Evaluation of Regional Drainage for Blackwood Basin, Western Australia
A Summary Report to the Engineering Evaluation Initiative

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The Blackwood Basin of about 2 million hectares in size is one of the largest basins in the southwest of Western Australia. The land use is predominantly agricultural. A large network of salt lakes lies in the basin to the east of the Great Southern Highway and it is largely an internally drained system except downstream river systems in the basin. It is flat with low rainfall. To reclaim the salt-affected land from salinity, farmers within the last 15 to 20 years have increasingly been considering installing deep open drains to lower the shallow watertables. Drains now exist in many subcatchments of the basin but they are generally scattered and without extensive regional linkages and drainage discharge management structures. No subcatchment or regional-scale drainage management studies have been conducted previously for the Blackwood Basin. This project assessed the feasibility and impacts of subcatchment and regional-scale artificial drainage systems, revegetation and climate change on flows, loads and salinity of downstream river systems in the basin. It also evaluated various subcatchment and regional-scale drainage discharge management systems including economic and preliminary environmental assessments.

A hydrological model called LASCAM (LAarge Scale CAtchment Model) was used in the study. The model as modified for the regional drainage evaluation of the Avon River Basin was used for the Blackwood Basin. The model was calibrated using historical climate, stream and groundwater data and then used to predict streamflows, salt and water yields, and groundwater levels under a variety of drainage, revegetation and climate scenarios. The study also used LASCAM outputs to look at the feasibility of different drainage discharge management systems.

**Predicting a baseline – the no drainage scenario**

The first step of the research was to establish what would happen if nothing was done to address dryland salinity – no artificial drainage or any other salinity management strategies would be implemented in the future. In constructing this baseline, or no drainage, scenario, the model highlighted that the current hydrological state of the Blackwood Basin is not at equilibrium. Watertables, streamflows, lake storages and salt loads are steadily increasing. The no drainage scenario suggests that, while these increases are expected to continue, rates of increase are now slowing and most parts of the Blackwood Basin will – in the absence of further land management changes – reach equilibrium some time during the current century. The equilibrium is a state when the recharge and discharge rates to and from the watertable are similar.

**Catchment scenarios**

The no drainage scenario forms the benchmark against which the predictions of various scenarios can be compared. Alternative scenarios included introducing various options for artificial drainage, revegetating large areas of the basin with woody perennials and changing the climate to be wetter or drier. The impact of these scenarios on groundwater trends, streamflow, salt load and lake discharge was assessed. A number of artificial drainage scenarios with various drainage discharge management strategies were modelled with varying results:

- **Drainage SSr scenario:** leveed or open farm and subcatchment drains with leveed or open arterial channels, drainage discharge stored in salt lakes to their existing outlet heights. This scenario can lead to decreases in groundwater levels and salinities in drained subcatchments; the degree and rapidity of these responses is largely dependent on drain density and zone of effectiveness of drains. It is also predicted that there will be modest increases (up to 7%) in flow at the catchment outlet and more substantial increases (up to 66%) in salt load. The impacts of artificial drainage on both streamflow and salt load increase downstream. Increases in the frequency, volume and salinity of lake discharges are also expected with artificial drainage.

- **Drainage SSe scenario:** leveed or open farm and subcatchment drains with leveed or open arterial channels, drainage discharge stored in the salt lakes where the capacity of salt lake storage is increased by elevating the discharge outlet height of the lakes by 0.3 m. This scenario has little effect in reducing streamflows, salt loads and flow salinity in most downstream subcatchments. It leads to modest reductions in lake discharge frequencies and volumes for some lakes, but to slight increases in discharge salinity.

- **Drainage SSf scenario:** leveed or open farm and subcatchment drains with leveed or open arterial channels, drainage discharge stored in the salt lakes by treating lakes as terminal and thus preventing salt lakes from discharging. This scenario is effective in reducing streamflows, salt loads and salinities in most downstream subcatchments, except for those that are downstream of terminal lakes. This retention scheme also leads to modest reductions in peak flows in lower parts of the catchment and larger reductions in the Beaufort and Coblinine Rivers.

- **Drainage EB scenario:** farm and subcatchment-scale leveed drains, drainage discharge retained in evaporation basins within the subcatchment in which they are generated. This scenario is highly effective in reducing flows, loads and salinities in both streams and lake discharges. It is also effective in reducing peak streamflows and salt loads.

- **Drainage LB scenario:** leveed or open farm and subcatchment drains with leveed or open arterial channels, no drainage discharge storage in the salt lakes (lakes are bypassed). This scenario leads to moderate increases in streamflow (including peak flow events) and slight increases in salt load, but has little impact on stream salinity in downstream subcatchments.
Revegetation of the catchment can lead to substantial decreases in streamflow and the magnitude of these changes increases with time. While peak flows are also reduced, this reduction is less than the reduction in mean annual flows. Under a full revegetation scenario (100 percent of the landscape is revegetated with woody perennials), predictions include enormous decreases in stream salt load and salinity, substantial declines in wettertables, but substantial increases in groundwater salinity.

Model predictions about climate change suggest that drier climates lead to lower wettertables and slower wettertable responses than wetter climates. In the short to medium term, wetter climates give rise to higher groundwater salinities than drier climates. There will be greater streamflows and salt loads in wetter climates than drier climates. While the driest climate leads to an almost complete cessation of discharge from all lakes, the wetter climate leads to increases in lake discharge occurrences, volumes and salt loads, but has little effect on lake discharge salinity.

**Drainage discharge management options**

Artificial drainage requires drainage discharge management systems. Four drainage scenarios were assessed for indicative size and construction cost. The arterial channels (either open or leveed) would convey discharge drainage for storage in the salt lakes (up to their existing outlet heights, S5e); leveed arterial channels would convey discharge downstream bypassing the salt lakes (LB); and leveed arterial channels would convey discharge to evaporation basins (EB) constructed at subcatchment outlets. The evaluation concluded that the excavation cost of evaporation basins is substantially higher than the excavation cost of arterial systems. The leveed arterial system which allows the entry and storage of drainage discharge in the salt lake system (S5e) is the most cost effective of all the arterial systems evaluated because of the relatively smaller required size of leveed arterial channels. However, this option assumes that the drainage discharge will be allowed to enter and be stored in all salt lakes encompassing the region, and this may be unacceptable.

**Economic analysis of drainage systems**

An economic analysis of the drainage systems was carried out considering the construction and maintenance cost of farm and subcatchment-scale artificial drains (leveed and open), arterial channels (leveed and open) and subcatchment-scale evaporation basins. Costs included deep drainage construction and maintenance and the disposal of drainage water. Benefits included the agricultural income generated from land reclaimed from salinisation as a result of artificial drainage and additional benefits associated with remnant vegetation and road reconstruction and maintenance protection.

The economic modelling suggested that the open and leveed drains with no disposal costs potentially provide the most consistent favourable returns for all drainage options in the Blackwood Basin. Open and leveed drains with arterial channels are unlikely to be economically viable across the Blackwood Basin given their high capital and maintenance costs and the substantial water disposal costs associated with arterial channels. It was concluded that the main economic drivers of deep drainage economics are: 1) effectiveness of the drainage program in reclaiming agricultural land for production; 2) cost of deep drainage engineering and annual maintenance; and 3) gross margins achieved on the land being returned to agricultural production as a result of the deep drainage program.

**CGSSLRC Channel**

The feasibility of an open channel (proposed by the Central Great Southern Salt Land Recovery Committee) between Lake Dumbleyung and the Albany Highway was assessed. This part of the study concluded that lake discharges into the lower Blackwood River system via an open channel are likely to heavily impact on its flow-weighted salinity (FWS). The FWS of the Blackwood River at Hut Pool is predicted to increase almost 2.6 times compared to that under the Drainage S5e scenario if the Lake Dumbleyung water with a 20 g L\(^{-1}\) concentration level is discharged into Arthur River at a daily rate of 0.65 GL. This means that the release of Lake Dumbleyung water into the Arthur and Blackwood rivers may result in adverse environmental impacts downstream.

**Preliminary assessment of environmental impacts**

A preliminary assessment of the environmental impacts was carried out for selected water management and climate change scenarios. The Drainage EB scenario (drainage discharge is managed using evaporation basins in each subcatchment) is predicted to cause the least change from the current conditions. Under the no drainage scenario, moderate increases in flows and FWS are expected for all catchments and therefore will have moderate environmental impacts. The Drainage S5e, Drainage LB and four CGSSLRC channel release rate scenarios all result in significant increases in both flows and FWS for all catchments. These drainage scenarios are expected to cause impacts to both flora and fauna. Although the wetlands or salt lakes respond differently and at different response scales under each scenario, overall trends show that a wet climate would increase wetland filling and a dry climate will reduce it.
Introduction

Historically, deep-rooted native vegetation helped maintain hydrological equilibrium and kept wheatbelt groundwater systems at deeper depths. After the clearing of native vegetation for agriculture in the Blackwood and the rest of the wheatbelt of WA, this natural hydrological equilibrium was disrupted. The remobilisation of salts as a result of rising watertables has resulted in extensive areas of the wheatbelt being affected by waterlogging and secondary salinity. The region currently has a salinised area of some 9%, and the area with a shallow watertable is expected to increase to 3–5 million hectares when a post-clearing groundwater recharge-discharge equilibrium is reached. Already many relatively small-scale farm enterprises in the area are finding it difficult to remain sustainable under the impacts of salinity and associated land degradation problems.

The relatively rapid spread of salt-affected lands in the last 25 years, and limited likely success of vegetation-based strategies, have refocused attention on engineering solutions for the management of rising saline groundwater. Despite problems such as variability in drainage response and the relatively flat landscapes in the region, deep drains are increasingly being seen as viable. Drains now exist in almost every subcatchment in the wheatbelt; however, most have been constructed with limited planning, design, and construction guidelines and/or principles, and usually with little analysis or understanding of downstream effects.

This project, which follows on from the Avon Basin evaluation, is the first of its kind in the Blackwood Basin of WA. It evaluated farm and subcatchment scale artificial drainage together with subcatchment and regional-scale drainage discharge management strategies. The project was undertaken as a joint initiative between Water for a Healthy Country Flagship, CSIRO Land and Water, Engineering Evaluation Initiative, Department of Water, Western Australia.

The project aimed to improve understanding of streamflows and salinity in the Blackwood Basin and thus reduce uncertainty about regional approaches for salinity management. Specifically, using the results from predictive models, the project conducted:

- an evaluation of farm and subcatchment scale drainage, subcatchment and regional-scale drainage discharge management systems, and estimate their indicative and construction costs
- a cost-benefit analysis of water management options
- a preliminary environmental assessment of these options

This report summarises the main findings of this project. Chapter 2 outlines a brief methodology for the regional drainage evaluation of the Blackwood Basin. Chapter 3 describes main findings from various modelling scenarios including do nothing, drainage, climate and revegetation. Main findings from drainage discharge management options are presented in Chapter 4. Chapter 5 outlines main results of the economic analysis of drainage systems. Main findings from a feasibility study of an open channel between Lake Dumbleyung and Albany Highway are outlined in Chapter 6. This open channel was proposed by Central Great Southern Saline Land Recovery Committee (CGSSLRC). Main results from a preliminary assessment of the environmental impacts of various salinity mitigation options and modelling scenarios are presented in Chapter 7. Conclusions are presented in Chapter 8.

Further details and more results are presented in the final report (Ali et al., 2010) of this project.
2 Method

2.1 Model selection and calibration

The hydrological model used to predict flows and loads in the Blackwood Basin is called LArge Scale CATchment Model (LASCAM). LASCAM was developed for predicting the impact of climate and land use changes on fluxes of water, salt, sediment and nutrients in agricultural catchments. The model was modified to include estimates of lake storage, natural creek/stream/river flow and storages, and artificial drainage. These modifications were introduced for the study of the Avon Basin. GIS data were used to create maps showing basin and subcatchment boundaries as well as the drainage network, flow direction and drainage density. The Blackwood Basin was subdivided into 111 subcatchments ranging in size from 5 km$^2$ to 9 000 km$^2$ (Figure 2.1).

LASCAM was calibrated using historical (1970 to 2005) data about streamflow, stream salinity, evaporation and rainfall and other input and/or physical data from the Blackwood Basin such as GIS data, leaf area index, soil properties, and regolith depth. This was done to find a set of model parameters that would best describe what is actually observed in the Basin. Once determined, this set of parameters would be applicable across all subcatchments in the basin and provide a level of confidence in the quality of predictions on both gauged and ungauged subcatchments.

Before calibration, performance targets were set to determine if the model could successfully predict streamflow and salt load at a number of sites that had actual historic data. The targets were not designed to be absolute or prescriptive. The expectation is that the predictions at most sites will meet or exceed most of the targets. However, it is not realistic to expect that all targets will be met at all sites, or even that every site will meet some targets.

2.1.1 Calibration results

The calibrated model achieved most of the performance targets. Overall predictions of streamflows at 18 gauging stations were accurate, but their timing was not. However, although daily time steps were either too fast or too slow, monthly or annual predictions were much more accurate (Figure 2.2). This suggested that the model is able to predict long-term yields quite well right across the basin.

For salt load, there was an overall tendency towards under-prediction (Figure 2.2). In some cases this under-prediction stems, at least in part from under-predictions in streamflow. In other cases it is clear that insufficient salt is being generated. The calibration statistics for salt load are compromised to some extent by the limited amount of observed data for some gauging sites. Therefore the discrepancies between the model and observed salt loads may be due to model error, poor quality data, or, more likely, a combination of both.

Predictions for lake discharge and storage appear to match reasonably well with the observed data and anecdotal evidence (Figure 2.3). However, it is difficult to assess the quality of these predictions given there is little historical observation to validate lake storages and discharges.

For most of the gauged subcatchments, performance targets in this project greatly exceeded the prediction accuracy achieved by an earlier river basin modelling exercise. Given the overall acceptable results of the calibration and the limited nature of historical data, the model was found suitable for predicting the impacts of various drainage systems, revegetation and climate relative to a baseline scenario. It should be noted that LASCAM was not designed to resolve below the subcatchment level.

> Figure 2.1. Subcatchment delineation of the Blackwood Basin
The calibrated model generated a set of hydrological predictions for a ‘no drainage’ or baseline scenario. These predictions are made on the assumption that there is no effective or hydrologically significant artificial drainage in the catchment – previously constructed artificial drainage is ignored. For the no drainage scenario, the LASCAM runs were from 1965 to 2100. After 2005, the 28-year period of observed weather data from 1978 to 2005 was repeated about three-and-a-half times to extend it to 2100. This rainfall period (1978–2005) was used since it is now widely believed that the post-1975 climate represents current climate more closely than earlier years. Land use, vegetation cover and lake characteristics are assumed to remain at their 2005 levels. The outputs include predicted groundwater levels, streamflows, salt loads and lake overflow frequencies and volumes. These results are presented for five main catchments: the Coblinine River, the Arthur River, the Beaufort River and at Winnejup and Hut Pool on the Blackwood River. The output data for other subcatchments can be found in Ali et al. (2010). Model predictions are assessed for two future 28-year time periods, 2006–2033 and 2073–2100.

### 2.3 Water management scenarios

The model simulations under various water management scenarios are carried out in the same way as under the no drainage scenario. The simulations commence in 1965 and end in 2100 and include the same initial values and model parameters. Predicted hydrological impacts at the five key sites are compared against the no drainage scenario.

#### 2.3.1 Artificial drainage

Artificial drainage is assumed to commence in 1999 and the length of drainage in each drained subcatchment is assumed to increase annually until an assumed equilibrium year is reached. It was assumed that most subcatchments will reach recharge-discharge equilibrium by 2020 and some by 2060 as detailed in Ali et al. (2010).

The lengths of the artificial drains were estimated from the salt-affected area and assumed zone of effectiveness (ZOE, the distance from the drain (both sides) at which land is returned to productivity). The salt-affected areas in 1998 and at the new hydrological equilibrium were derived from an assumed proportion of Land Monitor hazard mapping. The Blackwood Basin was divided into three regions of different ZOE based on previous studies, farmer input and anecdotal evidence. The western region (subcatchments below 30) was assumed not to require artificial drainage due to higher topographic gradients and lower salinity risk. In each of the central and eastern regions, two ZOEs were assumed (a high and low ZOE) to test the sensitivity of the drainage effectiveness. Using the 1998 salt-affected area, 2157 km and 4314 km of drains are assumed to be required (assuming high and low ZOE, respectively). To estimate the artificial drainage lengths at the new hydrological equilibrium, 50% of the Land Monitor hazard mapping was assumed as salt-affected area. Using this salt-affected area, the total length of artificial drains required in future was estimated to be 6201 km and 12401 km (assuming high and low ZOE, respectively).
This project separately assessed the impacts of implementing open and leveed artificial drainage. Open drains are installed along the creek lines and as well as receiving and transporting drainage water, also admit and transport the natural flows generated through surface and subsurface runoff. The leveed drains are often installed adjacent to the natural creek and drainage lines. The levees prevent the admission of surface water into the drain. For each type of drain, the dimensions (for a given subcatchment) are the same and the equations governing the discharge of groundwater to the drains are also the same.

2.3.2 Arterial channels

To accommodate the large flow volumes and rates that will be expected from artificial drainage, arterial channels through main catchments of the Blackwood Basin will be required. The purpose of the engineered channels is to convey water, not to drain shallow groundwater (although that may occur over much of its length), nor principally to recover salinised land for agricultural production. Two types of arterial channels were modelled: open and leveed. An open arterial channel carries both surface runoff and drainage discharge from an artificial drainage system while a leveed arterial channel carries only drainage discharge from deep leveed drains. In designing the arterial channel network, it was assumed that the natural channel downstream of the confluence of the Arthur and Beaufort Rivers would be sufficient to cope with peak flows without the need for additional engineering and channel maintenance (Figure 2.4).

2.4 Woody perennials

Two revegetation scenarios are modelled in which the area of deep-rooted vegetation is either 50% or 100% of the total area of each subcatchment. Revegetation is assumed to occur at the beginning of 2001, and is implemented in the model as fully mature forests from the outset. The model takes no account of any biological growth limitations that may be imposed by the salinity of the landscape.

2.5 Climate impacts

The impacts of climate on the no drainage scenario are assessed by modelling one wetter climate and three drier climates. The wetter climate has rainfall that is 10% greater than the no drainage scenario and is typical of what might be expected if the region’s climate returns to pre-1975 conditions. The three drier climates assume rainfall which is 10%, 20% and 30% less than the historical rainfall used for the no drainage scenario. In all cases, the changed climate is applied from the beginning of the simulation period (1965).
2.6 Cost of drainage discharge management systems

The indicative excavation costs of various drainage discharge management systems were evaluated based on the estimated size of arterial channels and evaporation basins. The indicative sizes of these systems were estimated from model predictions of flow rates. The feasibility was carried out based on their construction costs alone. A full economic analysis considering various benefits and costs (construction, maintenance, water disposal, water treatment) was conducted as well (section 2.7).

2.7 Economic analysis

A summary of the area at risk of salinity that would be protected under the low-effectiveness drainage scenario for the Blackwood Basin is shown in Table 2.1. It highlights the potential agricultural income that could be lost as a result of dryland salinity in the Blackwood Basin over time. It is estimated that the Blackwood Basin is currently (2000 figures) losing $10.4 million per year in agricultural income from the central and eastern zones (Figure 2.5) and without intervention (deep drainage or other vegetative options) by 2020 this more than doubles to $20.7 million per year and by 2060 it triples to $31.1 million per year.

An economic analysis was conducted to better understand the costs and benefits associated with a variety of farm-based and arterial drainage options in managing dryland salinity in the Blackwood Basin and present a broad indication of the potential benefit from subcatchment and catchment-scale drainage systems. A Benefit Cost model was developed to review the potential economics of open and leveed drains together with various drainage discharge management strategies in two separate zones (central and eastern) of the Blackwood Basin. Costs included deep drainage construction and maintenance and the disposal of drainage water. Benefits included the agricultural income generated from land reclaimed from salinisation as a result of drainage and additional benefits associated with remnant vegetation and road reconstruction and maintenance protection.

The analysis was conducted over two investment periods, 20 and 60 years, dependent on the subcatchment and its projected time to hydrological equilibrium. The 20 and 60-year investment periods were modelled using estimates (based on Land Monitor valley hazard predictions) of drain lengths required to reclaim saline land and/or assist in controlling shallow groundwater during different investment periods. Benefit and cost assumptions were checked with government and industry representatives currently involved in deep drainage research and consultancy.

The Blackwood Basin was divided into three zones (eastern, central and western) based on artificial drainage requirements and drainage effectiveness (Figure 2.5). The central zone includes Narrogin, Wagin and Katanning and the eastern zone includes Dumbleyung and Nyabing. Due to low salinity risks in the western zone it was assumed that this zone will not require any artificial drainage. In the remaining two zones different drainage effectiveness was assumed based on findings from previous studies, anecdotal evidence and expert knowledge from hydrologists. For example, in the eastern zone a low drainage effectiveness (zone of effectiveness, ZOE) of 100 m and a high ZOE of 200 m was assumed on each side of an artificial drain (Figure 2.5).
The benefit cost ratio (BCR) is calculated as the ratio of the present value of the benefits (of the drainage system) to the present value of the costs (of the drainage system). The results of this analysis are measured by the net present value of the discounted cash flow of costs and benefits over a fixed time horizon. A BCR of one indicates that the project is breaking even at the chosen discount rate (5%), with a BCR less than one indicating that the project is not economically viable and a BCR greater than one, indicating that the project could provide a favourable economic return.

To assist with the interpretation of the analysis a “favourable” BCR return is considered to be a BCR equal to or greater than one. The BCRs reported in this analysis have been ‘normalised’ to provide an average BCR for each zone in each scenario. This normalised BCR takes account of the area of each of the subcatchments in making up the central and eastern zone. The economic analysis for this study includes individual agricultural production data for the central and eastern zones only.

A number of assumptions should be noted in regard to the analysis:

- The new hydrological equilibrium is reached in either 20 or 60 years dependent on the subcatchment.
- The BCRs are calculated over a 20 or 60-year period dependent on the subcatchment’s estimated time to hydrological equilibrium.
- Costs include drain costs, annual maintenance costs and, land remediation costs.
- Land already saline has a nominal value of $30/ha, representing a low-productivity saltland pasture grazing use of the land.
- Drain efficacy includes a ‘low’ and ‘high’ data set.
- The cashflows generated by the Benefit Cost Analysis are discounted at a rate of 5% over the life of the investment period.
- Adjacent land is returned to full agricultural productivity in the third year after the drains are installed.

- Agricultural production values represent average gross margin returns on a “typical farm” in the central and eastern zones, as confirmed by local agricultural consultants.
- Governance costs associated with a subcatchment-based drainage systems are not included in this analysis.
- Drainage costs are limited to those noted in this report and do not include potential additional costs such as associated engineering of road and rail intersections, fencing where required and the long term monitoring of flows and salt fluxes. The drainage costs included in the analysis do not include the potential full costs of deep drainage.

### 2.8 CGSSLRC channel feasibility

This part of the study, proposed by the Central Great Southern Salt Land Recovery Committee (CGSSLRC), assessed the feasibility of a channel between Lake Dumbleyung and the Albany Highway for discharging Lake Dumbleyung water into the Arthur River in an effort to freshen the lake over time. For this report this part of the study is termed as the CGSSLRC channel scenario.

The proposed CGSSLRC channel (length of 81 km) starts at the Lake Dumbleyung outlet and ends at the outlet of subcatchment 58 (Figure 2.4) where it discharges into the Arthur River at around 10 km downstream from the Albany Highway (Figure 2.6). The purpose was to assess the flow travel times for different rates of lake discharges, size of the open channel required to convey the lake discharges into the Arthur River, the impact of varying quantity and quality of lake discharges on salinities of the downstream Arthur and Blackwood Rivers and impacts of salt exports from Lake Dumbleyung and available natural longitudinal gradient. The reader is referred to Ali et al. (2010) for additional details of this feasibility study.
The key aim of the preliminary environmental impact assessment component of the Blackwood Regional Drainage Project was to assess the likely environmental impacts of various no drainage, drainage and climate change scenarios on the Blackwood River as a result of changes to the hydrologic regime of the Blackwood Basin. The environmental assessment was principally against flows and salinity and did not consider other issues such as clearing, acidity, nutrients, toxic metals, etc., and as such this section only deals with a fraction of what would constitute an environmental impact assessment.

The number of days that the FWS at particular locations of the main rivers was above certain ecologically important thresholds (1000, 2000, 4000, 10000 and 30000 g L⁻¹ TDS) was used to assess environmental impacts. Change in the number of river flow days under various scenarios was also used to assess ecological impacts on major rivers. Changes to the water regimes of regionally important wetlands within the basin were also assessed and the number of days each wetland was full, half full or empty was compared between different scenarios.

A flood risk analysis was carried out to assess changes in the various magnitude floods of selected ARI (Average Recurrence Interval) flow events under various scenarios.

The following list gives a brief description of the various drainage and climate scenarios used to assess environmental impacts. All scenarios, except the current situation, represent the first quarter of the twenty-first century (2006–2033):

- Current situation: historical data from 1978–2005 were used to define the current state of the Blackwood Basin
- No drainage: prediction of flows and loads assuming the current land use and climate remains unchanged over time
- Drainage SSe: high ZOE
- Drainage LB: high ZOE
- Drainage EB: high ZOE
- Wet climate: the no drainage scenario with a 10% increase in the rainfall
- Dry climate: the no drainage scenario with 10% decrease in the rainfall
- CGSSLRC: CGSSLRC channel options – the impacts of two water release rates from Lake Dumbleyung at two different salinity levels.

Locations on three major rivers were selected for assessing the impacts of various scenarios on river flow days and FWS and their likely environmental impacts:

- Blackwood River: Hut Pool (subcatchment 1 and basin outlet), Winnejup (subcatchment 22 outlet) and Boyup Brook (subcatchment 27 outlet)
- Arthur River: Moodiarrup (subcatchment 34 outlet) and Mount Brown (subcatchment 45 outlet)
- Beaufort River: Manywaters (subcatchment 59 outlet).

Five regionally important lakes of the Blackwood Basin were selected for assessing the changes in the hydroperiod (period of time a wetland contains water): Towerrinning, Toolibin, Norring, Dumbleyung and Coyrecup. A lake was described as full when it was filled with water at or above 90% of its dead storage capacity, half full when it was filled between 45% and 55% of its dead storage capacity or empty when it was filled at or below 10% of its dead storage capacity. A change in the number of days that results in a difference greater than 20% of the no drainage scenario is considered to be a significant environmental impact for the purpose of this study. A change of below 10% is considered to be a change that has a relatively low environmental impact.

Flood risk analysis was undertaken at four subcatchment outlets: Hut Pool and Winnejup on the Blackwood River, Mount Brown on the Arthur River and Manywaters on the Beaufort River. A subset of the five scenarios was used in this analysis: current conditions, no drainage (do nothing), Drainage SSe, Drainage LB and the wet climate.
3 Results

3.1 No drainage scenario

The calibrated model generated hydrological predictions for the no drainage (baseline) scenario in which nothing is done to treat dryland salinity – that is, no artificial drainage or any other salinity management strategy is implemented. These predictions enable the assessment of impacts of current and future salinity on streamflows, salt loads, salinity of major river systems and overflow frequency of major lakes. The no drainage scenario provided a benchmark against which we could assess the impacts of all drainage, revegetation and climate scenarios. In general, findings for the Blackwood Basin no drainage scenario reflect those for the Avon Basin.

3.1.1 Subcatchment-average groundwater trends

If nothing is done to treat dryland salinity how will regional groundwater levels and salinity change over time?

The groundwater depths predicted by LASCAM are averages over an entire subcatchment; they are not intended to be representative of any specific point in the subcatchment. Modelling of the no drainage scenario indicates that most of the subcatchments will exhibit continuing rises in average groundwater level, but at a slower rate than is currently occurring (Table 3.1). The maximum subcatchment-averaged rise in watertable over the course of the twenty-first century is 1.7 m, in the far east of the basin. However, almost all subcatchments experience at least slight rises in groundwater levels during that period. Likewise, groundwater salinities tend to increase over time in all subcatchments. There is a clear east-west gradient with the lowest values occurring in the lower Blackwood. Averaged over the entire basin, groundwater salinity increases from 20 g L$^{-1}$ to 25 g L$^{-1}$ between 2006 and 2100.

3.1.2 Streamflow

If nothing is done to treat dryland salinity how will streamflows change over time?

A consequence of the rising watertables is that streamflows increase over the simulation period under the no drainage scenario. Of the five key subcatchments, the lowest flows (per unit of catchment area) are for the Coblinine and Beaufort Rivers. Low yields in the Coblinine are a result of its generally dry climate, while low flows in the Beaufort are a consequence of its outlet being immediately downstream of a chain of salt lakes. Averaged over the entire basin, groundwater salinity increases from 20 g L$^{-1}$ to 25 g L$^{-1}$ between 2006 and 2100.

Eastern and central regions of the Blackwood Basin contribute very little flow to the basin outlet during the first quarter of the twenty-first century. Only about 23% of the basin’s site also increases slightly from 53% to 55%. By contrast, for Coblinine in the east of the basin, mean annual streamflow increases from 22 GL y$^{-1}$ to 27 GL y$^{-1}$ over the same period and the proportion of days with flow increases from 34% to 49%. These increases in streamflow occur because the shallower watertables are able to contribute more water to the streams. In the eastern and central subcatchments, increasing streamflows are also influenced by the increasing frequency and volume of lake discharges (section 3.1.4).

3.1.3 Salt loads

If nothing is done to treat salinity how will salt loads change over time?

The increasing discharge of deeper groundwater into shallower aquifers also has a considerable impact on stream salinity and salt loads under the no drainage scenario. This increased salinity is exacerbated by the rising watertables dissolving some of the substantial amounts of salt stored in the unsaturated zone. The rates of increase in salt loads are faster than the corresponding rates of increase in streamflows. As a consequence of this, flow-weighted salinities also increase. In the Arthur River, for example, flow-weighted salinities increase from 4.1 g L$^{-1}$ to 6 g L$^{-1}$ during the twenty-first century, while for the Coblinine, they increase from 5.4 g L$^{-1}$ to 9.3 g L$^{-1}$. These large increases in salinity in the eastern part of the catchment are associated with increases in the discharge of saline groundwater and from increased volumes and salinities of lake discharges.

At the basin outlet, the annual salt load increases by 23% (to 1154 kt y$^{-1}$) by the end of the 2006–2033 time period (Table 3.2). In contrast to the water yields, the upper 65% of the basin’s area produces about 50% of its salt load.

3.1.4 Lake volumes and loads

If nothing is done to treat salinity how will lake overflow frequencies and discharges change over time?

Increased flows are also manifest as increased frequencies and volumes of lake discharge under the no drainage scenario. Discharge frequencies increase over time for all but two of the non-terminal lakes, although neither of the previously identified terminal lakes (Taarblin and Dumbleyung) overflows in the final 28 years of the simulation period (Table 3.3). Several of the lakes that are near-terminal in the twentieth century fill quite frequently by the late twenty-first (e.g., Queerearrup, Norring). The large frequencies and volumes of discharge for the relatively small Lake Ewylamartup are because its inflow and discharge points are essentially at the same level. By the end of the century, all discharging lakes are predicted to have increased discharge salinities, which reflect the increased salinity of lake inflows.

Since the lakes discharge more frequently, it is no surprise that the mean annual discharge is also greatly increased. There are also increases in discharge salinity (flow-weighted), which reflect the increased salinity of lake inflows.
3.1.5 Summary of no drainage scenario

The foregoing sections have highlighted that the current hydrological state of the Blackwood Basin is not at equilibrium. We are in a phase of steadily increasing watertables, streamflows, lake storages and salt loads. These increases have been occurring in some parts of the basin since European settlement and are in response to the widespread replacement of native vegetation with shallow-rooted crops and pasture. The results for the no drainage scenario suggest that while these increases are expected to continue, the rates of increase are now slowing and that most parts of the catchment will – in the absence of further land management changes – reach equilibrium some time during the current century.

A consequence of this changing catchment behaviour is that in assessing the impacts of any future management or climatic changes, it would be misleading to compare those impacts with the current state of the catchment. Instead, comparisons should be made against the benchmark scenario that has been established here.

Table 3.1. Average groundwater characteristics for five regions for the no drainage scenario.

<table>
<thead>
<tr>
<th>Region (subcatchment range)</th>
<th>Rate of watertable rise (mm y(^{-1}))</th>
<th>Depth (m)</th>
<th>Salinity (g L(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Blackwood (1–21)</td>
<td>2.3</td>
<td>0.2</td>
<td>–5.6</td>
</tr>
<tr>
<td>Middle Blackwood (22–39)</td>
<td>1.8</td>
<td>0.4</td>
<td>–4.7</td>
</tr>
<tr>
<td>Arthur (40–57)</td>
<td>5.4</td>
<td>0.7</td>
<td>–4.8</td>
</tr>
<tr>
<td>Lower Beaufort (58–74)</td>
<td>5.1</td>
<td>0.5</td>
<td>–4.6</td>
</tr>
<tr>
<td>Coblinine (75–111)</td>
<td>9.5</td>
<td>1.2</td>
<td>–4.9</td>
</tr>
</tbody>
</table>

Table 3.2. Mean annual streamflow and mean annual salt load for five selected subcatchments over three time periods for the no drainage scenario.

<table>
<thead>
<tr>
<th>Location (subcatchment number)</th>
<th>Water (GL y(^{-1}))</th>
<th>Salt (kt y(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hut Pool (1)</td>
<td>494</td>
<td>1154</td>
</tr>
<tr>
<td>Winnejup (22)</td>
<td>220</td>
<td>981</td>
</tr>
<tr>
<td>Arthur River (40)</td>
<td>75</td>
<td>372</td>
</tr>
<tr>
<td>Beaufort River (58)</td>
<td>37</td>
<td>196</td>
</tr>
<tr>
<td>Coblinine River (79)</td>
<td>22</td>
<td>159</td>
</tr>
</tbody>
</table>

Note: kt y\(^{-1}\) is kilo tons per year

Table 3.3. Comparison of predicted lake discharge characteristics for two different 28-year time periods for the no drainage scenario.

<table>
<thead>
<tr>
<th>Lake</th>
<th>1978–2005</th>
<th>2073–2100</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Freq.</td>
<td>Discharge</td>
</tr>
<tr>
<td></td>
<td>(GL y(^{-1}))</td>
<td>(g L(^{-1}))</td>
</tr>
<tr>
<td>Towerrinning</td>
<td>3</td>
<td>0.16</td>
</tr>
<tr>
<td>Taartlin</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>Toolbin</td>
<td>2</td>
<td>0.24</td>
</tr>
<tr>
<td>Charing</td>
<td>1</td>
<td>0.38</td>
</tr>
<tr>
<td>Queerarrup</td>
<td>1</td>
<td>0.57</td>
</tr>
<tr>
<td>Noring</td>
<td>1</td>
<td>0.55</td>
</tr>
<tr>
<td>Quarring</td>
<td>2</td>
<td>0.52</td>
</tr>
<tr>
<td>Wagen</td>
<td>3</td>
<td>0.06</td>
</tr>
<tr>
<td>Gundaring</td>
<td>8</td>
<td>0.82</td>
</tr>
<tr>
<td>Dumbleyung</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>Coyrecup</td>
<td>3</td>
<td>0.80</td>
</tr>
<tr>
<td>Ewlyamartup</td>
<td>28</td>
<td>14.46</td>
</tr>
</tbody>
</table>
3.2 Water management scenarios

Water management scenarios for this project included artificial drainage at the farm and subcatchment scale. The various scenarios differ in type of drain used (open or leveed) used, assumed drain zone of effectiveness (high or low) and how the drainage discharge is conveyed (arterial channels) and managed. Drainage discharge management was of five different types:

- Drainage SSe: leveed and open farm and subcatchment drains with leveed and open arterial channels and storage of the drainage discharge in salt lakes up to existing discharge outlet heights (dead storage capacity)
- Drainage SSR: leveed and open farm and subcatchment drains with leveed and open arterial channels and storage of the drainage discharge in salt lakes up to raised discharge outlet heights (increased dead storage capacity)
- Drainage SSf: leveed and open farm and subcatchment drains with leveed and open arterial channels and storage of the drainage discharge in salt lakes assuming they are terminal
- Drainage EB: leveed farm and subcatchment drains with the retention of subcatchment drainage discharge in evaporation basins
- Drainage LB: leveed and open farm and subcatchment drains with leveed and open arterial channels assuming no lakes exist or lakes are bypassed (no salt lake storage).

In this section, these five drainage strategies are assessed. The impacts on streamflows, peak flows and salt loads are discussed. Only the main findings are presented in this summary; the reader is referred to Ali et al. (2010) for further details.

3.2.1 Impacts of Drainage SSe

What are the impacts of the Drainage SSe scenario on groundwater trends, streamflows, salt loads and lake overflow frequencies?

The Drainage SSe scenario is defined as the open farm and subcatchment-scale artificial drains together with open arterial channels with drainage discharge storage in the salt lakes up to their existing dead storage capacity. It may be assumed that these results are also appropriate for leveed artificial drainage.

In all subcatchments with artificial drainage, watertables are lower and reach an earlier maximum than in the no drainage scenario. The watertables then begin to decline towards a new, lower equilibrium value. Watertable response rates vary between subcatchments, with those having greater drain densities showing the fastest responses. By 2100, average watertable levels under Drainage SSe in the lower Beaufort region are almost one metre below their level in the no drainage scenario (Table 3.4).

Groundwater salinities are slightly reduced in this scenario. This is because the increased groundwater discharges are more saline than the (relatively unchanged) recharge, thus leading to a net freshening. Once again, the impact is greatest for subcatchments with large drainage densities. By 2100, under the assumption of high ZOE, average reductions in groundwater salinity exceed 1.0 g L⁻¹ for all three of the heavily drained upper regions and there are smaller reductions in the partially drained middle Blackwood (Table 3.4).

In the 102-year period of simulated artificial drainage from 1999 to 2100, cumulative streamflow increases by 7% for the Drainage SSe scenario compared to under the no drainage scenario (Table 3.5). This increase occurs in both high and low flow years and is greater towards the end of the simulation as drainage densities increase. In proportional terms, the differences between non-drained and drained cumulative discharges increase considerably in the upstream reaches of the basin. For the drainage SSe scenario, there is a 87% increase in total discharge between 1999 and 2100 for the Beaufort River and a 78% increase for the Coblinine River.

A persistent feature of the annual streamflow predictions is the steady increase over time of flow in the drains or channels. This is mainly a result of increasing drainage lengths across the catchment, but may also be attributed partly to continuing increases in watertable levels in many subcatchments, especially in the first half of the twenty-first century.

There are two main reasons for the observed moderately increased peak flows in the drainage scenarios (Table 3.5). One is that the artificial drainage scenarios are characterised by larger lake storages, and therefore larger and more frequent lake overflow events. The second reason for increased peak flow stems from the increased stream velocities in the engineered arterial channels. Increased velocities result in less stream evaporation and less attenuation through temporal spreading of the peak flow. In fact, tests of the drainage scenarios show that the second reason has greatest impact on the increases in peak flows in most subcatchments.

For the five featured subcatchments, the proportional increases in cumulative salt load under drainage are much greater than the corresponding increases in streamflow. For example, while the 2073–2100 streamflow under drainage increases at Hut Pool by 7% above the baseline, the corresponding increase in salt load is 66% (Table 3.5). There is a strong increasing trend in annual salt loads associated with the artificial drainage scenarios. The strength of the increasing trends in salt load, relative to those of streamflow suggests that streams will generally be more saline under artificial drainage than under the no drainage scenario, with stream salinity being limited either by groundwater salinity or by lake salinity.

The modelled lakes tend to discharge more frequently, at greater volumes and with greater salinity under artificial drainage than in the baseline scenario (Table 3.6). The Lake Taarblin and Lake Dumbleyung, predicted to be terminal without drainage, discharge in the Drainage SSe scenario.
Table 3.4. Rates of watertable rise for the Drainage SSe scenario, together with differences in final groundwater depth and salinity between the Drainage SSe scenario and the no drainage scenario averaged over five regions.

<table>
<thead>
<tr>
<th>Region (subcatchment range)</th>
<th>Rate of watertable rise (mm y^{-1})</th>
<th>Depth change (m)</th>
<th>Salinity change (g L^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2006–2033</td>
<td>2073–2100</td>
<td>2100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2100</td>
<td></td>
</tr>
<tr>
<td>High ZOE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower Blackwood (1–21)</td>
<td>2.4</td>
<td>0.2</td>
<td>0.0</td>
</tr>
<tr>
<td>Middle Blackwood (22–39)</td>
<td>1.5</td>
<td>0.3</td>
<td>0.0</td>
</tr>
<tr>
<td>Arthur (40–57)</td>
<td>3.2</td>
<td>–0.6</td>
<td>–1.0</td>
</tr>
<tr>
<td>Lower Beaufort (58–74)</td>
<td>–7.3</td>
<td>–0.7</td>
<td>–1.4</td>
</tr>
<tr>
<td>Coblinine (75–111)</td>
<td>4.9</td>
<td>0.0</td>
<td>–1.1</td>
</tr>
<tr>
<td>Low ZOE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower Blackwood (1–21)</td>
<td>2.4</td>
<td>0.2</td>
<td>0.0</td>
</tr>
<tr>
<td>Middle Blackwood (22–39)</td>
<td>1.5</td>
<td>0.4</td>
<td>0.0</td>
</tr>
<tr>
<td>Arthur (40–57)</td>
<td>4.2</td>
<td>–0.6</td>
<td>–0.7</td>
</tr>
<tr>
<td>Lower Beaufort (58–74)</td>
<td>–6.6</td>
<td>–0.8</td>
<td>–1.3</td>
</tr>
<tr>
<td>Coblinine (75–111)</td>
<td>5.8</td>
<td>0.4</td>
<td>–0.7</td>
</tr>
</tbody>
</table>

Table 3.5. Streamflows, salt loads and salinities for mean annual discharges and 10-year-return peak discharges for the Drainage SSe scenario, expressed as a proportion of the corresponding quantities under the no drainage scenario. Predictions are for the 2073–2100 period and drainage is assumed to have a high zone of effectiveness.

<table>
<thead>
<tr>
<th>Location</th>
<th>Mean Annual</th>
<th>10-Year-Return Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flow</td>
<td>Salt load</td>
</tr>
<tr>
<td>Hut Pool</td>
<td>1.07</td>
<td>1.66</td>
</tr>
<tr>
<td>Winnejup</td>
<td>1.17</td>
<td>1.77</td>
</tr>
<tr>
<td>Arthur River</td>
<td>1.10</td>
<td>1.38</td>
</tr>
<tr>
<td>Beaufort River</td>
<td>1.87</td>
<td>3.74</td>
</tr>
<tr>
<td>Coblinine River</td>
<td>1.78</td>
<td>3.10</td>
</tr>
</tbody>
</table>

Table 3.6. Comparison of predicted lake discharge characteristics for various drainage scenarios for the period 2073–2100.

<table>
<thead>
<tr>
<th>Lake</th>
<th>Freq.</th>
<th>Discharge (GL y^{-1})</th>
<th>Salinity (g L^{-1})</th>
<th>Freq.</th>
<th>Discharge (GL y^{-1})</th>
<th>Salinity (g L^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Drainage SSe (High ZOE)</td>
<td></td>
<td></td>
<td>Drainage SSe (Low ZOE)</td>
<td></td>
</tr>
<tr>
<td>Towerrinning</td>
<td>16</td>
<td>0.70</td>
<td>13.8</td>
<td>16</td>
<td>0.70</td>
<td>13.9</td>
</tr>
<tr>
<td>Taarblin</td>
<td>1</td>
<td>0.12</td>
<td>56.0</td>
<td>1</td>
<td>0.05</td>
<td>43.9</td>
</tr>
<tr>
<td>Toolibin</td>
<td>28</td>
<td>2.72</td>
<td>26.8</td>
<td>24</td>
<td>1.54</td>
<td>23.8</td>
</tr>
<tr>
<td>Charling</td>
<td>21</td>
<td>23.22</td>
<td>36.8</td>
<td>21</td>
<td>17.57</td>
<td>32.6</td>
</tr>
<tr>
<td>Queerarrup</td>
<td>22</td>
<td>24.46</td>
<td>35.4</td>
<td>22</td>
<td>18.81</td>
<td>31.1</td>
</tr>
<tr>
<td>Norring</td>
<td>22</td>
<td>22.70</td>
<td>38.6</td>
<td>22</td>
<td>17.02</td>
<td>34.9</td>
</tr>
<tr>
<td>Quarbing</td>
<td>25</td>
<td>21.49</td>
<td>40.2</td>
<td>24</td>
<td>15.89</td>
<td>37.1</td>
</tr>
<tr>
<td>Wagen</td>
<td>17</td>
<td>0.38</td>
<td>4.3</td>
<td>17</td>
<td>0.38</td>
<td>4.3</td>
</tr>
<tr>
<td>Gundaring</td>
<td>23</td>
<td>15.40</td>
<td>55.0</td>
<td>23</td>
<td>9.79</td>
<td>58.0</td>
</tr>
<tr>
<td>Dumbleyung</td>
<td>19</td>
<td>11.78</td>
<td>68.1</td>
<td>12</td>
<td>6.17</td>
<td>84.1</td>
</tr>
<tr>
<td>Coyrecup</td>
<td>28</td>
<td>8.53</td>
<td>22.0</td>
<td>28</td>
<td>6.19</td>
<td>18.2</td>
</tr>
<tr>
<td>Ewlyamartup</td>
<td>28</td>
<td>17.66</td>
<td>10.7</td>
<td>28</td>
<td>17.40</td>
<td>10.0</td>
</tr>
</tbody>
</table>

Drainage SSe (High ZOE) | Drainage SSe (Low ZOE) | Drainage SSr (High ZOE) | Drainage SSr (Low ZOE) | Drainage EB (High ZOE) | Drainage EB (Low ZOE) |

Table 3.6. Comparison of predicted lake discharge characteristics for various drainage scenarios for the period 2073–2100.
3.2.2 Impacts of Drainage SSf and Drainage SSr

These two drainage scenarios involve open farm and subcatchment-scale artificial drains together with open arterial channels with the options of reducing downstream flows of water and salt by increasing the storage capacity of the major lakes. It may be assumed that these results are also appropriate for leveed artificial drainage. In the first scenario, Drainage SSf, all 12 modelled lakes are made terminal by preventing all discharge of water downstream. In the second modelling strategy, Drainage SSr, the discharge height for all lakes is raised by 30 cm. The raised discharge heights mean that the lakes will have an increased dead storage capacity, but it remains possible that they may exceed this capacity and therefore discharge some water downstream. The second strategy will not be as severe as the first and it will also be more feasible from an engineering viewpoint.

What are the impacts of the Drainage SSf scenario on streamflows and salt loads?

The Drainage SSf scenario has flows reduced by less than 10% at three of the key subcatchments compared to the Drainage SSe scenario (Table 3.7). However, flow reductions for the Beaufort and Cobline River lie far outside this range at 29% and 53%, respectively. The reasons for these large reductions are that in each case, the nearest upstream lakes are frequent dischargers under the Drainage SSe scenario and provide a large proportion of the streamflow at the river outlets. Retention of this large fraction then leaves little water flowing in either river below the lakes. By contrast, under the Drainage SSe scenario the Arthur River receives only a single, small discharge event from Lake Taarblin in the period 2073–2100 and the removal of this discharge in the Drainage SSf scenario therefore has little impact.

At all sites (except Cobline), the retention of what are normally fairly saline lake discharges, leads to reductions in salt load that exceed those of streamflow (Table 3.6). As a consequence, stream salinities in the Blackwood and Beaufort Rivers under the Drainage SSf scenario are only 40–75% of those under the Drainage SSe.

What are the impacts of the Drainage SSr scenario on streamflows, salt loads and lake overflow frequencies?

The Drainage SSr scenario has considerably less impact than the Drainage SSf scenario on mean annual flows at the five main sites and practically no influence on mean annual salt loads (Table 3.7). The reason for the lack of impact on loads is that, despite the slightly increased lake losses of water to evaporation, the salt remains in storage in the lake and when the lake eventually overfills this slightly more concentrated salt discharges a similar mass, but dissolved in less water, than in the drainage scenario. Inevitably, this means that streamflows at the key sites are slightly more saline than in the Drainage SSe scenario.

In comparison with the Drainage SSe scenario, the Drainage SSr scenario has little effect in reducing the frequencies and volumes of lake overflows (Table 3.6). Discharge frequencies are unchanged for four of the lakes and only slightly reduced for the other eight. Discharge volumes decrease by less than 20% for most lakes. However, the slightly increased detention times lead to increases in discharge salinity for most lakes. The combination of slightly decreased discharge and slightly increased salinity means that for all lakes with substantial discharges (i.e., more than 1 GL y⁻¹, on average), the discharge of salt changes by less than 10% between the Drainage SSr and the Drainage SSe scenarios.

Table 3.7. Streamflows, salt loads and salinities for mean annual discharges and 10-year-return peak discharges for the Drainage SSf and Drainage SSr scenarios, expressed as a proportion of the corresponding quantities for the Drainage SSe. Predictions are for the 2073–2100 period and drainage is assumed to have a high zone of effectiveness.

<table>
<thead>
<tr>
<th>Location</th>
<th>Drainage SSf</th>
<th>Drainage SSr</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean Annual</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Flow</td>
<td>Salt load</td>
</tr>
<tr>
<td>Hut Pool</td>
<td>0.96</td>
<td>0.70</td>
</tr>
<tr>
<td>Winnejup</td>
<td>0.92</td>
<td>0.67</td>
</tr>
<tr>
<td>Arthur River</td>
<td>1.00</td>
<td>0.99</td>
</tr>
<tr>
<td>Beaufort River</td>
<td>0.71</td>
<td>0.28</td>
</tr>
<tr>
<td>Cobline River</td>
<td>0.47</td>
<td>0.52</td>
</tr>
<tr>
<td></td>
<td>10-Year-Return Peak</td>
<td></td>
</tr>
<tr>
<td>Flow</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Salt load</td>
<td>1.04</td>
<td>0.96</td>
</tr>
</tbody>
</table>

A Regional Drainage Evaluation for Blackwood Basin, Western Australia
3.2.3 Impacts of Drainage EB

The Drainage EB scenario involves retaining all drainage discharge from farm and subcatchment-scale leveed drainage in the subcatchments in which they are generated. This is done by constructing evaporation basins (EB) at subcatchment outlets. This option applies only to the leveed channel scenario, and not to the open channel scenario. In addition, the retention does not impact on flows in the natural creek channels, which continue to discharge to downstream subcatchments as before.

What are the impacts of the Drainage EB scenario on streamflows, salt loads and lake overflow frequencies?

Mean annual flow, under the Drainage EB scenario, is reduced at all sites compared with the Drainage SSe scenario (Table 3.8). The impacts on salt load are even greater; loads are reduced to between 20% and 45%. With the magnitude of the load reductions exceeding the magnitude of the flow reductions, stream salinities are reduced at all sites (by at least 30%). The largest reduction in salinity is 61% in the Beaufort River, just downstream of the freshened Lake Charling.

The Drainage EB scenario leads to reductions in peak flows of 30–50% upstream of Hut Pool and reductions in peak salt loads of at least 30%. In the Beaufort River there is a 92% decrease in the 10-year-return peak load, thanks to the near elimination (at the level of the 10-year-return peak) of saline discharge from Lake Charling.

In comparison with the Drainage SSe scenario, most lakes experience substantial reductions in predicted discharge frequency (Table 3.6). Two lakes (Taarblin and Dumbleyung) cease to discharge altogether, while Toolibin is reduced from discharging every year to discharging just three times in 28 years between 2073 and 2100. Annual lake discharge volumes also decrease substantially. The diversion of the saline drainage water away from the lakes also results in large decreases in the salinity of discharges for most lakes.

> Table 3.8. Streamflows, salt loads and salinities for mean annual discharges and 10-year-return peak discharges for the Drainage EB scenario, expressed as a proportion of the corresponding quantities for the Drainage SSe scenario. Predictions are for the 2073–2100 period and drainage is assumed to have a high zone of effectiveness.

<table>
<thead>
<tr>
<th>Location</th>
<th>Mean Annual</th>
<th>10-Year-Return Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flow</td>
<td>Salt load</td>
</tr>
<tr>
<td>Hut Pool</td>
<td>0.86</td>
<td>0.44</td>
</tr>
<tr>
<td>Winnerup</td>
<td>0.70</td>
<td>0.39</td>
</tr>
<tr>
<td>Arthur River</td>
<td>0.62</td>
<td>0.44</td>
</tr>
<tr>
<td>Beaufort River</td>
<td>0.48</td>
<td>0.18</td>
</tr>
<tr>
<td>Cobline River</td>
<td>0.41</td>
<td>0.21</td>
</tr>
</tbody>
</table>

3.2.4 Impacts of Drainage LB

This scenario assesses the impacts of the farm and subcatchment-scale leveed artificial drains together with leveed arterial channels assuming no storage of drainage discharge in the salt lake system, i.e., lake bypass (LB). The lakes are removed and the arterial channel is fully connected down to the junction of the Blackwood and Balgarup Rivers.

What are the impacts of the Drainage LB scenario on streamflows and salt loads?

In the absence of lakes, mean annual flow is greater at all locations compared to the Drainage SSe scenario (Table 3.9). This is because lake evaporation represents an important mechanism for loss of water from the catchment. The increases range from 9% for the Arthur and Coblineine Rivers to 83% at the Beaufort River. The large increase for the Beaufort River is largely due to the removal of the chain of large lakes immediately upstream.

Salt loads also increase in the absence of the lakes. That they are increasing at all suggests that under the drainage scenario, some lakes are still net accumulators of salt at the end of the current century. This, of course, will be true of the lakes that are terminal or near-terminal.

The combination of large increases in mean annual flow and smaller increases in mean annual salt load, mean that the flow-weighted salinity decreases at most sites. For the Beaufort River, the salinity in the absence of lakes is little more than half the salinity with lakes. The increase in salinity for the Arthur River is a consequence of the flows generated upstream of Lake Taarblin being more saline than the flows generated downstream (which constitute almost all the flow when lakes are included).

> Table 3.9. Streamflows, salt loads and salinities for mean annual discharges and 10-year-return peak discharges for the Drainage LB scenario (total discharges), expressed as a proportion of the corresponding quantities for the Drainage SSe. Predictions are for the 2073–2100 period and drainage is assumed to have a high zone of effectiveness.

<table>
<thead>
<tr>
<th>Location</th>
<th>Mean Annual</th>
<th>10-Year-Return Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flow</td>
<td>Salt load</td>
</tr>
<tr>
<td>Hut Pool</td>
<td>1.10</td>
<td>1.13</td>
</tr>
<tr>
<td>Winnerup</td>
<td>1.23</td>
<td>1.14</td>
</tr>
<tr>
<td>Arthur River</td>
<td>1.09</td>
<td>1.22</td>
</tr>
<tr>
<td>Beaufort River</td>
<td>1.83</td>
<td>1.16</td>
</tr>
<tr>
<td>Cobline River</td>
<td>1.09</td>
<td>1.02</td>
</tr>
</tbody>
</table>
3.3 Woody perennials

Two revegetation scenarios are modelled: 50% or 100% of the area of each subcatchment is planted with deep-rooted perennials. In modelling these scenarios, we recognise that revegetation on this scale is likely to be impractical throughout most of the Blackwood Basin and the scenarios are to be used as indicators only.

For the Blackwood Basin as a whole, the 50% revegetation scenario involves the replanting of 31% of the basin, while the 100% revegetation scenario involves replanting of a further 44% of the basin. However, these amounts are not distributed uniformly throughout the basin. In the lower Blackwood region, 83% of the area is already forested and since only one subcatchment is less than 50% forested, there is negligible replanting there in the 50% revegetation scenario. In contrast, the Arthur, lower Beaufort and Coblinine regions are currently only about 10% forested with no subcatchments currently having a 50% forest cover, so the 50% revegetation scenario in those catchments involves replanting of an additional 40% of their area.

3.3.1 Groundwater trends

How will revegetation affect groundwater levels and salinity?

Revegetation has a major impact on groundwater depths in all subcatchments that are currently comprised primarily of pasture and cropping land (Table 3.10). The assumption that the revegetated forests are fully mature in 2001 leads to immediate reductions in groundwater levels in all affected subcatchments. In the Arthur, lower Beaufort and Coblinine regions, the watertables are continuing to fall near the end of the century. In contrast, watertables in the two western regions are rising marginally faster between 2073 and 2100 than they are in the no drainage scenario. Nonetheless, their average watertable depths are lower. By 2100, the 100% scenario has predicted no drainage scenario for the three eastern regions, while the 50% scenario assessed in this report. However, these increases are not evident for the 50% revegetation scenario. In those catchments involving replanting of an additional 40% of their area.

Predicted groundwater salinities for the three eastern regions show substantial increases for the 100% revegetated scenarios, increases that are substantially greater than those for any other scenario assessed in this report. However, these increases are not evident for the 50% revegetation scenario. The substantial increases with 100% revegetation would appear to be caused by the substantial reductions in the volume of water held in the groundwater stores, reductions that are primarily attributable to the increased transpiration of the revegetated landscapes. Transpiration removes water from the ground, but leaves the salt behind, concentrating it in a smaller volume of water. It is interesting to note that while the clearing of native vegetation over the past 160 years has resulted in increased salinisation, so too does the wholesale reintroduction of similar land cover.

3.3.2 Streamflows, salt loads and lake overflow

How will revegetation affect streamflows, salt loads and lake overflow frequencies?

Revegetation of the catchment with woody perennials causes reductions in predicted mean annual streamflow at Hut Pool of 19% and 35% for the partial and full revegetation scenarios, respectively, over the period 2073–2100 (Table 3.11). Further upstream the impact of revegetation on streamflows is even greater. By the end of the century, streamflows in the other key catchments for the full revegetation option are less than 35% of those without revegetation. The impacts are not as severe for the Blackwood River at Hut Pool because much of the catchment area below Winnejup is already woodland and a large proportion of the flow there is generated from these wetter, forested parts of the far west of the basin.

For both revegetation scenarios, there is a substantial reduction in salt loads, and for all five subcatchments, the reductions are greater than the corresponding reductions in streamflow. Like the streamflow impacts, the salt loads predicted for the revegetation scenarios decrease over time. By the end of the twentieth century, salt loads discharging at Hut Pool are just 11% of the discharges in the no drainage scenario. Salt discharges from the other four subcatchments for the full revegetation scenario are less than 2% of the discharges in the no drainage scenario, with the lowest being 0.4% for the Beaufort River. The low salt loads are a consequence of the lower watertables being less able to discharge highly saline water to the surface, and of the reduced discharge frequencies and volumes from the modelled lakes.

Predictions of flow-weighted stream salinity for the full revegetation case are less than 0.3 g L\(^{-1}\) for the last 28 years of the simulation period for the four upstream sites, but interestingly are larger (0.5 g L\(^{-1}\)) at Hut Pool. Evidently groundwater remains a more important source of streamflow in the lower Blackwood than it does elsewhere in the catchment. However, the reverse is true for the 50% revegetation scenario, where Hut Pool (1.0 g L\(^{-1}\)) remains slightly less saline than the other four sites, which range up to 2 g L\(^{-1}\).

In comparison with the no drainage scenario, all modelled lakes have greatly reduced discharge frequencies in the revegetation scenarios as a consequence of the widespread reductions in inflow (Table 3.12). Four lakes in the Beaufort system (Charling, Queerearrup, Norring and Quarbing) become terminal under the partial revegetation scenario, as do Taarblin and Coyrecup. Under the full revegetation scenario, all lakes become terminal except for Towerrinning (which discharges rarely) and Ewlyamartup. The salinity of the revegetated lake discharges is also substantially less than those in the no drainage scenario. Reduced discharge frequencies mean longer residence times and more opportunity for evaporative concentration, but this is clearly more than offset by the large reductions in salt inflow.
Table 3.10. Rates of watertable rise for the 100% and 50% revegetation scenarios, together with differences in final groundwater depth and salinity between the revegetation scenarios and the baseline scenario averaged over five regions.

<table>
<thead>
<tr>
<th>Region (subcatchment range)</th>
<th>Rate of watertable rise (mm y$^{-1}$)</th>
<th>Depth change (m)</th>
<th>Salinity change (g L$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2006–2033</td>
<td>2073–2100</td>
<td>2100</td>
</tr>
<tr>
<td>100% revegetation scenario</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower Blackwood (1–21)</td>
<td>–4.9</td>
<td>0.3</td>
<td>–0.3</td>
</tr>
<tr>
<td>Middle Blackwood (22–39)</td>
<td>–76.0</td>
<td>0.6</td>
<td>–3.9</td>
</tr>
<tr>
<td>Arthur (40–57)</td>
<td>–102.7</td>
<td>–5.0</td>
<td>–5.7</td>
</tr>
<tr>
<td>Lower Beaufort (58–74)</td>
<td>–126.7</td>
<td>–7.1</td>
<td>–6.9</td>
</tr>
<tr>
<td>Coblinine (75–111)</td>
<td>–143.5</td>
<td>–16.6</td>
<td>–8.5</td>
</tr>
<tr>
<td>50% revegetation scenario</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower Blackwood (1–21)</td>
<td>2.2</td>
<td>0.2</td>
<td>0.0</td>
</tr>
<tr>
<td>Middle Blackwood (22–39)</td>
<td>–19.1</td>
<td>0.9</td>
<td>–1.0</td>
</tr>
<tr>
<td>Arthur (40–57)</td>
<td>–34.0</td>
<td>–1.9</td>
<td>–2.0</td>
</tr>
<tr>
<td>Lower Beaufort (58–74)</td>
<td>–44.1</td>
<td>–3.0</td>
<td>–2.6</td>
</tr>
<tr>
<td>Coblinine (75–111)</td>
<td>–48.7</td>
<td>–9.2</td>
<td>–3.4</td>
</tr>
</tbody>
</table>

Table 3.11. Streamflows, salt loads and salinities for mean annual discharges and 10-year-return peak discharges for the 50% and 100% revegetation scenarios, expressed as a proportion of the corresponding quantities without revegetation. Predictions are for the 2073–2100 period.

<table>
<thead>
<tr>
<th>Location</th>
<th>Mean Annual</th>
<th>10-Year-Return Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flow</td>
<td>Salt load</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hut Pool</td>
<td>0.81</td>
<td>0.30</td>
</tr>
<tr>
<td>Winnieup</td>
<td>0.57</td>
<td>0.19</td>
</tr>
<tr>
<td>Arthur River</td>
<td>0.51</td>
<td>0.13</td>
</tr>
<tr>
<td>Beaufort River</td>
<td>0.42</td>
<td>0.08</td>
</tr>
<tr>
<td>Coblinine River</td>
<td>0.37</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hut Pool</td>
<td>0.65</td>
<td>0.108</td>
</tr>
<tr>
<td>Winnieup</td>
<td>0.35</td>
<td>0.017</td>
</tr>
<tr>
<td>Arthur River</td>
<td>0.33</td>
<td>0.007</td>
</tr>
<tr>
<td>Beaufort River</td>
<td>0.24</td>
<td>0.004</td>
</tr>
<tr>
<td>Coblinine River</td>
<td>0.25</td>
<td>0.006</td>
</tr>
</tbody>
</table>

Table 3.12. Comparison of predicted lake discharge characteristics for two different revegetation scenarios for the period 2073–2100.

<table>
<thead>
<tr>
<th>Lake</th>
<th>50% revegetation</th>
<th>100% revegetation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Freq.</td>
<td>Discharge (GL y$^{-1}$)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Towerminiing</td>
<td>2</td>
<td>0.07</td>
</tr>
<tr>
<td>Taatlin</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>Toolin</td>
<td>1</td>
<td>0.01</td>
</tr>
<tr>
<td>Charling</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>Queerertup</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>Norring</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>Quarring</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>Wagn</td>
<td>1</td>
<td>0.00</td>
</tr>
<tr>
<td>Gundaring</td>
<td>2</td>
<td>0.08</td>
</tr>
<tr>
<td>Dumbleyung</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>Coyrecup</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>Ewlyamartup</td>
<td>28</td>
<td>9.00</td>
</tr>
</tbody>
</table>
3.4 Climate impacts

Climates that were wetter (10% greater rainfall) or drier (10%, 20% or 30% less rainfall) than the no drainage scenario were modelled. Only the wetter and driest scenario results are presented here.

3.4.1 Groundwater trends

How will changing climate affect groundwater levels and salinity?

In general, greater amounts of rain lead to greater recharge and therefore higher watertables (Table 3.13). The wetter climate also leads to a faster equilibration of watertable levels. By 2100, the predicted difference in watertable levels between the wettest and driest scenarios is greater for subcatchments in the east of the basin than it is for those in the west. This is exemplified by ranges in groundwater levels of 0.6 m for the lower Blackwood, but a range of 1.1 m for the drier Coblinine region. This wide range in the impact of climate differences is partly caused by a slower rate of response for the dry climates in what is already a dry part of the catchment.

Groundwater salinities in 2100 are slightly greater in the eastern regions under the wetter climate than under the no drainage climate. However, they are substantially smaller in all areas under the drier climate. The increased salinity in the wetter climate appears to be a short to medium consequence of the rises in water level being more rapid than those for drier climates. This leads to greater dissolution of mineral salt from the soil profile and results in increasing groundwater salinities. However, were the simulations carried on beyond 2100, it might be expected that the trend for increasing groundwater salinity with increasing climate wetness would reverse.

3.4.2 Streamflows, salt loads and lake overflow

How will changing climate affect streamflows, salt loads and lake overflow frequencies?

By the end of the current century, mean annual streamflows at the five key sites in the wetter climate are 40–100% greater than the no drainage case, while those for the driest climate are 80–95% less (Table 3.14). In the wetter climate scenario, salt load increases (in comparison with the unchanged climate of the no drainage scenario) are greater than the corresponding streamflow increases. As a consequence, flows are more saline under the wetter climate. For the driest climate scenario, however, salt load reductions are more substantial than streamflow reductions, so stream salinity decreases. This decrease in salinity is greatest in the Blackwood River. Between 2073 and 2100, flow-weighted salinity at Hut Pool in the drier climate is about 1.2 g L\(^{-1}\), less than half the salinity of the current climate and about one-third of the salinity of the wetter climate.

All lakes discharge more frequently for the wet climate scenario than for the no drainage scenario (Table 3.15). In the wetter climate scenario, no lakes remain terminal and all but three discharge at least every second year. The differences between the no drainage and drier scenarios are even starker. Only one lake (Ewlyamartup) discharges at all in the 28 year period in the driest scenario. All lakes have much greater discharges in the wetter climate than in the no drainage scenario, most by more than 300%. The wetter climate tends to have similar lake discharge salinities to the no drainage scenario; however, the combination of substantial flow increases and relatively unchanged salinity means that the lakes discharge considerably more salt in the wetter climate than in the no drainage scenario.

> Table 3.13. Rates of watertable rise for the wetter climate scenario and the 30% drier climate scenario, together with differences in final groundwater depth and salinity between the wetter and drier climate scenarios and the no drainage scenario averaged over five regions.

<table>
<thead>
<tr>
<th>Region (subcatchment, range)</th>
<th>Rate of watertable rise (mm (y^{-1}))</th>
<th>Depth change (m)</th>
<th>Salinity change (g L(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2006–2033</td>
<td>2073–2100</td>
<td>2100</td>
</tr>
<tr>
<td>Lower Blackwood (1–21)</td>
<td>2.3</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Middle Blackwood (22–39)</td>
<td>1.8</td>
<td>0.3</td>
<td>0.1</td>
</tr>
<tr>
<td>Arthur (40–57)</td>
<td>5.1</td>
<td>0.6</td>
<td>0.1</td>
</tr>
<tr>
<td>Lower Beaufort (58–74)</td>
<td>3.5</td>
<td>0.4</td>
<td>0.1</td>
</tr>
<tr>
<td>Coblinine (75–111)</td>
<td>7.9</td>
<td>1.1</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Wetter climate (10% increase in rainfall)

| Lower Blackwood (1–21)      | 0.8       | 0.5      | –0.5 | –1.5 |
| Middle Blackwood (22–39)    | –0.6      | 0.6      | –0.6 | –6.0 |
| Arthur (40–57)              | 3.3       | –0.4     | –0.6 | –5.8 |
| Lower Beaufort (58–74)      | 5.1       | 0.6      | –0.6 | –6.5 |
| Coblinine (75–111)          | 9.7       | –1.3     | –0.9 | –6.8 |

Drier climate (30% decrease in rainfall)
Table 3.14. Streamflows, salt loads and salinities for mean annual discharges and 10-year-return peak discharges for a climate that is 10% wetter or 30% drier, expressed as a proportion of the corresponding quantities for the current climate. Predictions are for the 2073–2100 period.

<table>
<thead>
<tr>
<th>Location</th>
<th>Mean Annual</th>
<th>10-Year-Return Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flow</td>
<td>Salt load</td>
</tr>
<tr>
<td>Hut Pool</td>
<td>1.43</td>
<td>1.81</td>
</tr>
<tr>
<td>Winnejup</td>
<td>1.56</td>
<td>1.89</td>
</tr>
<tr>
<td>Arthur River</td>
<td>1.49</td>
<td>1.50</td>
</tr>
<tr>
<td>Beaufort River</td>
<td>1.99</td>
<td>3.31</td>
</tr>
<tr>
<td>Coblinine River</td>
<td>1.71</td>
<td>1.82</td>
</tr>
</tbody>
</table>

Wetter climate (10% increase in rainfall)

<table>
<thead>
<tr>
<th>Location</th>
<th>Flow</th>
<th>Salt load</th>
<th>Salinity</th>
<th>Flow</th>
<th>Salt load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hut Pool</td>
<td>0.20</td>
<td>0.08</td>
<td>0.42</td>
<td>0.31</td>
<td>0.15</td>
</tr>
<tr>
<td>Winnejup</td>
<td>0.13</td>
<td>0.06</td>
<td>0.47</td>
<td>0.18</td>
<td>0.13</td>
</tr>
<tr>
<td>Arthur River</td>
<td>0.10</td>
<td>0.07</td>
<td>0.70</td>
<td>0.14</td>
<td>0.14</td>
</tr>
<tr>
<td>Beaufort River</td>
<td>0.07</td>
<td>0.03</td>
<td>0.50</td>
<td>0.13</td>
<td>0.12</td>
</tr>
<tr>
<td>Coblinine River</td>
<td>0.05</td>
<td>0.05</td>
<td>0.93</td>
<td>0.16</td>
<td>0.50</td>
</tr>
</tbody>
</table>

Drier climate (30% decrease in rainfall)

Table 3.15. Comparison of predicted lake discharge characteristics for two different climate scenarios for the period 2073–2100.

<table>
<thead>
<tr>
<th>Lake</th>
<th>10% wetter</th>
<th>30% drier</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Freq.</td>
<td>Discharge (GL yr⁻¹)</td>
</tr>
<tr>
<td>Towerrinning</td>
<td>19</td>
<td>0.96</td>
</tr>
<tr>
<td>Taarblin</td>
<td>1</td>
<td>0.09</td>
</tr>
<tr>
<td>Toolbin</td>
<td>12</td>
<td>1.05</td>
</tr>
<tr>
<td>Charling</td>
<td>18</td>
<td>20.95</td>
</tr>
<tr>
<td>Queererrrup</td>
<td>21</td>
<td>22.30</td>
</tr>
<tr>
<td>Norring</td>
<td>22</td>
<td>21.88</td>
</tr>
<tr>
<td>Quarbing</td>
<td>22</td>
<td>18.88</td>
</tr>
<tr>
<td>Wagan</td>
<td>17</td>
<td>0.41</td>
</tr>
<tr>
<td>Gundaring</td>
<td>23</td>
<td>15.51</td>
</tr>
<tr>
<td>Dumbleyung</td>
<td>12</td>
<td>11.47</td>
</tr>
<tr>
<td>Coyrecup</td>
<td>17</td>
<td>4.96</td>
</tr>
<tr>
<td>Ewlyamartup</td>
<td>28</td>
<td>24.11</td>
</tr>
</tbody>
</table>

Lake Dumbleyung (Photo: Department of Water, Western Australia)
3.5 Summary of catchment scenarios

How will groundwater trends vary between all scenarios?
- The artificial drainage scenarios lower groundwater levels and salinities in the drained subcatchments; the degree and rapidity of these responses largely depends on drain density and zone of effectiveness.
- Full revegetation of the catchment with woody perennials causes substantial falls in watertables but substantial increases in groundwater salinity.
- Drier climates lead to lower watertables and slower watertable responses than wetter climates.
- In the short to medium term, wetter climates give rise to greater groundwater salinities than drier climates.

How will streamflow and salt load vary between all scenarios?
- There is negligible difference in flows and loads between the open drainage scenario and the sum of the leveed and natural channel flows in the leveed drainage scenarios.
- Artificial drainage leads to modest increases (up to 7%) in flow at the catchment outlet and to more substantial increases (up to 66%) in salt load.
- The scenarios with high zones of effectiveness typically produce more streamflow and salt load than the scenarios with low zones of effectiveness.
- Revegetation reduces streamflows substantially and the magnitude of these changes increases with time. While peak flows are also reduced, this reduction is less than the reduction in mean annual flows.
- Full revegetation leads to enormous reductions in stream salt load and salinity.
- Streamflows and salt loads are greater for the wetter climates than for the drier climates.

How will lake discharge and salinity vary between all scenarios?
- Artificial drainage increases the frequency, volume and salinity of lake discharges.
- The wetter climate leads to increases in lake discharge occurrences, volumes and salt loads, but has little effect on lake discharge salinity.
- The driest climate leads to an almost complete cessation of discharge from all lakes.
- Revegetation reduces the frequency, volume and salinity of lake discharges.

How will different drainage discharge management systems affect streamflow and salt load?
- Mitigation of the impacts of artificial drainage by preventing the lakes from discharging (SSf) is effective in reducing streamflows, salt loads and salinities in most downstream subcatchments, except for those downstream of terminal lakes. This retention scheme also leads to modest reductions in peak flows in lower parts of the catchment and larger reductions in the Beaufort and Coblinine Rivers.
- Mitigation of the impacts of artificial drainage by elevating the discharge height of the lakes by 0.3 m (SSr) has little effect in reducing streamflows, salt loads and flow salinity in most downstream subcatchments. It leads to modest reductions in lake discharge frequencies and volumes for some lakes, but to slight increases in discharge salinity.
- Mitigation of the impacts of leveed drainage by retaining the leveed channel flows in evaporation basins (EB) within the subcatchment in which they are generated is highly effective in reducing flows, loads and salinities in both streams and lake discharges. It is also effective in reducing peak streamflows and salt loads.
- Mitigation of the impacts of artificial drainage by complete elimination of the lakes (LB) leads to moderate increases in streamflow (including peak flow events) and slight increases in salt load, but has little impact on stream salinity in downstream subcatchments.
4 Drainage discharge management options

Various drainage discharge management strategies are assessed on the basis of their construction costs alone. Options include arterial systems (both open and leveed channels) and subcatchment retention (evaporation basins).

4.1 Leveed and open arterial drainage discharge management

An arterial or conveyance channel is engineered with the prime function of conveying surface runoff and/or drainage water received from subcatchment-scale leveed and open drainage to downstream locations. Such a channel may also lower the water table in the adjacent areas depending upon its depth and that of the surrounding groundwater system. Three arterial channel management strategies were assessed on the basis of construction costs alone: an open arterial system with salt lake storage, a leveed arterial system with salt lake storage and a leveed arterial system without salt lake storage.

What are the likely costs of different arterial channel drainage discharge management systems?

In total 11 arterial channel sections or reaches were assumed for this study (Figure 2.4). Their lengths vary depending on the size and number of subcatchments involved and the alignment and meandering of the natural creeks/streams/rivers within these subcatchments. The size of arterial channels in various sections was estimated using LASCAM outputs (daily peak flows of 1 in 10 years). The indicative excavation costs were then estimated based on their required size (Table 4.1). The main assumptions related to the excavation cost of arterial channels were:

- The cost estimates represent excavation costs only.
- No road and railway crossing (bridges and culverts) and maintenance costs are included.
- The same unit construction costs are applied to both leveed and open arterial channels.
- The construction costs are applied uniformly across all sections of the arterial channels.
- Accessibility, mobilisation, soil types, waterlogging, etc are not considered in these cost estimates and therefore the actual construction costs may differ from these indicative estimates depending on the field conditions.
- Extra protective banks, that may be required near towns, are not included in the cost estimates.
- The construction cost for an arterial channel of 1.5 to 2.5 m depth is $1.50/m³.
- The construction cost for an arterial channel of 2.5 to 3 m depth is $1.75/m³.

- The construction cost is increased by 50% from $1.75/m³ to $2.625/m³ if the top width is greater than 10 m due to double handling of the soil.
- The cost of shaping of batters, if required, is not included.
- The cost impact of using bulldozers and scrapers for larger channels depending on the field conditions and accessibility is not considered.
- No blasting costs, that may be required to cut the channels through rock formations, are included.
- Site investigation costs (soil testing, drilling, monitoring, surveying, etc.) are not included.

To manage the drainage discharge from subcatchment-scale leveed drainage systems during first 25 years of the twenty-first century the estimated construction cost of leveed arterial channels is likely to be about $9 million (Table 4.1). For managing the drainage discharge during 2073–2100, the estimated excavation cost is around $11 million if these channels are constructed new (assuming the previously constructed channels were filled-in completely). Because of the small differences in the size of channels required during the first and last quarters of the twenty-first century, the preferred option will be to construct these such that they have enough capacity to handle drainage discharge for the next 100 years.

The total indicative excavation cost of leveed arterial system (LB) is around $14 million (Table 4.1) for managing the drainage discharge from subcatchment-scale leveed drainage systems during first 25 years of the twenty-first century (2006–2033). To manage the drainage discharge during 2073–2100, a bigger size leveed arterial system will be required and an estimate of its total excavation cost is around $19 million, assuming the construction of new channels. The cost associated with remodelling, of previously constructed channels to increase their size, is not assessed; however, it is very likely that these costs will be substantially less than the costs for excavating a brand new arterial system.

Total indicative excavation cost of an open arterial system (SSe) will be around $45 million for managing the drainage discharge and surface runoff during 2006–2033 (Table 4.1). Around $61 million will be required for excavating a larger open arterial system to manage both drainage discharge and surface runoff during 2073–2100, assuming the construction of a brand new system.
> Table 4.1. Size and excavation cost of arterial channels with various salt lake storage options.

<table>
<thead>
<tr>
<th>Channel section</th>
<th>Total length (km)</th>
<th>Channel size (2006–2033)</th>
<th>Total cost ($ million)</th>
<th>Channel size (2073–2100)</th>
<th>Total cost ($ million)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Bed width (m)</td>
<td>Channel depth (m)</td>
<td>Bed width (m)</td>
<td>Channel depth (m)</td>
</tr>
<tr>
<td>Leveed arterial system with salt lake storage (SSe) option</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arthur River Upper (A1)</td>
<td>65</td>
<td>3.3</td>
<td>2.2</td>
<td>0.94</td>
<td>3.3</td>
</tr>
<tr>
<td>Arthur River Mid (A2)</td>
<td>49</td>
<td>8.8</td>
<td>2.0</td>
<td>2.52</td>
<td>9.9</td>
</tr>
<tr>
<td>Arthur River Lower (A3)</td>
<td>18</td>
<td>13.2</td>
<td>1.6</td>
<td>1.06</td>
<td>14.3</td>
</tr>
<tr>
<td>Arthur River Lower (A4)</td>
<td>13</td>
<td>18.7</td>
<td>1.7</td>
<td>1.13</td>
<td>19.8</td>
</tr>
<tr>
<td>Hillman River (ABr1)</td>
<td>20</td>
<td>2.2</td>
<td>2.3</td>
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</tr>
<tr>
<td>Dongolocking</td>
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<td>1.1</td>
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<td>Cobline (C1)</td>
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<tr>
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</tr>
<tr>
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<td>0.47</td>
<td>1.1</td>
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<td>4.4</td>
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<td>0.73</td>
<td>7.7</td>
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<tr>
<td>Carlecatup Creek (BBr1)</td>
<td>32</td>
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<td>2.4</td>
<td>0.39</td>
<td>6.6</td>
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<td>Total cost ($ million)</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Leveed arterial system without salt lake storage (LB) option</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arthur River Upper (A1)</td>
<td>65</td>
<td>3.3</td>
<td>2.2</td>
<td>0.94</td>
<td>3.3</td>
</tr>
<tr>
<td>Arthur River Mid (A2)</td>
<td>49</td>
<td>9.9</td>
<td>1.9</td>
<td>2.65</td>
<td>11.0</td>
</tr>
<tr>
<td>Arthur River Lower (A3)</td>
<td>18</td>
<td>13.2</td>
<td>1.6</td>
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<td>2.3</td>
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<td>2.2</td>
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<td>5.5</td>
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<td>2.58</td>
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<tr>
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<td>2.39</td>
<td>17.6</td>
</tr>
<tr>
<td>Carlecatup Creek (BBr1)</td>
<td>32</td>
<td>2.2</td>
<td>2.4</td>
<td>0.39</td>
<td>6.6</td>
</tr>
<tr>
<td>Total cost ($ million)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>13.6</td>
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<tr>
<td>Open arterial system with salt lake storage (SSe) option</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Arthur River Upper (A1)</td>
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<td>2.4</td>
<td>4.30</td>
<td>18.7</td>
</tr>
<tr>
<td>Beaufort River Lower (B2)</td>
<td>36</td>
<td>22.0</td>
<td>2.0</td>
<td>4.73</td>
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<tr>
<td>Carlecatup Creek (BBr1)</td>
<td>32</td>
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<td>1.6</td>
<td>2.69</td>
<td>27.5</td>
</tr>
<tr>
<td>Total cost ($ million)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>44.8</td>
</tr>
</tbody>
</table>

Note: The construction cost for the 2073–2100 period assumes the construction of a brand new channel. It is assumed that the previously constructed channels do not exist any more. The construction cost during 2073–2100 is not applicable where the channels were constructed during 2006–2033 and their sizes remained unchanged over time. The cost of remodelling previously constructed channels is likely to be significantly less than that for the new channel which is a highly likely and practicable option.
An alternative for managing the drainage discharge from farm and subcatchment-scale leveed artificial drainage systems, is to build evaporation basins within each subcatchment. Under this scenario any drainage discharge generated within a subcatchment will not flow beyond its outlet. By managing the drainage discharge at subcatchment outlets, the arterial drainage system will not be required and most downstream hydrological and ecological impacts of drainage discharge can be avoided. This part of the study looked at the technical feasibility, size requirements and indicative construction costs associated with the construction of such evaporation basins.

**What are the likely costs of subcatchment-scale evaporation basins as a drainage discharge management system?**

The evaporation basin sizes were estimated using the net evaporative loss and design inflow rates. Design annual inflow rates were determined for two periods, 2006–2033 and 2173–2100. Two levels of drainage water salinity (10 000 mg L\(^{-1}\) and 50 000 mg L\(^{-1}\)) were assumed when determining the size of evaporation basins as the size is also impacted by the salinity of the water stored in the evaporation basins.

The size of the evaporation basins varies significantly among subcatchments depending on the evaporative loss, design inflow and assumed salinity of the drainage water (Figure 4.1). In general, larger-sized basins will be required in the central region due to low evaporative loss and high rainfall and smaller basins in the eastern region due to high evaporative loss and low rainfall. Larger basins will be required during the last quarter of the twenty-first century as compared to the size required during the first quarter of the twenty-first century.

The indicative construction costs of the evaporation basins were estimated from their size based on the following assumptions:

- The indicative construction cost is $10,000 per ha of basin area.
- This cost is uniformly applicable across all subcatchments where the evaporation basins will be required.
- The cost is not dependent on soil type, landscape, groundwater level, permeability, allowable leakage, size, etc. The actual construction cost may vary considerably from the assumed cost depending on the field conditions and a multitude of other factors.
- The construction cost estimates do not include any planning, design, operation and maintenance costs.
- The salt disposal costs are not included in the indicative cost estimates.

A number of subcatchments that contain lakes will not require evaporation basins and therefore had zero costs. The indicative construction cost of evaporation basins varies greatly among subcatchments depending on their required size (Figure 4.2). Their cost varies from as low as $0.1 million to as high as $36 million in various subcatchments. The total indicative construction cost of evaporation basins is expected to be around $445 million during the first quarter of the twenty-first century assuming the salinity of the drainage water as 10 000 mg L\(^{-1}\). This cost will increase to around $770 million if the salinity of the drainage water is assumed to be 50 000 mg L\(^{-1}\). These indicative construction costs are extremely high and seem prohibitive and are much higher than the construction cost of arterial systems for drainage discharge management.

Of the three systems assessed and based on excavation costs only, the leveed arterial system with salt lake storage option is least expensive. However, this option assumes that the drainage discharge will be allowed to enter and be stored in all salt lakes encompassing the region.

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> Figure 4.1. Evaporation basin size required in various subcatchments of the Blackwood Basin during 2006–2033 assuming the salinity of the drainage water as 10 000 mg L\(^{-1}\) (left) and 50 000 mg L\(^{-1}\) (right).

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> Figure 4.2. Indicative construction cost of evaporation basins in various subcatchments of the Blackwood Basin during 2006–2033 assuming salinity of the drainage water to be stored in the evaporation basins as 10 000 mg L\(^{-1}\) (left) and 50 000 mg L\(^{-1}\) (right).
5 Economic analysis of drainage systems

This analysis utilised a spreadsheet model which investigated the costs and benefits associated with a number of different drainage options over two different time horizons (20 and 60-year time periods) dependent on the hydrology of the subcatchment at a discount rate of 5% per year. The benefit cost ratio (BCR) is calculated as the ratio of the present value of the benefits (of the drainage system) to the present value of the costs (of the drainage system). A BCR of one indicates that the project is breaking even at the chosen discount rate (5%), with a BCR less than one indicating that the project is not economically viable and a BCR greater than one, indicating that the project could provide a favourable economic return.

The BCRs reported in this analysis have been ‘normalised’ to provide an average BCR for each zone in each scenario.

In reviewing the BCR results a ‘benchmark scenario’ (scenario 10) was assessed to be the most objective reference point in analysing the results. Scenario 10 is based on medium costs and medium drainage benefits (agricultural benefits only) and is believed to provide a balanced assessment of deep drainage economics in the Blackwood Basin over a 20–60 year investment period. Two additional indicator scenarios are also illustrated in the report – scenario 14 (high benefits and low costs) and scenario 18 (low benefits and high costs).

The wide variation in BCR returns across the Blackwood region suggests that it may be difficult to implement a profitable regional drainage scheme across the entire catchment. Open and leveed drains with no disposal costs potentially provide the most consistent favourable returns for all the drainage options for the remediation of rising groundwaters in the Blackwood Basin (Table 5.1). However, it is important to note that this report does not consider the economic or environmental consequences of disposing of drainage waters into local creek lines (i.e., the ‘no disposal cost option’), and therefore the BCRs stated in this option may be strongly overstated in terms of their economic potential.

Open and leveed drains with arterial connections for the disposal of drainage waters are unlikely to be an economic option for rising groundwater remediation across the Blackwood Basin given their high capital and maintenance costs and the substantial water disposal costs associated with arterial drains. Farm and subcatchment-scale drains with evaporation basins are also not considered from the analysis to be an economically viable drainage option.

The analysis highlights the significant impact of drainage costs and potential gross margins received on land returned to production, on the potential favourability of the investment returns from deep drainage for subcatchments in the Blackwood Basin.

In general the BCR returns on leveed drains were typically more favourable than for open drains across the benchmark scenarios. This is largely due to the higher annual maintenance costs associated with open drains. In addition, for most scenarios, the eastern zone provided higher BCR returns across all drain types modelled than the central zone, with eastern zone 2060 drainage options providing more favourable BCR returns than eastern zone 2020 drainage options.
Table 5.1. Synopsis of main results of the economic analysis.

<table>
<thead>
<tr>
<th>Normalised BCR results by scenario</th>
<th>Central zone</th>
<th>Eastern zone</th>
<th>Eastern zone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2020L</td>
<td>2020H</td>
<td>2060L</td>
</tr>
<tr>
<td>Open drain with no disposal costs</td>
<td>1.38</td>
<td>2.51</td>
<td>1.52</td>
</tr>
<tr>
<td>Leveed drain with no disposal costs</td>
<td>1.57</td>
<td>2.83</td>
<td>1.74</td>
</tr>
<tr>
<td>Open drain with arterial connection</td>
<td>0.25</td>
<td>0.61</td>
<td>0.32</td>
</tr>
<tr>
<td>Leveed drain with arterial connection</td>
<td>0.49</td>
<td>1.15</td>
<td>0.62</td>
</tr>
<tr>
<td>Leveed drain /arterial and evaporation basin</td>
<td>0.06</td>
<td>0.16</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Scenario 10 (medium costs and medium benefits)

| Open drain with no disposal costs | 3.42        | 7.14         | 4.04         | 8.33         | 5.78         | 11.98        |
| Leveed drain with no disposal costs| 3.36        | 7.09         | 4.02         | 8.36         | 7.10         | 14.86        |
| Open drain with arterial connection| 0.63        | 1.58         | 0.82         | 1.92         | 1.08         | 2.59         |
| Leveed drain with arterial connection| 1.48        | 3.71         | 2.01         | 4.70         | 2.32         | 5.54         |
| Leveed drain/arterial and evaporation basin | 0.14       | 0.36         | 0.18         | 0.42         | 0.55         | 1.30         |

Scenario 14 (low costs and high benefits)

| Open drain with no disposal costs | 0.44        | 0.79         | 0.48         | 0.82         | 0.66         | 1.25         |
| Leveed drain with no disposal costs| 0.59        | 1.01         | 0.63         | 1.03         | 1.15         | 2.03         |
| Open drain with arterial connection| 0.08        | 0.18         | 0.09         | 0.21         | 0.14         | 0.33         |
| Leveed drain with arterial connection| 0.13        | 0.30         | 0.16         | 0.34         | 0.25         | 0.56         |
| Leveed drain/arterial and evaporation basin | 0.02       | 0.06         | 0.03         | 0.07         | 0.09         | 0.21         |

Note: L (low drainage effectiveness or ZOE); H (high drainage effectiveness); numbers in blue indicate BCRs at or above break even and in red show BCRs below break even.
The feasibility of an open channel between Lake Dumbleyung and the Albany Highway was assessed to evaluate the impact of varying quantity and quality of lake discharges on salinities of the downstream Arthur and Blackwood Rivers and the impacts of salt exports from Lake Dumbleyung on its salt balance. The proposal for this assessment was put forward by the Central Great Southern Salt Lands Recovery Committee (CGSSLRC).

**What is the feasibility of the CGSSLRC channel?**

The impacts of lake discharges on the flow-weighted salinity (FWS) of the Arthur and Blackwood Rivers will depend on both the rates of lake water discharge and their salinity levels (Table 6.1). It is predicted that the FWS of the Blackwood River at Hut Pool will increase almost 2.6 times compared to that under the Drainage SSe scenario if lake water with a 20 g L\(^{-1}\) concentration level is discharged at a daily rate of 0.65 GL. This means that the release of Lake Dumbleyung water into the Arthur River may result in adverse environmental impacts downstream. The main purpose of the lake water discharge is to export salts stored within Lake Dumbleyung. This purpose is likely to be fulfilled only if the concentration level of the lake discharge is at or above 50 g L\(^{-1}\) and it is released at a daily rate of 0.65 GL for about 30 days every second year; but this will have a substantial impact on downstream water quality. In light of the negative results from this feasibility study, the CGSSLRC is considering other options for the conveyance of lower salinity waters past the salt stored in Lake Dumbleyung with the aim of freshening downstream Wagin lakes.

<table>
<thead>
<tr>
<th>Salinity (g L(^{-1})) of lake water released into the Arthur River via CGSSLRC channel</th>
<th>Winter FWS (g L(^{-1})) of the River after the release of 1.29 GL day(^{-1})</th>
<th>Net Increase in FWS (g L(^{-1})) after the discharge of Lake Dumbleyung water</th>
<th>Winter FWS (g L(^{-1})) of the River after the release of 0.65 GL day(^{-1})</th>
<th>Net increase in FWS (g L(^{-1})) after the discharge of Lake Dumbleyung water</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Arthur River</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>12.1</td>
<td>7.0</td>
<td>9.6</td>
<td>4.5</td>
</tr>
<tr>
<td>30</td>
<td>17.4</td>
<td>12.3</td>
<td>13.3</td>
<td>8.2</td>
</tr>
<tr>
<td>40</td>
<td>22.3</td>
<td>17.2</td>
<td>16.7</td>
<td>11.6</td>
</tr>
<tr>
<td>50</td>
<td>27.3</td>
<td>22.2</td>
<td>20.0</td>
<td>14.9</td>
</tr>
<tr>
<td><strong>Blackwood River at Winnejup</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>10.8</td>
<td>6.0</td>
<td>8.6</td>
<td>3.8</td>
</tr>
<tr>
<td>30</td>
<td>14.8</td>
<td>10.0</td>
<td>11.2</td>
<td>6.3</td>
</tr>
<tr>
<td>40</td>
<td>18.7</td>
<td>13.9</td>
<td>13.6</td>
<td>8.8</td>
</tr>
<tr>
<td>50</td>
<td>22.7</td>
<td>17.9</td>
<td>16.1</td>
<td>11.3</td>
</tr>
<tr>
<td><strong>Blackwood River at Hut Pool</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>7.2</td>
<td>4.5</td>
<td>5.4</td>
<td>2.6</td>
</tr>
<tr>
<td>30</td>
<td>9.9</td>
<td>7.1</td>
<td>6.9</td>
<td>4.1</td>
</tr>
<tr>
<td>40</td>
<td>12.5</td>
<td>9.7</td>
<td>8.4</td>
<td>5.7</td>
</tr>
<tr>
<td>50</td>
<td>15.1</td>
<td>12.3</td>
<td>9.9</td>
<td>7.2</td>
</tr>
</tbody>
</table>

Note: The net increase is increase in the salinity of the Arthur River, above that under the open drainage scenario, due to the discharge of lake water.
7 Preliminary assessment of environmental impacts

This part of the study evaluated the preliminary environmental impacts resulting from various salinity mitigation and climate change scenarios against data from the current condition of the Blackwood Basin and the no drainage scenario. The study did not consider other issues (such as clearing, acidity, nutrients, toxic metals, etc.) and as such, only deals with a fraction of what would constitute an environmental impact assessment.

What are the preliminary environmental impacts associated with various drainage discharge management scenarios?

Moderate increases in the flows and FWS are expected during the first quarter of the twenty-first century under the no drainage scenario for all subcatchments assessed. The Drainage EB scenario is predicted to cause the least change, while the Drainage SSe, Drainage LB and CGSSLRC release options are all predicted to increase both flows and FWS significantly during the first quarter of the twenty-first century in lower parts of the Blackwood Basin. The wet climate scenario is predicted to cause small increases to flows and moderate increases to FWS thresholds; while the dry climate scenario is predicted to result in moderate reductions in both flows and FWS.

The number of river flow days at all FWS thresholds are predicted to increase under the Drainage SSe and Drainage LB scenarios and are expected to significantly impact all elements of the ecosystem within the Blackwood River (a significant impact is defined as a scenario that has more than 20% change in FWS when compared to the no drainage scenario) (Figure 7.1). A reduction in overall species richness of algae, aquatic plants, micro invertebrates and invertebrates could be expected. Importantly for the Hut Pool area, this could also have an impact on the remaining riparian vegetation of the Blackwood River. As the number of days of FWS at or above 2 000 mg L\(^{-1}\) increases, the overall health of the riparian vegetation would be expected to deteriorate. Further environmental degradation in this area could have major environmental implications to the local region.

The wetlands or salt lakes respond differently and at different response scales under each scenario (Figure 7.2). Some show very moderate differences from the current scenario to the no drainage scenario while others show considerable difference. Overall trends show that a wet climate would increase wetland filling while a dry climate reduces it. The drainage scenarios, except the Drainage EB scenario, are likely to increase lake hydropериods. The most likely impacts on wetlands from a substantial increase in days at full would be the drowning of any surviving lakebed-emergent vegetation or fringing habitats and possible changes to wetlands functions such as nutrient or oxygen availability. While congruent years with a substantially reduced hydropériod (likely to occur under a dry climate) could result in complications for species to complete lifecycles.

Flooding risks are not likely to increase greatly during the first quarter of the twenty-first century under the no drainage scenario. However, under the Drainage LB scenario, flooding risks are likely to be much higher than those under the no drainage scenario at all locations. Flooding risks under the wet climate scenario are substantially lower than those under the Drainage LB scenario at most locations while being slightly higher than the no drainage scenario. The predictions for the Drainage SSe scenario fall between the Drainage LB and the wet climate scenario.

Table 7.1. The Lake Dumbleyung release options assessed in the preliminary environmental impact analysis.

<table>
<thead>
<tr>
<th>Option</th>
<th>Salinity of Lake Dumbleyung(mg L(^{-1}))</th>
<th>Water volume released (GL day(^{-1}))</th>
<th>Amount of salt released (tons day(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>A 30,000</td>
<td>1296</td>
<td>38880</td>
<td></td>
</tr>
<tr>
<td>B 30,000</td>
<td>648</td>
<td>19440</td>
<td></td>
</tr>
<tr>
<td>C 20,000</td>
<td>1296</td>
<td>25920</td>
<td></td>
</tr>
<tr>
<td>D 20,000</td>
<td>648</td>
<td>12960</td>
<td></td>
</tr>
</tbody>
</table>

> Table 7.1. The Lake Dumbleyung release options assessed in the preliminary environmental impact analysis.

> Lower Blackwood River at Hut Pool crossing (Photo: Department of Water, Western Australia)
> Figure 7.1. Flow days in an average year at Hut Pool at or above various threshold flow-weighted salinity levels.

> Figure 7.2. Number of empty, half full and full water storage days in an average year under various scenarios in Lake Towerinning (top left), Lake Toolibin (top right), Lake Norring (bottom left) and Lake Dumbleyung (bottom right).
In this report, the LASCAM model was used to assess and evaluate artificial drainage systems in the Blackwood Basin of WA. The model was calibrated using streamflow and salt load data collected over a historical time period from 1970 to 2005. The calibrated model was used for simulating the impacts of various artificial drainage, revegetation and climate change scenarios relative to a baseline or no drainage scenario. Following are the main conclusions from this study.

Scenario predictions

In a no drainage scenario, where nothing is done to address dryland salinity, the model predicts that most of the subcatchments in the Blackwood Basin will exhibit continuing rises in average groundwater level, but at a slower rate than is currently occurring under the no drainage conditions. A consequence of the rising watertables is that streamflows and salinity increase over the simulation period. Increased flows are predicted to cause increased frequencies and volumes of lake discharge.

These increases are expected to continue but at slower rates. In the absence of further management strategies most of the catchment is likely to reach equilibrium some time during this century. A consequence of this catchment behaviour is that in assessing the impacts of any future management or climatic changes, it would be more meaningful to make comparisons against the benchmark scenario that has been established here instead of comparisons with the current state of the catchment.

Artificial drainage (with storage of discharge drainage in salt lakes up to their existing outlet heights, SSE) is likely to lower the groundwater levels and groundwater salinities over time. The drainage effectiveness and density are the main determinants of the extent and rate of decline in watertables and groundwater salinity. Artificial drainage causes modest flow increases (up to 7%) and substantial salt load increases (up to 66%) at the catchment outlet. The drainage scenarios with high zones of effectiveness typically produce more streamflow and salt load than the scenarios with low zones of effectiveness. Peak streamflows are predicted to be considerably larger under the drained scenarios than under the no drainage scenario in arid subcatchments downstream of lakes, but in first-order subcatchments drainage has less impact on peak streamflows. Artificial drainage increases the frequency, volume and salinity of lake discharge.

The management of drainage discharge was modelled using a number of scenarios. The Drainage SSF scenario (i.e., drainage discharge is stored in salt lakes assuming they are terminal) results in substantial reductions in streamflows, salt loads and salinities in most downstream subcatchments. Modest reductions in peak flows in lower parts of the catchment and larger reductions in the Beaufort and Coblinine Rivers are expected. The Drainage S Sr scenario (i.e., drainage discharge is stored in salt lakes after raising their outlet heights by 0.3 m) is relatively ineffective in reducing streamflows, salt loads and flow salinity in most downstream subcatchments. Modest reductions in lake discharge frequencies and volumes occur for some lakes, but at the cost of slight increases in discharge salinity. The Drainage EB scenario (i.e., retention of subcatchment drainage discharge in evaporation basins constructed at subcatchment outlets) leads to large reductions in flows, loads and salinities in both streams and lake discharges. The Drainage LB scenario (i.e., drainage discharge bypasses the salt lake) results in moderate increases in streamflow and slight increases in salt load, but has little impact on stream salinity in downstream subcatchments.

Full revegetation of the catchment with woody perennials is predicted to cause substantial falls in watertables, but substantial increases in groundwater salinity. The streamflows are predicted to substantially reduce as well. The reduction in peak flows is less than the reduction in mean annual flows. The full revegetation scenario is predicted to cause enormous reductions in stream salt load and salinity. Revegetation will also reduce the frequency, volume and salinity of lake discharges.

The five climate scenarios assessed in this report are all well within the realms of possibility for the Blackwood Basin over the next 100 years. Despite this, they give rise to enormous variability in hydrological response in the catchment. The drier, eastern subcatchments are more sensitive to climate change than the wetter, western subcatchments. Lower watertables and slower watertable responses are predicted under the drier climates than under the wetter climates. Higher groundwater salinity is expected under a wet future climate than under a dry future climate. Streamflows and salt loads are greater under the wetter climates than under the drier climates. The wet climate leads to increases in lake discharge occurrences, volumes and salt loads, but has little effect on lake discharge salinity. The driest climate leads to an almost complete cessation of discharge from all lakes.

Drainage discharge management

The indicative size and construction cost of four artificial drainage discharge management systems were assessed. The feasibility is assessed on the basis of construction costs alone. This analysis concluded that the arterial channels are more feasible than evaporation basins because of high excavation cost of evaporation basins. The most effective of all is the leveed arterial system which allows the entry and storage of drainage discharge in evaporation basins constructed at subcatchment outlets. Open arterial systems require larger (very wide and shallow) channels to handle both surface water and drainage water and therefore are more expensive than leveed arterial systems.
Economic analysis of drainage systems

The economic analysis of the drainage systems was conducted considering the construction and maintenance cost of farm and subcatchment-scale artificial drains, arterial channels and evaporation basins and a range of benefits such as gross margins, remnant vegetation benefits, rail and road benefits, etc. Scenario 10 with medium costs and medium benefits is considered to be a benchmark scenario and reasonable reflection of potential drainage cost effectiveness. Under this scenario the normalised BCR results suggest that both the central and eastern zones may have potential opportunities for land remediation using both open and leveed drains if there are no disposal costs associated with the safe conveyance and management of the drainage discharge from the farm and subcatchment drainage systems.

Overall, the eastern zone yields more favourable BCR returns than the central zone, and leveed drains typically yield higher BCR returns than open drains given their lower maintenance costs. When the additional costs of drainage water disposal are considered in the analysis, the potential economic returns on deep drainage are further reduced for the leveed drains with leveed arterial channels and leveed drains with evaporation basins. The drainage effectiveness, construction and maintenance cost of drains and productivity of reclaimed land are the main drivers of deep drainage economics.

CGSSLRC channel feasibility

The feasibility of an open channel between Lake Dumbleyung and the Albany Highway was assessed. The CGSSLRC channel feasibility study concluded that discharges from Lake Dumbleyung into the lower Blackwood River system via an open channel are likely to adversely impact its flow-weighted salinity (FWS). The FWS of the Blackwood River at Hut Pool is predicted to increase substantially from that under the Drainage SS scenario if Lake Dumbleyung water with a 20 g L^{-1} concentration level is discharged into the Arthur River at a daily rate of 0.65 GL via this channel.

Preliminary assessment of environmental impacts

A preliminary assessment of the environmental impacts conducted for selected water management and climate change scenarios concluded that the Drainage EB scenario causes the least change from the current conditions. Moderate increases in flows and FWS are expected for all catchments under the no drainage scenario and therefore will have moderate environmental impacts. The Drainage SS, Drainage LB and CGSSLRC channel scenarios result in substantial increases in flows and FWS, and are likely to impact flora and fauna. A wet climate is likely to increase wetland filling frequency and a dry climate will reduce it. The best management scenario for each wetland is dependent on its individual response to the scenarios and the overriding goals of the management plan.

Applying the model to other basins and systems

This model is recommended for catchment and regional-scale evaluations of water management strategies and climate change impacts in other data-poor dryland catchments and basins across Australia.

The model calibrated for a large basin can also be applied in individual catchments to assess the localised impacts of drainage management strategies on flows and loads. It can be used to prioritise investment strategies across dryland basins by identifying areas or catchments where the installation of drainage systems is likely to result in significant local benefits and minimal off-site impacts on the stream salinity, flooding risks and increased flows in downstream rivers. The model is able to predict the impacts of integrated plant-based and engineering solutions in various individual catchments or the basin as a whole. For example the model could be used to aid the design and assessment of any proposed regional drainage scheme where some lakes may be available for storage of drainage discharge and others may be protected. It could be used to assess whether or not a proposed drainage scheme will result in excessive stream salinity in sensitive areas (e.g., Arthur, Beaufort). This model will be useful for predicting sediment and nutrient loads from individual catchments or a basin (if observed data are available for calibration).

This model is not suitable for evaluating detailed drainage or water management strategies within individual subcatchments because it is not designed to resolve below subcatchment scale. The model is not able to simulate the detailed water and salt balance of salt lakes. It assumes full mixing of salts stored within the lake with water, irrespective of its volumes, and there is no capability to include the impacts of fluid density on water and salt movement.
Further Reading

This summary report of Wheatbelt Drainage Evaluation — Blackwood River Basin, Western Australia covers only a brief description of methods, calibration and results of various scenarios carried out in this project. The final report covers the full detailed descriptions of the project methods, model calibration and modifications, assumptions, scenario descriptions and results. For further reading about the detailed descriptions of various components of this project, the reader is referred to the final report entitled ‘Wheatbelt Drainage Evaluation — Blackwood River Basin, Western Australia’ by Riasat Ali et al. (2010). References to other relevant studies that have been conducted in the Blackwood Basin are also covered in the final report.
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