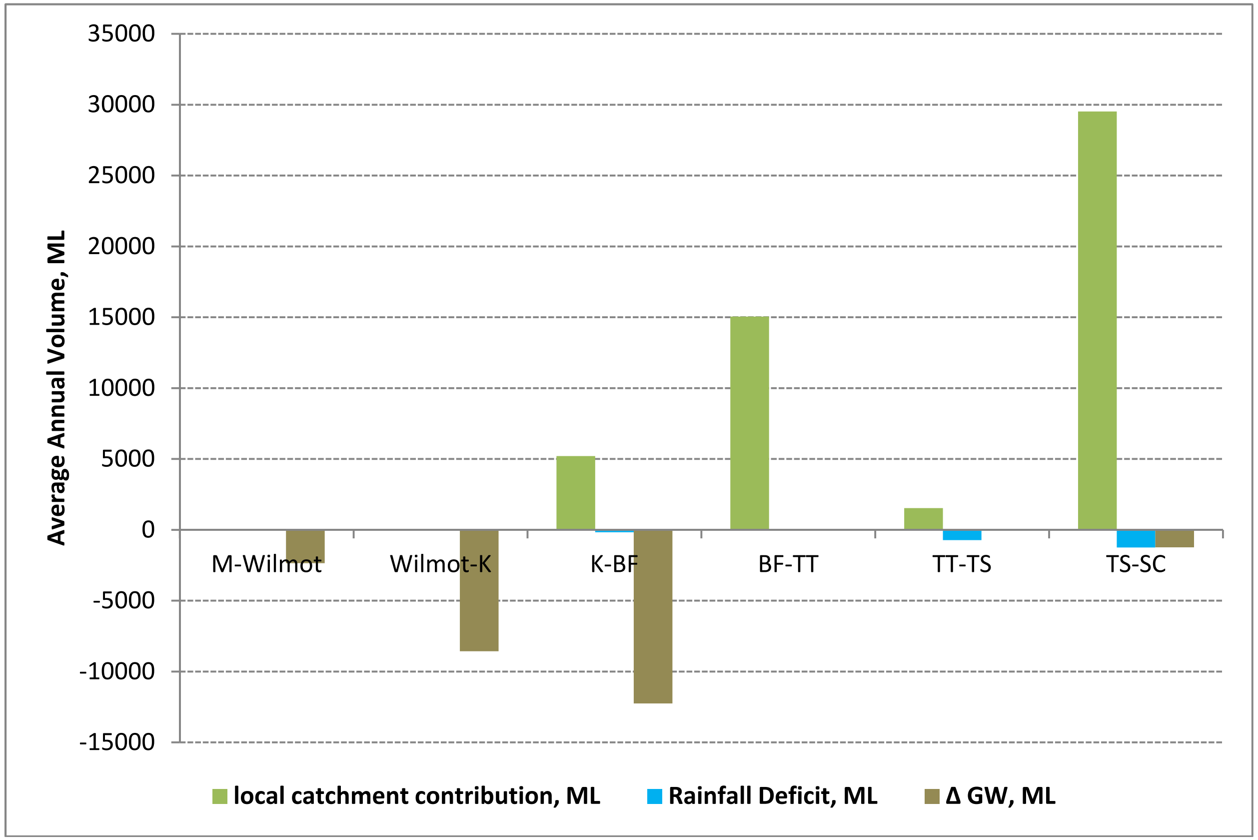

Figure 48 Average annual loss and gain along Flow-path 02, ML — historic climate condition

Table 22 Average annual loss and gain along Flow-path 02, ML — climate change median

Reach	M–Wilmot	Wilmot–K	K–BF	BF–TT	TT–TS	TS–SC
Local catchment contribution	**0**	**0**	**3902**	**11727**	**1191**	**22917**
Rainfall deficit	**-44**	**39**	**-130**	**-9**	**-753**	**-1417**
Groundwater loss	**-1380**	**-6929**	**-8528**	**0**	**55**	**-1199**

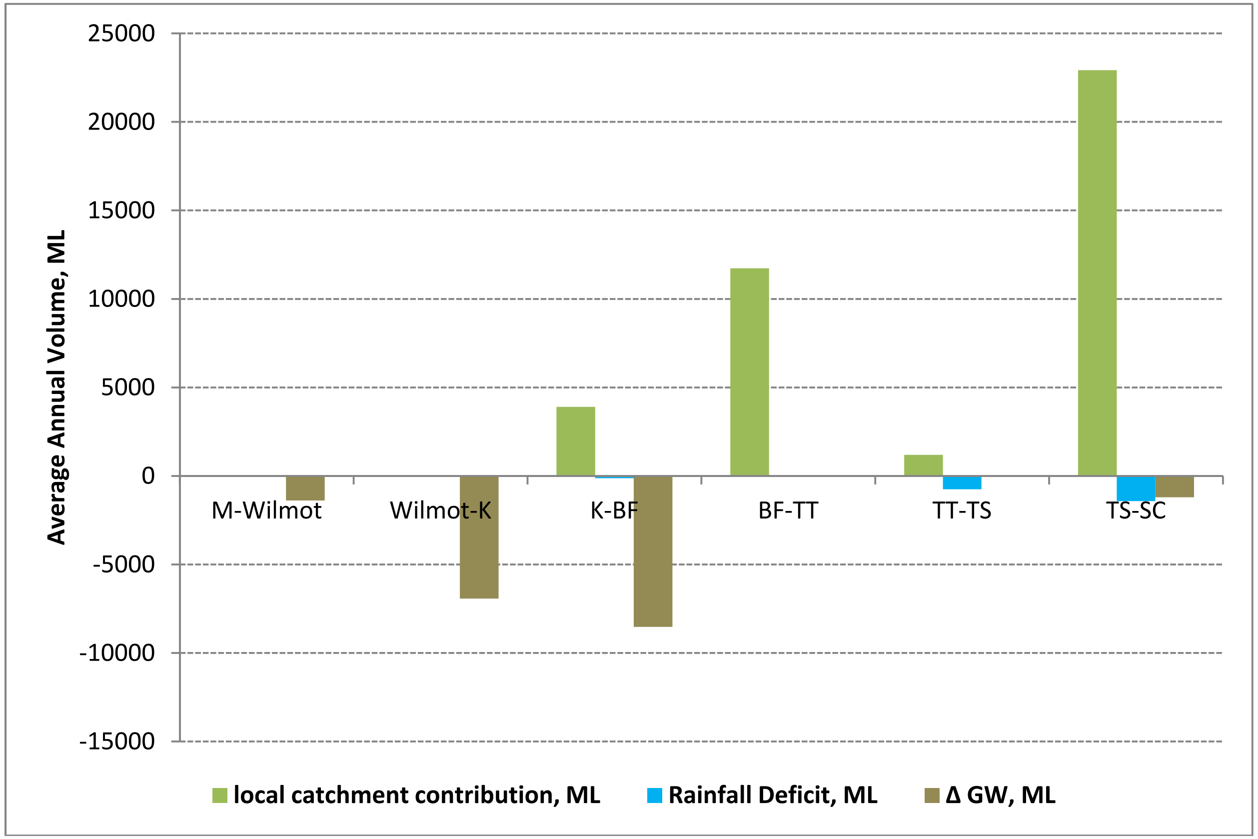

Figure 49 Average annual loss and gain along Flow-path 02, ML — climate change median

Table 23 Average annual loss and gain along Flow-path 02, ML — climate change dry

Reach	M–Wilmot	Wilmot–K	K–BF	BF–TT	TT–TS	TS–SC
Local catchment contribution	**0**	**0**	**2896**	**8726**	**776**	**17387**
Rainfall deficit	**-25**	**32**	**-129**	**-8**	**-785**	**-1552**
Groundwater loss	**-744**	**-5056**	**-6158**	**0**	**104**	**-1139**

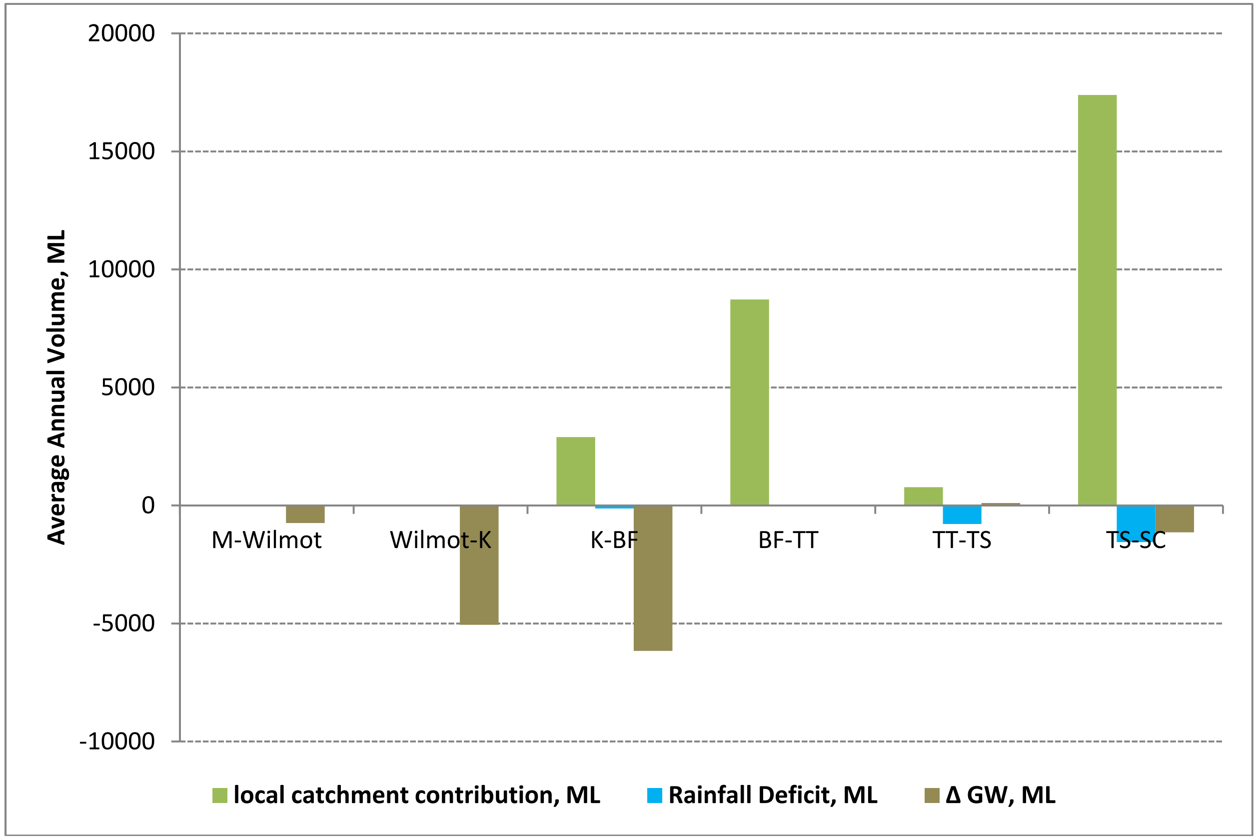

Figure 50 Average annual loss and gain along Flow-path 02, ML — climate change dry

Table 24 Average annual loss and gain along Flow-path 03—SELs, ML — historic climate condition

Reach	M-Wilmot	Wilmot-K	K-BF	BF	Lagoon1	Lagoon2	Lagoon3	Lagoon4
Local catchment contribution	0	0	5205	16909	842	1380	309	329
Rainfall deficit	-55	42	-173	-36	-1233	-6921	-3309	-1200
Groundwater loss	-2355	-8565	-12253	351	-562	2195	993	474

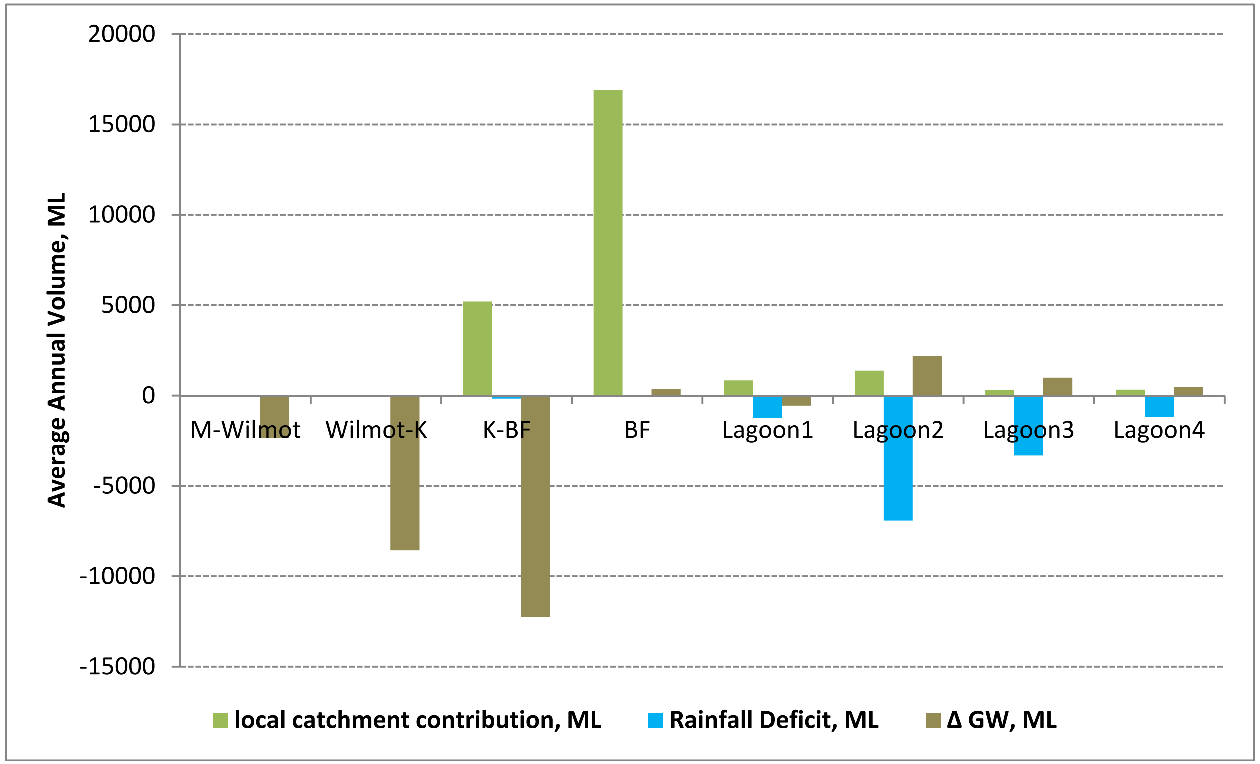

Figure 51 Average annual loss and gain along Flow-path 03—SELs, ML — historic climate condition

Table 25 Average annual loss and gain along Flow-path 03—SELs, ML — climate change median

Reach	M-Wilmot	Wilmot-K	K-BF	BF	Lagoon1	Lagoon2	Lagoon3	Lagoon4
Local catchment contribution	0	0	3902	13072	563	923	208	222
Rainfall deficit	-44	39	-130	-39	-1241	-6488	-3117	-1060
Groundwater loss	-1380	-6929	-8528	355	-520	1989	978	517

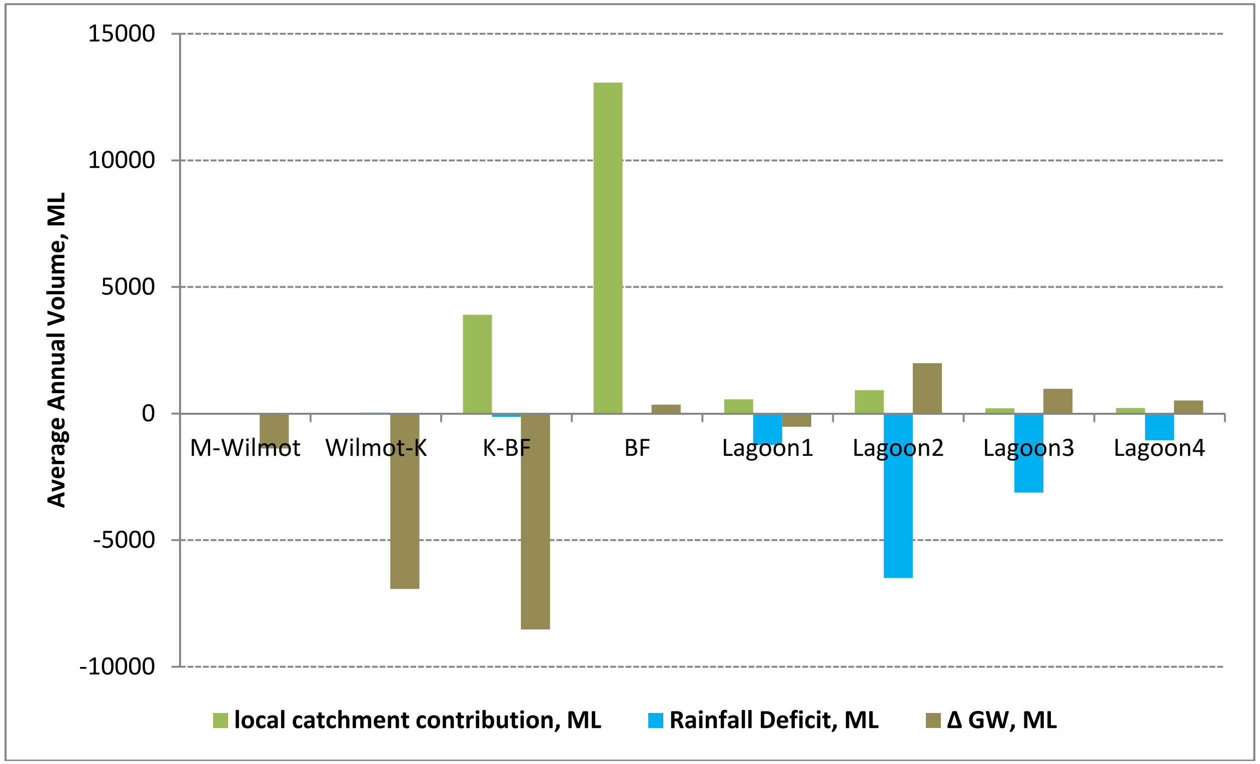

Figure 52 Average annual loss and gain along Flow-path 03—SELs, ML — climate change median

Table 26 Average annual loss and gain along Flow-path 03—SELs, ML — climate change dry

Reach	M-Wilmot	Wilmot-K	K-BF	BF	Lagoon1	Lagoon2	Lagoon3	Lagoon4
Local catchment contribution	0	0	2896	9654	345	566	133	142
Rainfall deficit	-25	32	-129	-38	-1241	-6412	-2891	-995
Groundwater loss	-465	-5348	-6071	-544	-469	2337	1118	547

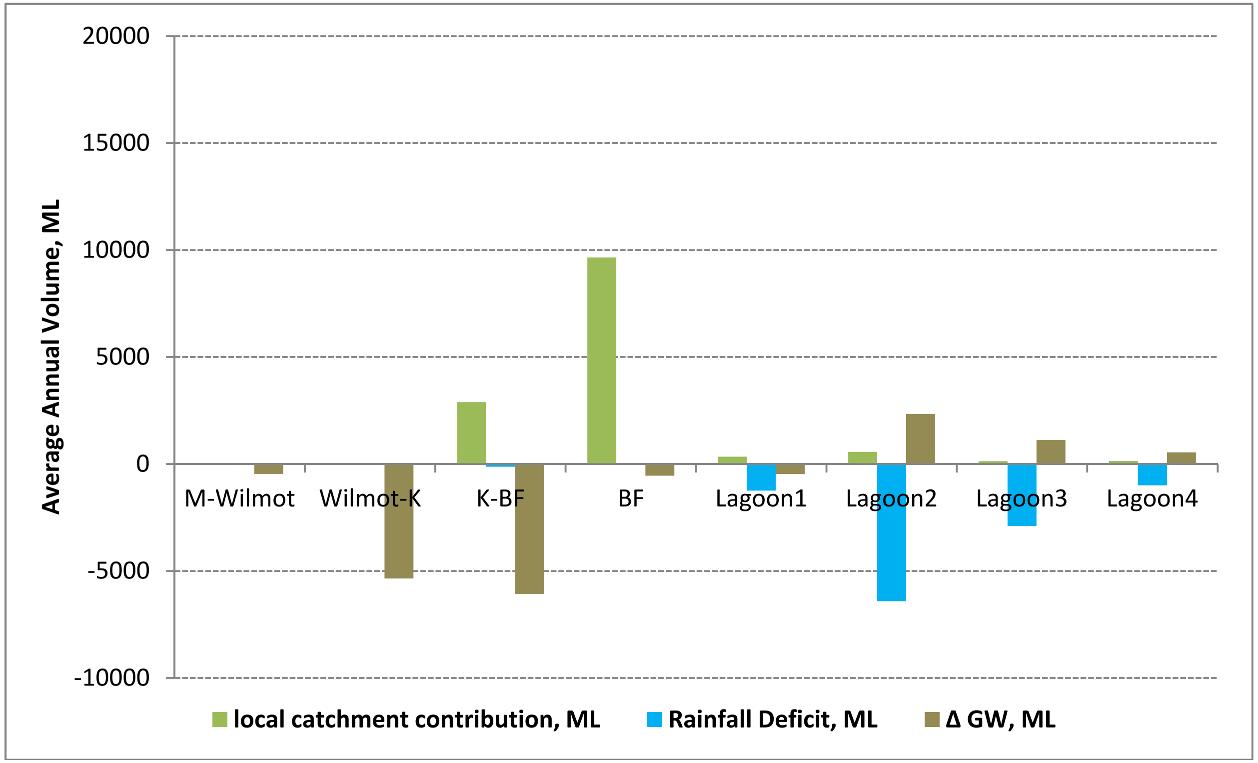

Figure 53 Average annual loss and gain along Flow-path 03—SELs, ML — climate change dry

Table 27 Average annual loss and gain along Flow-path 03—Floodway, ML — historic climate condition

Reach	M-Wilmot	Wilmot-K	K-BF	BF	floodway	Lagoon3	Lagoon4
Local catchment contribution	0	0	5205	16909	0	309	329
Rainfall deficit	-55	42	-173	-36	-1157	-1943	-1117
Groundwater loss	-2355	-8565	-12253	351	-8594	291	483

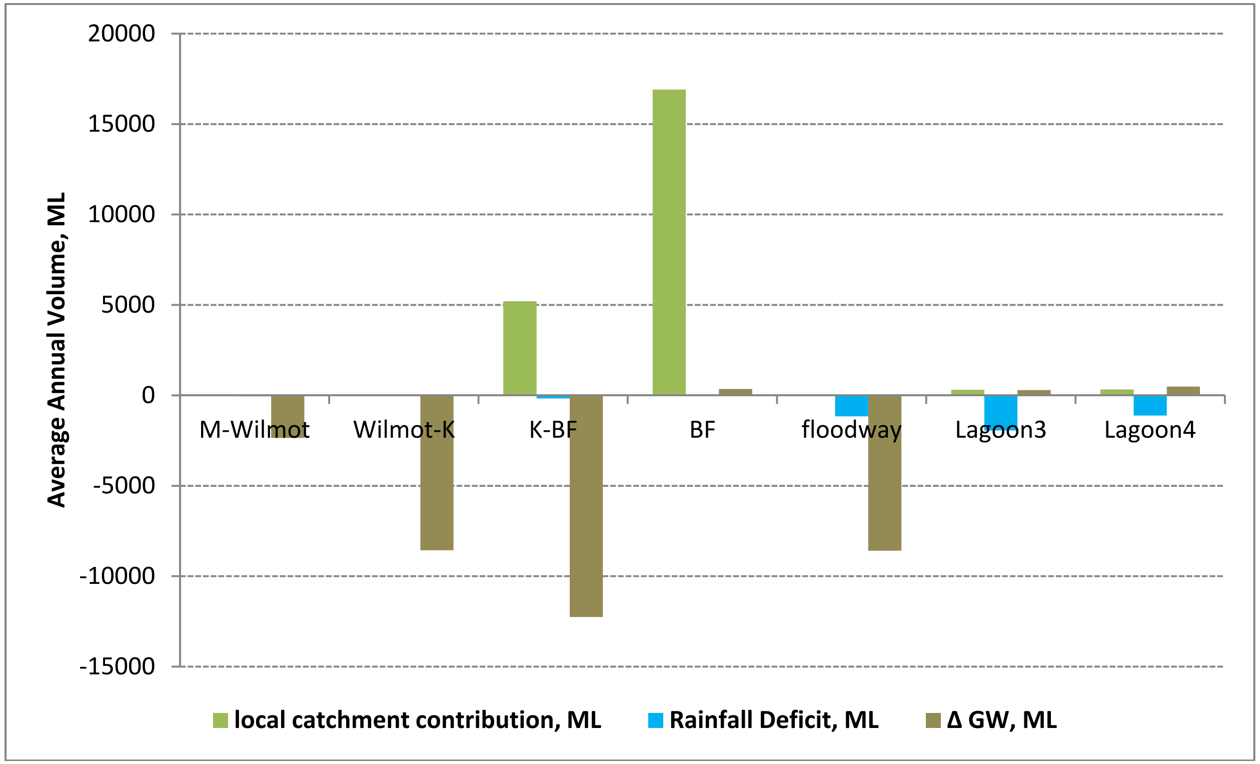

Figure 54 Average annual loss and gain along Flow-path 03— Floodway, ML — historic climate condition

Table 28 Average annual loss and gain along Flow-path 03— Floodway, ML — climate change median

Reach	M-Wilmot	Wilmot-K	K-BF	BF	floodway	Lagoon3	Lagoon4
Local catchment contribution	0	0	3902	13072	0	208	222
Rainfall deficit	-44	39	-130	-39	-1198	-1950	-1072
Groundwater loss	-1380	-6929	-8528	355	-7174	322	514

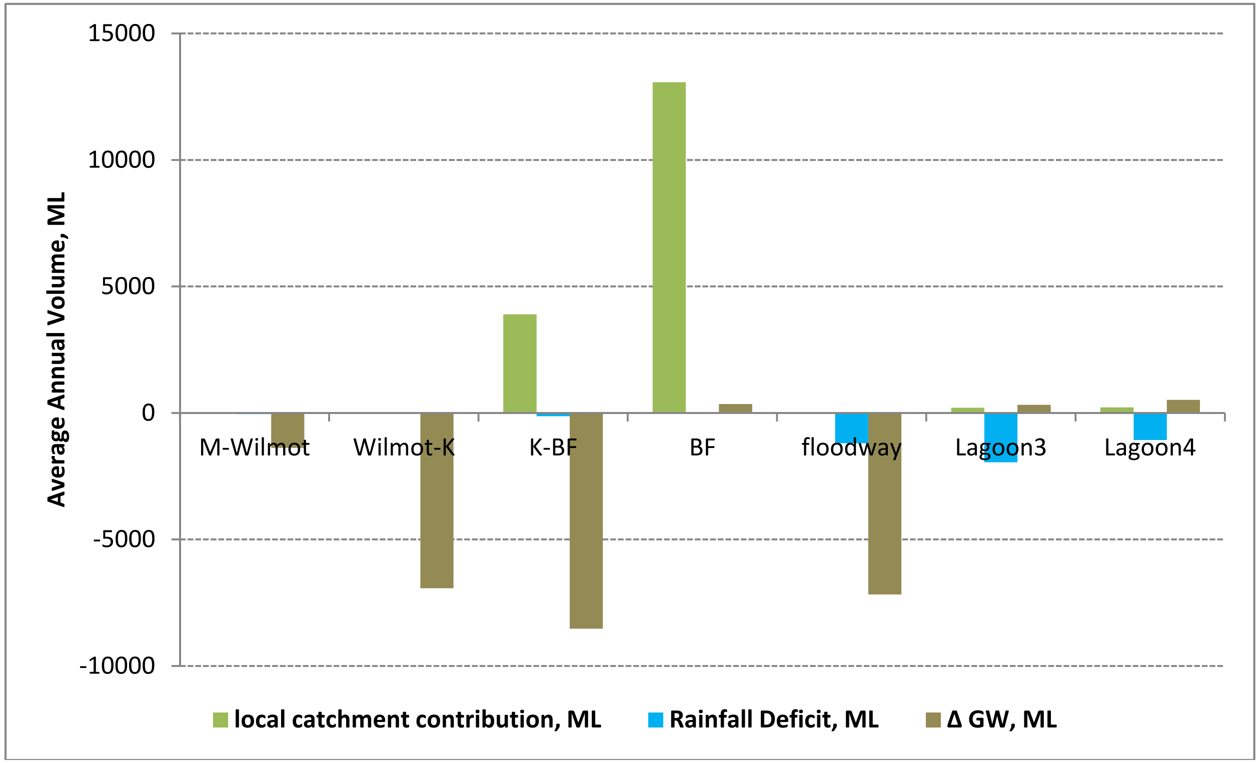

Figure 55 Average annual loss and gain along Flow-path 03— Floodway, ML — climate change median

Table 29 Average annual loss and gain along Flow-path 03— Floodway, ML — climate change dry

Reach	M-Wilmot	Wilmot-K	K-BF	BF	floodway	Lagoon3	Lagoon4
Local catchment contribution	0	0	2896	9654	0	133	142
Rainfall deficit	-25	32	-129	-38	-1248	-1893	-1014
Groundwater loss	-465	-5348	-6071	-544	-6707	431	511

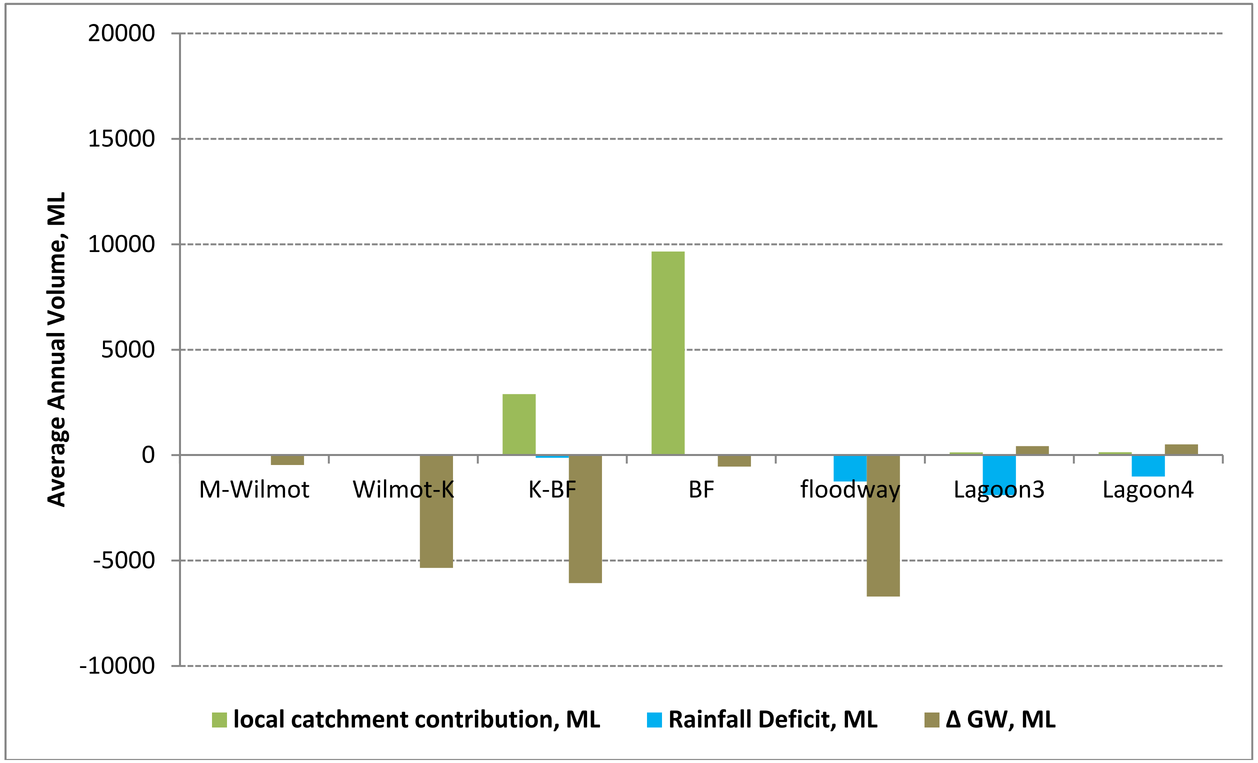

Figure 56 Average annual loss and gain along Flow-path 03— Floodway, ML — climate change dry

DISCUSSION

This study extends previous investigations (Way and Heneker 2007; AWE 2009a) that considered the feasibility of restoring flows from the south to the CSL through:

- establishing a daily modelling of the rainfall runoff processes of the region
- undertaking detailed hydraulic analysis to estimate water surface levels
- investigating the feasibility of delivering flows along very flat terrain
- extending the hydro-geological analyses of AWE (2009a) to estimate the losses to groundwater involved.

CATCHMENT MODELLING

Due to the differences in methodologies, direct comparisons with previous studies are not straightforward. There are significant differences in the way the runoff volumes are estimated, with conceptual daily time-step rainfall runoff models used in this work. While models in this study are likely to represent the soil storage processes more accurately than the annual rainfall runoff relationships used in previous studies, calibration of models was difficult for the northern catchments due to the limited flow records available for calibration. Generally, the modelling approach used in this study has led to larger local catchment contributions compared to the AWE (2009a) study. Also, due to the daily time-step runoff simulation undertaken in this study, negative rainfall deficits are produced for most cases compared to mostly positive rainfall deficit values for AWE (2009a). However, the magnitude of the rainfall deficit is generally lower than the other components of loss and is relatively insignificant.

DIVERSION RATES

Different maximum rates of diversion from the proposed diversion points have been used by the two studies, with a range of diversion rates considered in AWE (2009a) and the optimised diversion rates in this study. Also, as determined by the structure of the drainage network, the flows from the southern catchments have been accumulated in the Blackford Drain in this work, resulting in larger diversion rates, which was not considered by AWE (2009a).

LOSS TO GROUNDWATER

There are a number of significant differences in the way that the groundwater losses have been computed in this study compared with AWE (2009a). The previous study used a simple relationship to determine the water depth. This was found to be within 25% of the true depth for large channels and 40% less than the true depth of smaller channels. The analytical equation used by AWE (2009a) to represent the groundwater losses results in a loss that is linearly proportional to the head difference and hence, an underestimation of the water level will lead to an underestimation of the groundwater loss. In comparison, this study has used one-dimensional hydraulic modelling (outlined in the *Methodology* section) to provide a more accurate representation of the water surface level and therefore, greater confidence in this input to the groundwater model. Also, the approach used to calculate the soil conductivity is different between the two studies. AWE (2009a) adopted the conductivity of the soil estimated at a depth of 1.5m, where this study has implemented a weighted conductivity based on the soil layers present.

YIELDS

Given these significant differences between the assumptions around the attributes of the system (reduced lagoon sill levels and different maximum diversion rates) and the conceptual processes involved (hydraulic, hydrologic and hydrogeologic), the average and median yields expected at the CSL are slightly different for this study and the AWE (2009a) results. A comparison between the median and average yields estimated by both studies for the three climate scenarios considered is provided in Table 30 for Flow-path 02 and Table 31 for Flow-path 03—SELs. The floodway option for Flow-path 03 was not considered as part of AWE (2009a).

Table 30 Annual yields expected (ML) from Flow-path 02

		Historic	CC median	CC dry
Median	Current study	58,095	37,834	26,192
	AWE (2009a)	34,100	22,600	12,600
Average	Current study	53,200	38,093	26,498
	AWE (2009a)	47,500	34,600	21,800

Table 31 Annual yields expected (ML) at CSL from Flow-path 03—SELs

		Historic	CC median	CC dry
Median	Current study	15,387	4,634	0
	AWE (2009a)	1,200	0	0
Average	Current study	19,475	10,297	4,577
	AWE (2009a)	18,200	8,500	900

It can be seen from Table 30 and Table 31 that the average yield expected from both flow-paths from both studies is very similar. However, there are significant differences in the median yields, approximately 20 GL higher for Flow-path 02 in this work compared to the previous study. Similar trends between the yields reported by the two studies are seen for the two climate scenarios, however the magnitude of the difference generally decreases.

When comparing Flow-path 02 and Flow-path 03—SELs, it should be kept in mind that an average of 29 GL/year is expected to be delivered to the CSL via the existing drainage network (Table 12). This volume is included in the yield estimates for Flow-path 02, as the existing network is used to deliver flows to the CSL, but is not included in the estimates for Flow-path 03—SELs. Hence, after accounting for this increased volume, there is little difference between the total yields delivered to the CSL for these two options on average (53 GL compared to 49 GL). However, the distribution of flows is highly skewed, as even when including the flows expected from the existing drainage network, Flow-path 02 is expected to delivery significantly higher volumes to the CSL than Flow-path 03—SELs for a median year (58 GL compared to 44GL). Also, Flow-path 02 is more reliable, with some yield expected from Flow-path 02 for historic climate conditions in all years simulated, compared to 70% from Flow-path 03—SELs and the reliability of Flow-path 03—SELs also reduces much quicker for the climate change scenarios due to the requirement to fill each of the four ephemeral lagoons before flow can be delivered to the CSL.

COMPARISON OF BENEFITS

The extra yield and reliability of that yield provided by Flow-path 02 should be contrasted against other potential benefits provided by Flow-path 03—SELs. However, potential benefits to the Southern Ephemeral Lakes needs to be balanced against the requirement for significant infrastructure works to provide the hydraulic capacity for diverting flows through this route. Hydraulic modelling of two alternative options for diverting water through the SEL (via the natural lake system and via an adjacent floodway) will require, as a minimum, an upgraded Princes Highway crossing and road raising, as well as all-weather crossings for several other minor roads and property accesses. Furthermore, the alternatives involve either excavating channels between the lakes or constructing a floodway adjacent to them. These works have the potential to have significant environmental impacts in themselves.

UNCERTAINTIES

There are a number of uncertainties involved in producing the results presented in this report. Climate data (evaporation and rainfall) and flow records are relatively sparse in the South East. This presents a challenge for hydrological modelling. Modelling of catchments in the Upper South East has relied on calibration results principally from the well-gauged Drain L and Drain K catchments to the south and applying the assumption that these dune and swale catchments are similar to those encountered further north. This, along with the paucity of climate data, will introduce significant uncertainty into the estimates of yield from catchments of the Upper South East. This uncertainty has principally been considered as part of the NWI South East Regional Hydrological Model (Wood and Way 2010) and has not therefore been allowed for specifically in this proposal. It is mentioned here because the model underpins this project.

AWE (2009a) identified that the saturated hydraulic conductivity values adopted are likely to be a significant source of uncertainty in the analysis, both in the way they have been derived (disturbed sample laboratory falling head tests) and collated (averaged to account for only the dominant soil type). Saturated hydraulic conductivities such as these typically vary by orders of magnitude depending on the soil type, so it follows that there is significant potential for error in the groundwater loss estimation if unrepresentative values are adopted. Local variability of soils along flow-path alignments serves to increase the potential for error. The accuracy of the stratigraphic representation and hence, the degree to which flow-paths could be in direct contact with the water table aquifer, is another source of potential error given the sparse coverage of pizometers in the region. Finally, the degree to which fine sediment deposits and accretion of bio-film to stream beds, resulting in an unsaturated (rather than fully saturated) connection between the flow-path and the underlying water table aquifer, could lead to reduced groundwater losses compared to those estimated in this work.

Projections of the possible future climate scenarios vary considerably and are largely uncertain. To allow for a direct comparison, the same projections as those adopted by AWE (2009a) have also been implemented in this study. The projections are for 2030 conditions based on information provided by Suppiah et al. (2006) and CSIRO and BoM (2007). Also, the implementation of the future climate case is relatively simplistic, as a seasonal percentage scaling for the wet and dry periods. Hence, the future climate projections should be treated as a possible future scenario based on current climate science only (IPCC, 2007).

CONCLUSIONS

This study has extended previous studies investigating water availability to be delivered from the South East drainage system to the south lagoon of the Coorong. Daily time-step hydrological modelling has been combined with hydraulic modelling and analytical groundwater models to estimate the yields available to be diverted from the South East region to the CSL. This approach has also accounted for transmission losses in the network and lagoons.

RELIABILITY OF FLOW-PATHS

The volumes of water delivered to the CSL were found to be highly variable from one year to the next. For instance, under historic climate condition along Flow-path 02, annual flows varied between 7 GL and 120 GL, with volumes greater than 79 GL occurring two out of ten years on average. Similarly, for Flow-path 03—SELs the annual flows varied between 0 ML and 78 GL with two out of ten years expecting a yield of greater than 34 GL. The simulated yield for the third option considered, Flow-path 03—Floodway, was slightly less, where in this case, the annual flows varied between 0 ML and 58 GL, and 30 GL expected for a two in ten year event. The floodway adopted for this path produces a water level over 2 m above the spring groundwater level on average and therefore, large groundwater losses are expected. Conversely, the SEL path has been assumed to be supported by groundwater from June to December and therefore, is not subject to the same degree of groundwater losses, but the open lagoons are subject to greater losses through evaporation (rainfall deficit).

When the total volume delivered to the CSL is considered (i.e. including the contribution of the existing drainage network for Flow-path 03—SELs), there is little difference between the total yields delivered to the CSL for the two higher yielding options on average, with 53 GL expected from Flow-path 02 compared to 49 GL from Flow-path 03—SELs. However, Flow-path 02 is more reliable, with some yield expected from this path for historic climate conditions in all years considered compared to 70% of the years considered from Flow-path 03—SELs. In addition, the reliability of Flow-path 03—SELs also reduces much quicker for the climate change scenarios. Hence, when the variability of flows is considered, Flow-path 02 is likely to provide the highest volume to restore flows to the CSL.

BENEFIT OF EXTENDING THE PROJECT

A staged implementation of the proposed flow-paths was also considered as part of this study. It was found that the local catchment contributing flow to the Blackford Drain provided a significant yield for most events occurring in the 30-year study period considered. Similarly, the contribution from the Drain L and Drain K catchments combined was of a similar magnitude to that expected from the upstream Blackford catchments, after considering transmission losses. However, there was little benefit in drawing water from the furthest diversion point considered (on Drain M) with only 1–5 GL expected in wet years, when over 55 GL is already expected from the upstream diversion points. This is due to the majority of flow along Drain M already being allocated, with the existing REFLOWS project diverting up to 1000 ML/day at the Callendale regulator, as well as the environmental requirements of Lake George at terminus of the drain.

UNCERTAINTY OF GROUNDWATER LOSS ANALYSIS

The potential groundwater losses involved in the drainage network and lagoons provides the largest source of uncertainty in the estimated yields presented in this work. Also, these losses are the most likely to influence the most suitable flow-path to be adopted to restore flows to the CSL. For example, in this study it has been assumed that there is a certain volume that will be sustained in each of the four lagoons and that the groundwater level will be high enough to make any losses to groundwater negligible. If this is not the case and the lagoons are a losing system, the yield expected from Flow-path 03—SEL will be significantly reduced and no longer comparable to Flow-path 02. However, there is also the possibility that the lagoons and surrounding drainage network are a gaining system, increasing the yield expected from this flow-path.

Hence, based on the assumptions and limitations outlined in the transmission loss methodology, a number of recommendations can be made that may improve estimates of transmission loss in the proposed flow restoration channels. These include:

- Aquifer conductivity values are likely to vary over the length of a flow-path and determining aquifer properties (conductivity and thickness) in the area of interest may improve the transmission loss estimates. This would likely require the drilling of new production and observation wells to perform aquifer tests. However, AWE (2009b) concluded that further hydrogeological investigations were likely to be of limited value, as the natural variability in soil properties makes it difficult to accurately determine representative values at the reach or reach segment scale.

- The southern ephemeral lakes of the Coorong are particular sites of interest in terms of groundwater discharge, however this process has not been quantified. Collection of surface water and groundwater chemistry (isotopes and major ions) at different times of the year would greatly improve understanding of groundwater interactions in the Coorong and help constrain any future models of groundwater discharge.

- The analytical, steady state, model used for groundwater loss analysis has allowed for reach scale transmission losses to be estimated. A more detailed, transient numerical groundwater modelling approach may be able to improve the assessment of volumes gained and lost from the drainage network. However, this is likely to be extremely computationally intensive and the suitability of available data for this type of modelling should first be assessed. The calibration of a river reach model, that includes a groundwater interaction module, to observed flow records may be able to be developed and this will at least provide some representation of the accuracy of the models developed. However, data availability should again be assessed first, as there are limited drain reaches with suitable flow records that allow for a direct investigation into transmission losses, due to unknown inflows between gauging stations being of a magnitude larger than the losses, or the influence of regulation of the drainage network.

APPENDIX A

The following schematics illustrate the average annual yield, diversion and loss and gain in each flow-path.

GW: Groundwater Loss R-E: Δ (Rainfall - Evaporation) CC: Catchment Contribution

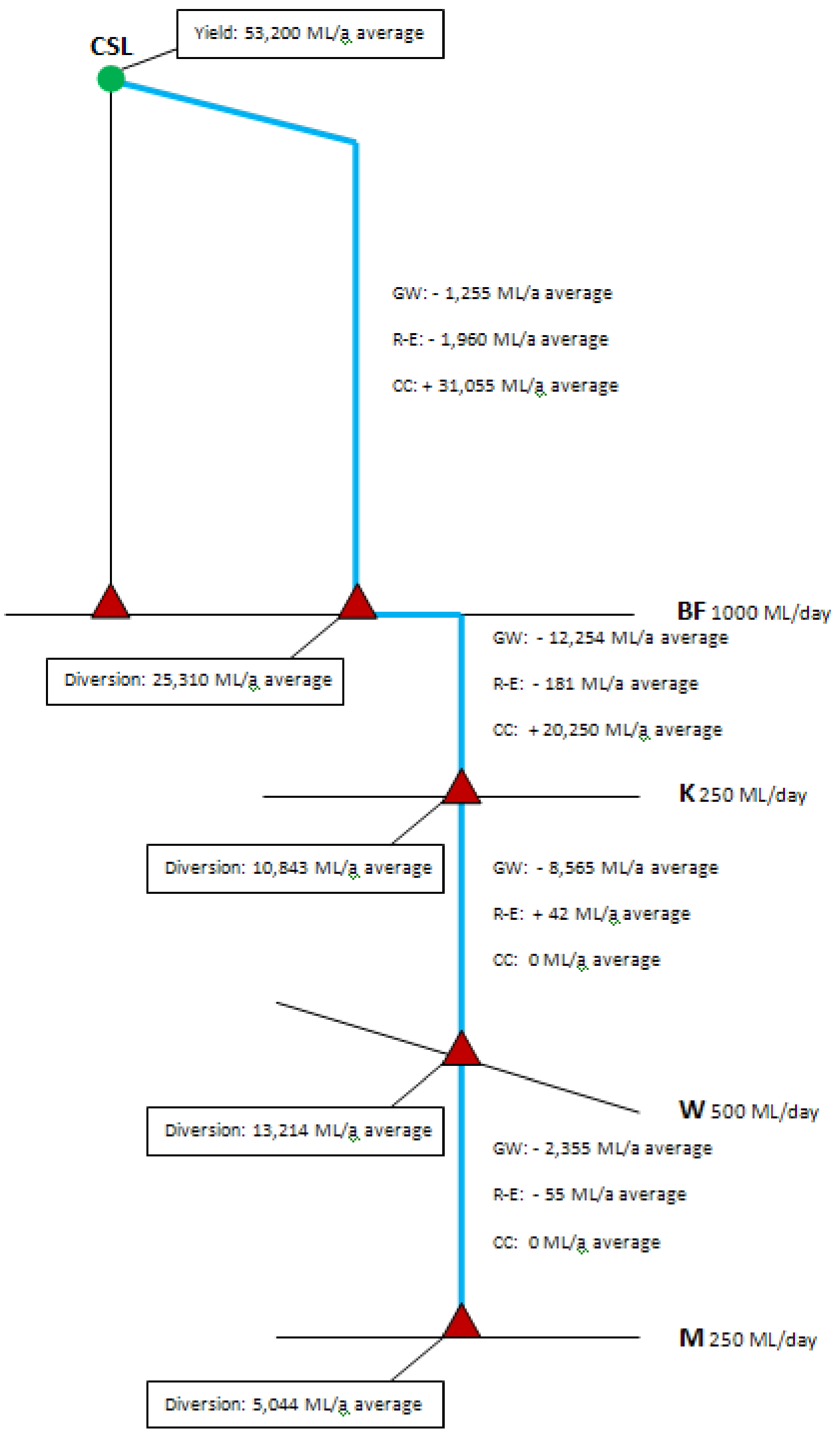

Figure 57 Flow-path 02 — historic climate condition

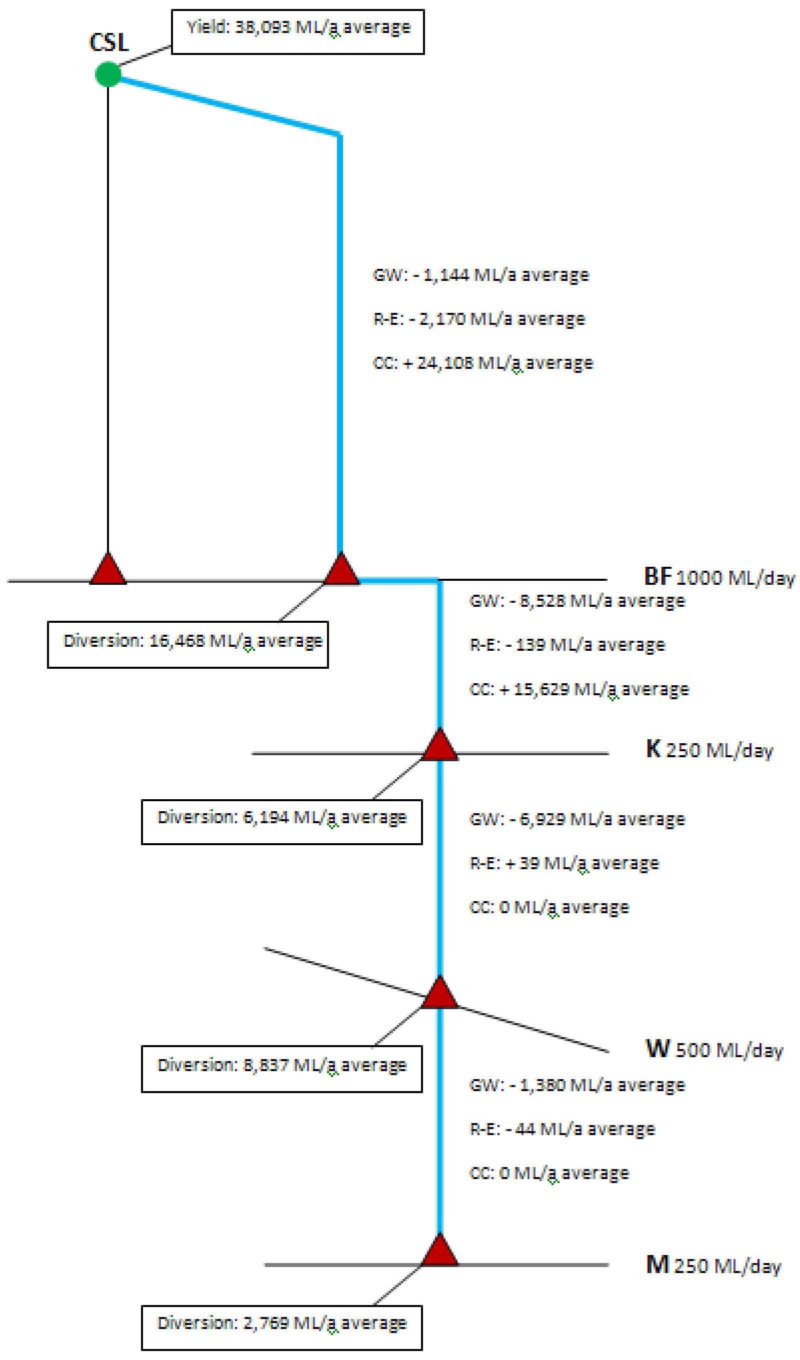

Figure 58 Flow-path 02 — climate change median

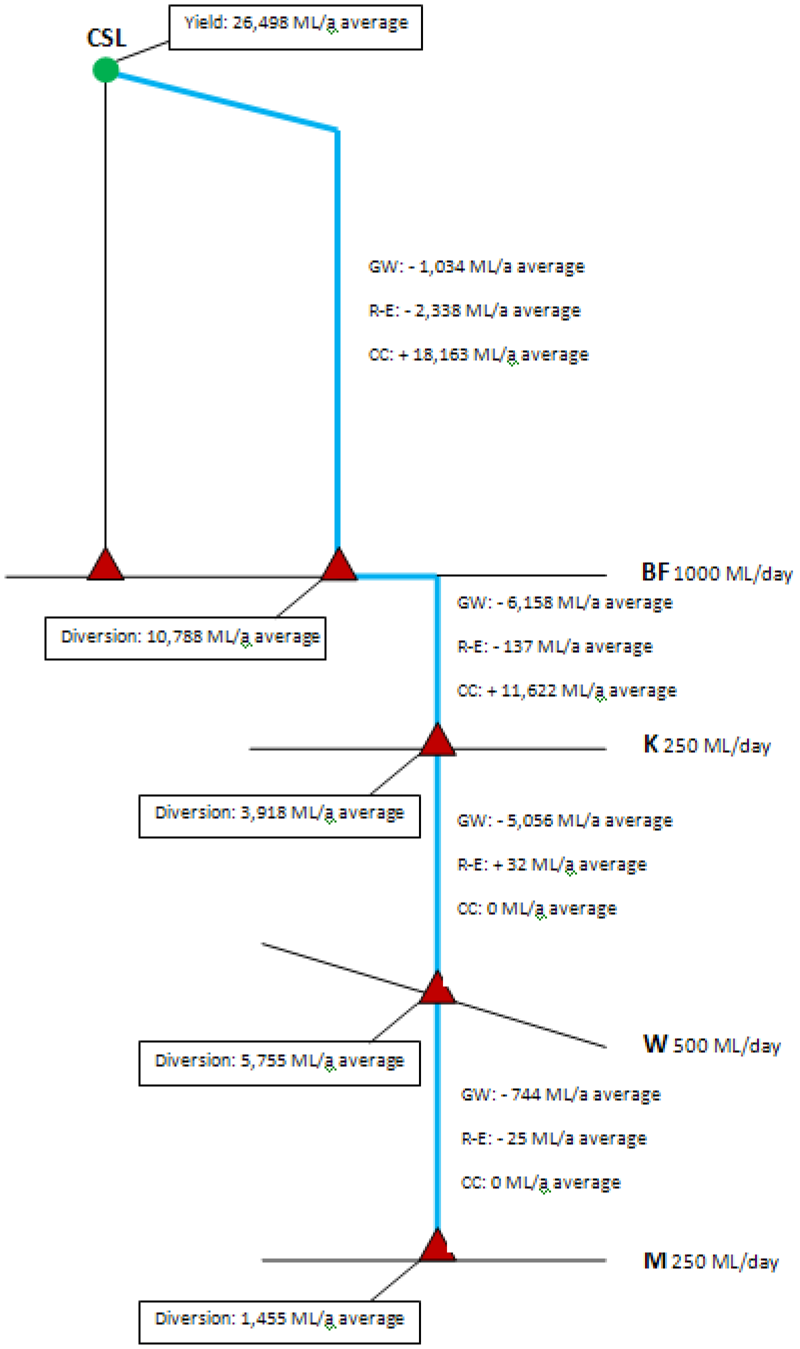

Figure 59 Flow-path 02 — climate change dry

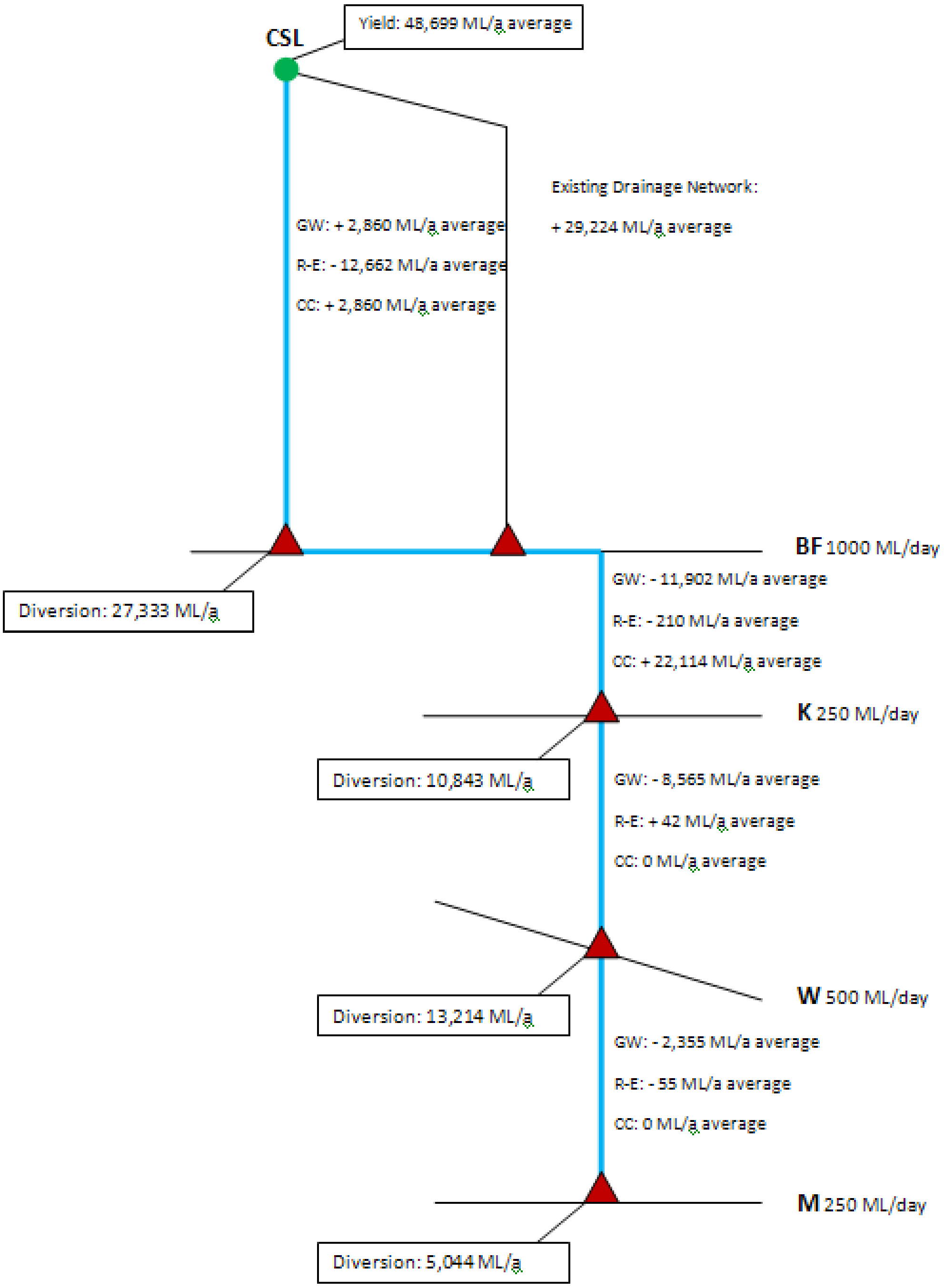

Figure 60 Flow-path 03—SELs — historic climate condition

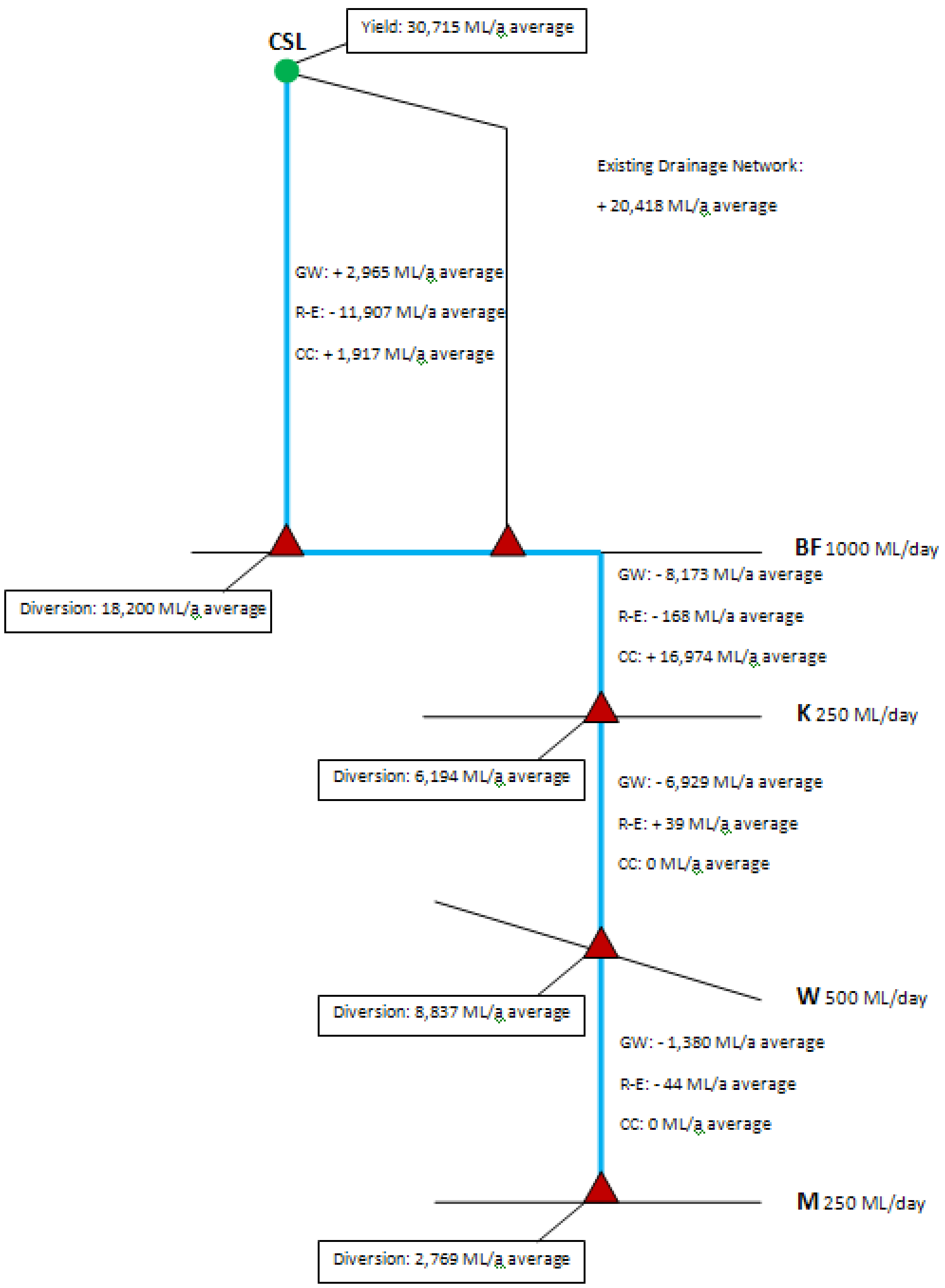

Figure 61 Flow-path 03—SELs — climate change median

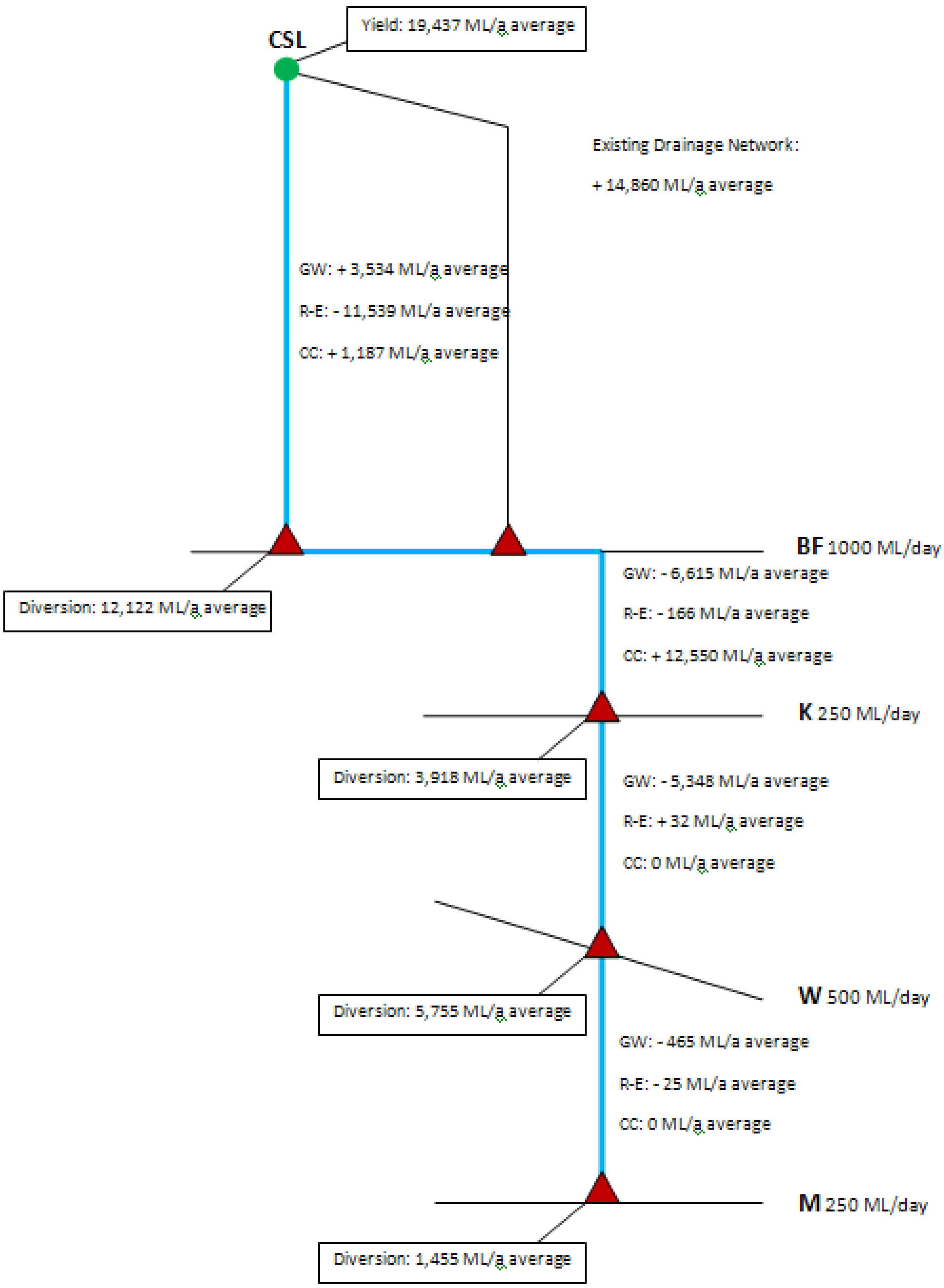

Figure 62 Flow-path 03—SELs — climate change dry

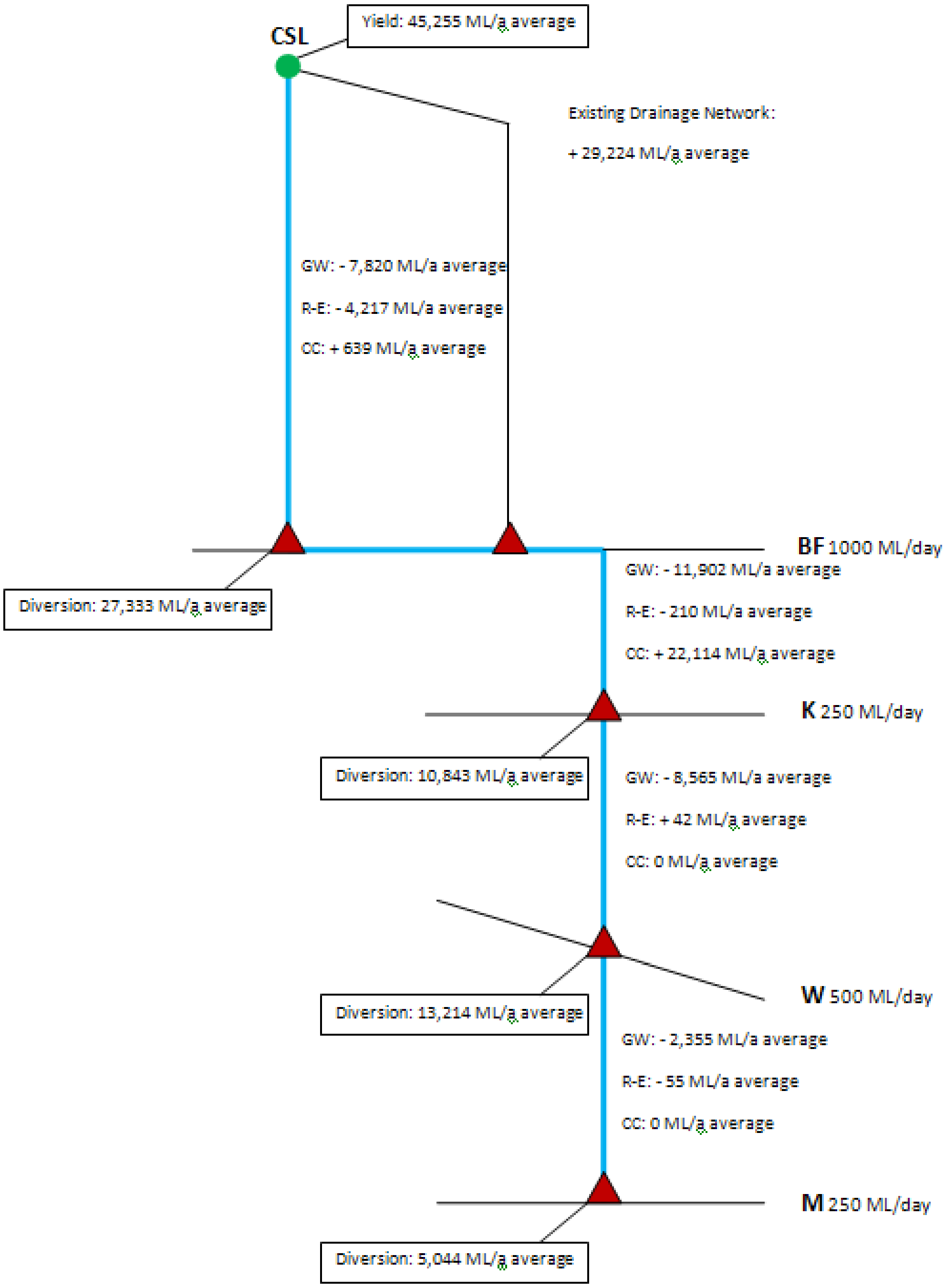

Figure 63 Flow-path 03—Floodway — historic climate condition

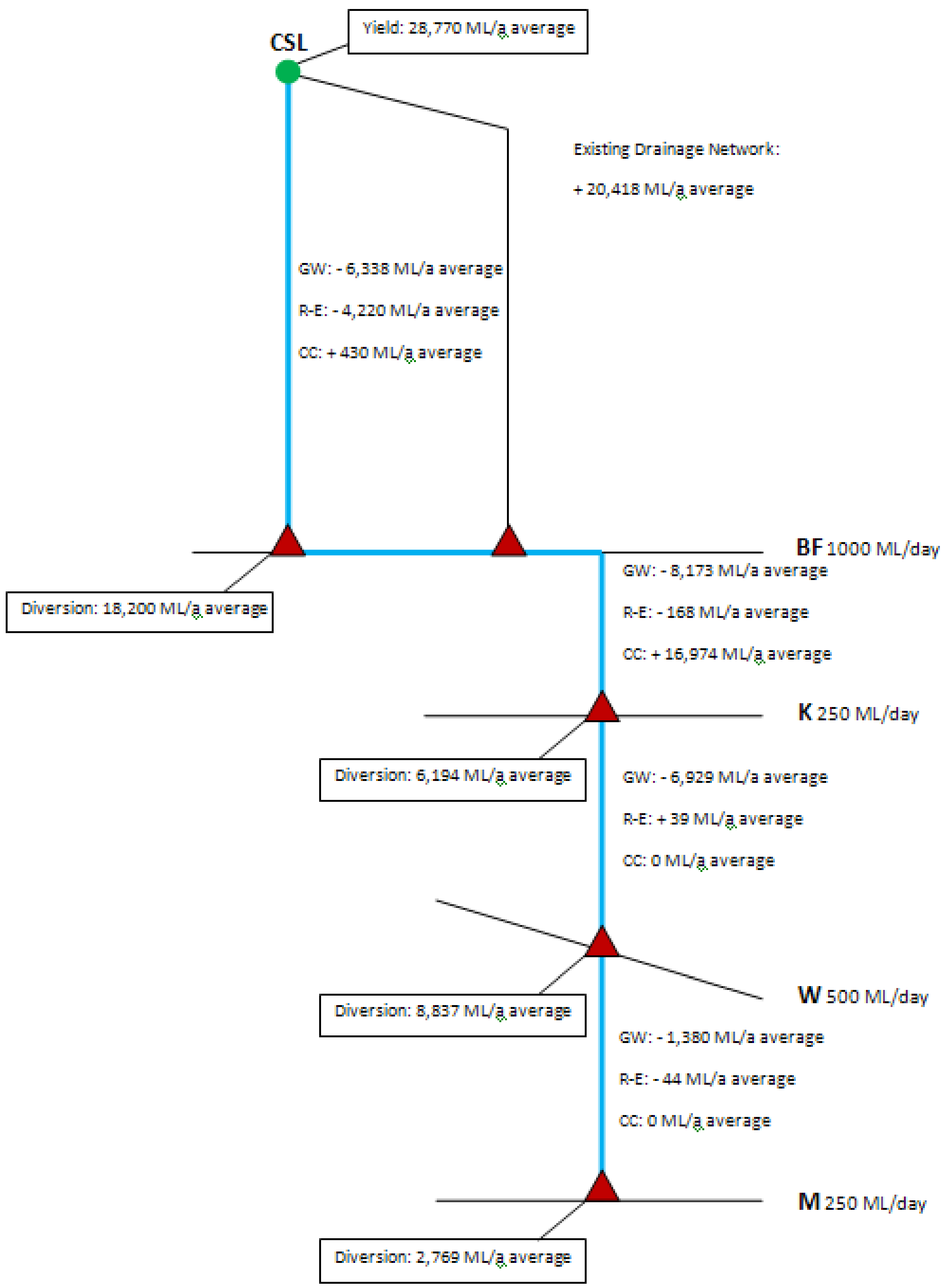

Figure 64 Flow-path 03—Floodway — climate change median

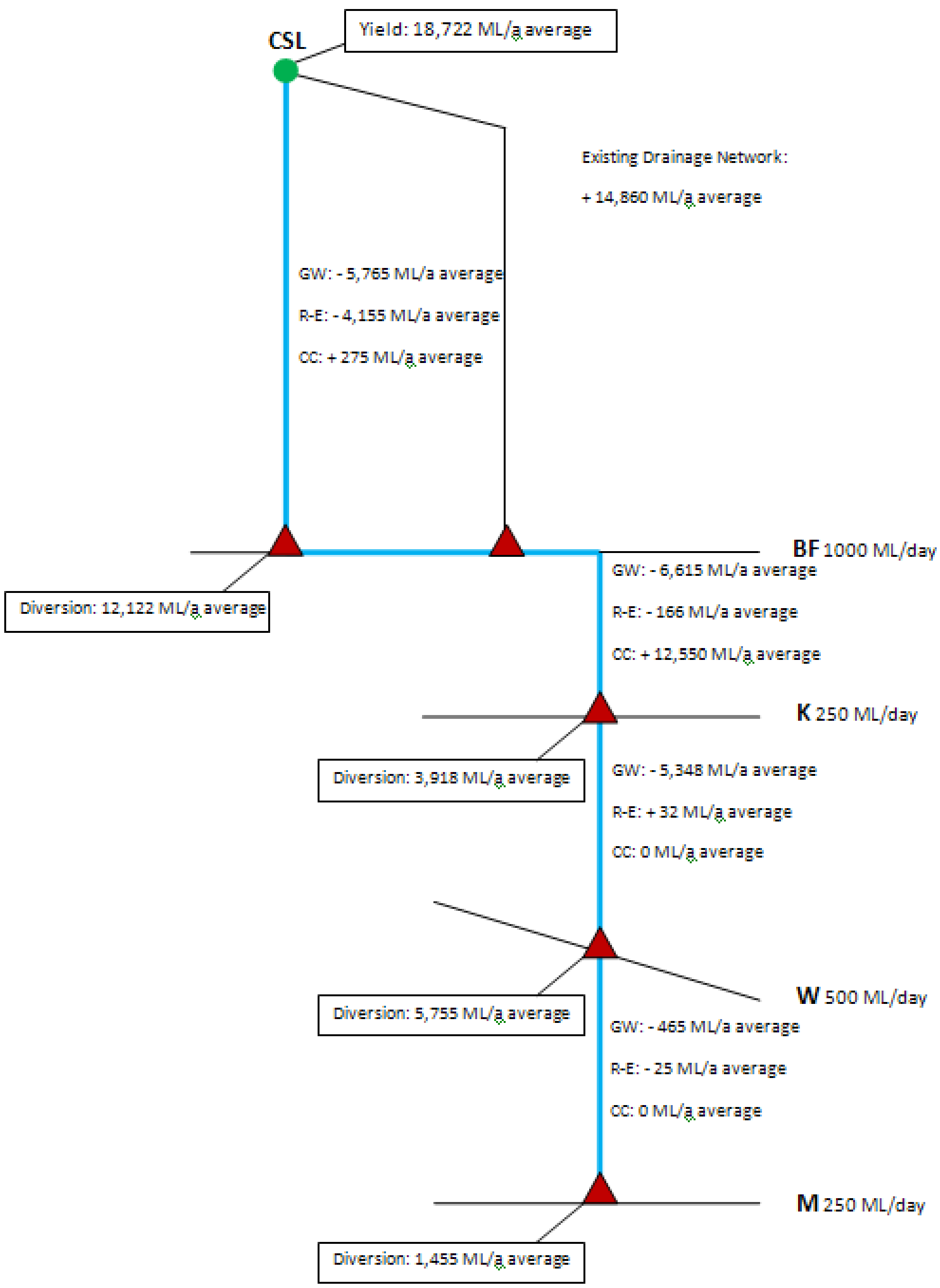

Figure 65 **Flow-path 03—Floodway — climate change dry**

APPENDIX B

Typical cross-sections for conceptual modelling of contributing drain.

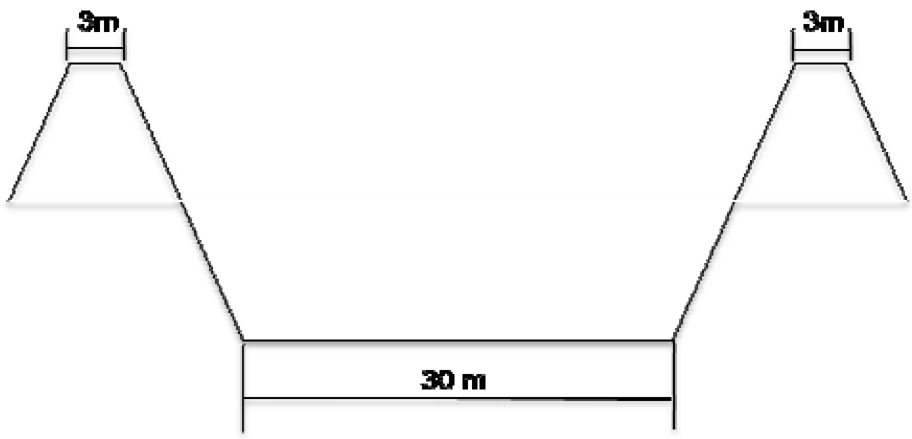

Figure 66 Reedy Creek Drain

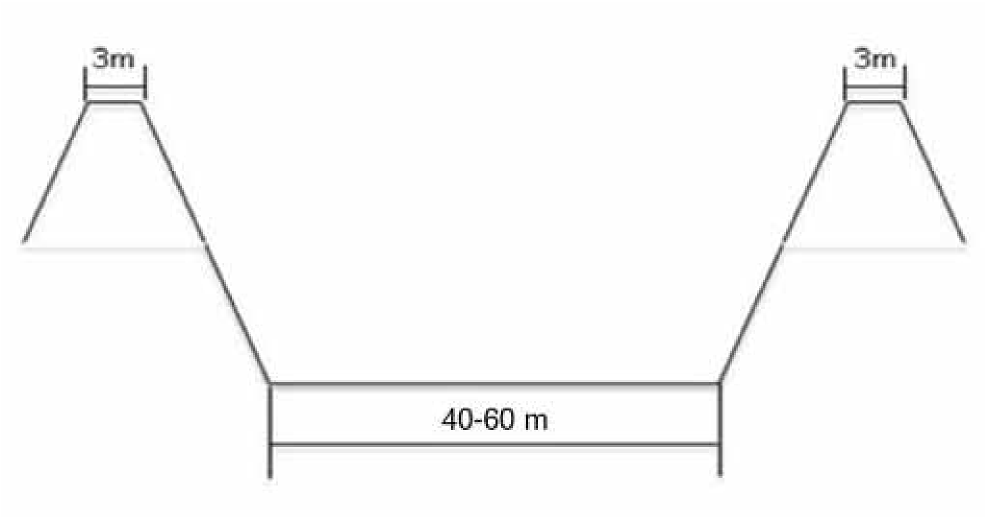

Figure 67 Southern ephemeral floodway

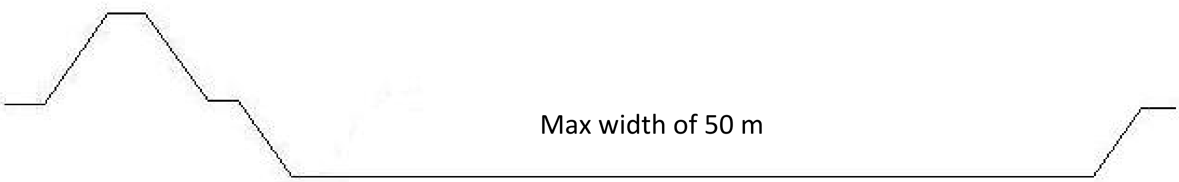

Figure 68 Taratap and Tilley Swamp Drain

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