The Salinity Audit

OF THE MURRAY-DARLING BASIN

A 100-year perspective, 1999

THE COMMONWEALTH • NSW • VIC • SA • QLD • ACT
Acknowledgments

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A 100-year perspective, 1999
Foreword

In calling for this audit of current and future threats of salinity to the Murray-Darling Basin, the Murray-Darling Basin Ministerial Council has taken an important step forward in addressing this major natural resource management issue for the long term.

The Basin Salinity Audit identifies the need to further change our way of managing land in order to prevent ongoing damage to very important land and water resources, regional infrastructure, and regional biodiversity.

The Audit provides a much better basis for developing public policy to address salinity. As a result of this audit we now have much better information. This covers individual river valleys as well as the Basin as a whole. Governments, rural communities and agricultural industries will be able to better judge for themselves what is achievable in economic and technical terms.

Salinity is a Basin-wide issue, which will increasingly link river valleys, irrigation and dryland areas, because of likely off-site impacts. Its potential impacts are far reaching, not only for agriculture and the regional economy, but also for urban areas and the environment. This reinforces the need for an integrated approach.

Effective management of salinity is a long-term commitment, which will require many years of concerted effort. However early action is vital, and early identification and adoption of appropriate management strategies are required, followed up with future innovation and adaptation.

In some rainfall and geological zones there may be a need for quite different land uses in the future from the ones we see today. The challenge is to manage salinity at a socially acceptable level.

The Murray–Darling Basin Commission is capable of developing an effective strategy for consideration by the Ministerial Council. It now has improved its capacity for predicting salinity outcomes, with or without new management interventions. The States now have regional catchment management organisations in place, a high degree of planning has been carried out and the Commission facilitates public policy that is focused on results and is accountable.

The Commission invests in key research and development organisations that will develop the new innovations, improved land uses and farming systems, and decision support models for catchment management. The new Basin Salinity Management Strategy will further evolve with improved knowledge and further reviews of its effectiveness. The new strategy will have a Basin-wide focus, and it will incorporate a reviewed Salinity and Drainage Strategy.

The Council will take advice from its Community Advisory Committee in its consideration of the strategy and will distribute the draft strategy for widespread public consultation.

This Basin Salinity Audit is the first step to the new strategy. Its conclusions on the salinity damage that may occur deserve to be widely read and discussed by catchment management organisations, industry bodies, local government, Landcare and conservation groups, landholders and the public as a whole.

As part of the next step the Council has requested a draft salinity management strategy, which addresses aspects identified in the Audit, be prepared by June 2000. This strategy will build on ten years of achievement under the Salinity and Drainage Strategy, which is being reviewed by the Murray–Darling Basin Commission. This will enable both dryland and irrigation salinity to be tackled within the Council’s established integrated catchment management approach.

The people and governments of the Murray–Darling Basin are now well equipped to manage the Basin’s productive and environmental resources to ensure that the size of the salinity problem predicted in the Audit is not allowed to eventuate.

Hon. Warren Truss
Chairman, Murray–Darling Basin Ministerial Council
Contents

Foreword iv
Executive Summary vi
Introduction 1
Salinity in the Murray-Darling Basin 2
Source of Salt 2
Groundwater Salinity 3
River Salinity Trends 4
Land Salinisation 4
Scope of the Audit 5
Salt Loads Study 5
Other Data Sources 6
Future Salt Mobilisation 7
Catchment Salt Loads 7
Salt Loads to the River Murray 7
Salt Loads to Other Rivers in the Basin 9
Salt Retained in the Landscape 9
River Salinity 10
The River Murray 10
State Summaries 14
Landscape Salinisation 18
Irrigation Areas 18
Dryland Catchments 18
Productivity and Infrastructure Impacts 22
Cost Impacts to River Murray Users 22
Cost Impacts in Other Catchments 23
Environmental Impacts 25
Floodplain Impacts — South Australia 25
Wetland Impacts — Victoria 26
Wetland Impacts — New South Wales 26
Terrestrial Impacts — Basin-wide 27
Local Impacts in the Catchments 28
South Australia 28
Victoria 28
New South Wales 30
Queensland 33
Salinity Management Interventions 34
The Salinity and Drainage Strategy 34
Dryland Salinity 35
State Management Plans 35
Conclusion 37
Information Sources 38
Glossary 39
Executive summary

The Murray-Darling Basin is geologically and climatically prone to concentrating salt in the landscape.

Land use changes since European settlement mean that less of the rainfall that soaks into the ground is used by vegetation, in dryland areas, causing a gradual filling of shallow aquifers, bringing this natural salt to the land surface and to the rivers. Meanwhile, problems of rising water tables and soil salinisation arose soon after the establishment of the first irrigation schemes in the 1890s. By 1987 it was estimated that 96,000 hectares of the Basin’s irrigated land were salt-affected and 560,000 hectares had water tables within 2 metres of the land surface.

Because of its pervasiveness in the landscape, salinity is more than just a threat to water quality. It also impacts on environmental values for rivers and wetlands. It causes damage on the land — to built infrastructure, agricultural production and the environment.

This Salinity Audit establishes a trend, river valley by river valley, for salt mobilisation in the landscape and its expression in rivers and at the land surface. It provides predictions for increases in salinity if there are no new management interventions to prevent them.

The Audit enlarges and refines existing knowledge of the threat of salinity, building on a range of studies commissioned by State and Commonwealth governments.

One very important finding of this Audit is the estimation that much of the salt mobilised does not get exported through the rivers to the sea. It stays in the landscape or gets diverted into the irrigation areas and floodplain wetlands.

Previously, salinity of rivers was considered to be a problem for the lower River Murray. A major conclusion of this Audit is the extent to which salinity levels are rising in tributaries of the Murray–Darling system. A further very significant outcome of this Audit is the recognition that future salt exports will shift from irrigation-induced sources to dryland catchment sources. Of the projected increase in River Murray salinity at Morgan, South Australia, about 40 per cent will come from the nearby Mallee dryland zone and 25 per cent from tributary catchments upstream.

It is important not only to estimate the salt load involved but also the time over which salinisation will occur. The Salt Loads studies by the States, a major data source for the Audit, provide estimates for the years 2020, 2050 and 2100. The average salinity of the lower River Murray (monitored at Morgan) will exceed the 800 EC threshold for desirable drinking water quality in the next 50–100 years. By 2020 the probability of exceeding 800 EC will be about 50 per cent.

At the downstream end of several tributary river valleys, rising salinity will be even greater, threatening consumptive use of water resources and in-stream environmental values. The Macquarie, Namoi and Bogan Rivers will exceed the 800 EC threshold within 20 years, and exceed the 1,500 EC threshold for irrigation crop and environmental damage within 100 years. The Lachlan and Castlereagh Rivers will exceed 800 EC within 50 years. The Condamine–Balonne, Warrego and Border Rivers will exceed 800 EC before 2020. The Avoca and Loddon Rivers already exceed 800 EC on average. Some reaches of these rivers will rise to higher salinity levels again.

As part of of the Salinity Audit, the Salinity and Drainage Strategy is being reviewed. The Audit has updated the future salinity trend line for the River Murray used in the Salinity and Drainage Strategy. The review has estimated the achievements of the Strategy and updated the costs associated with rising salinity.

The two most common types of cost from salinity are those associated with the use of saline river water in irrigated agricultural land and in urban areas, and those associated with rising water tables under land, in both urban and rural areas. The 1999 costs functions study commissioned by the Murray–Darling Basin Commission found that under current conditions, the cost of one EC unit increase in river salinity at Morgan in South Australia lies in the range of $93,000 to $142,000 per year. Already the total economic impact is estimated at $46 million a year, and will rise further with the projected 330 EC increase over the next century. This study also found that the cost to agricultural users, especially horticulturalists,
is much higher than previously estimated, while domestic and industrial costs are lower than previous estimates.

Salinity impacts on the environment in a number of ways. The Audit distinguishes between the riverine environment and the terrestrial environment, and focuses on what is known or can reasonably be predicted about loss of biodiversity. The major wetlands of the Basin — Macquarie Marshes, Great Cumbung Swamp, Avoca Marshes and Chowilla Floodplain — are likely to suffer additional impacts.

In response to the earlier understanding of the salinity threat, governments and communities have invested heavily in salinity management. Under the Salinity and Drainage Strategy there has been an improvement in River Murray salinity without limiting the rehabilitation of degraded lands and the undertaking of drainage works to control the rise of groundwater tables. This was made possible by reducing the amount of salt entering the river through construction of salt interception schemes and from implementation of the salinity and land and water management plans by the States.

Salinity levels in the lower Murray have been much lower in the post-strategy period than the pre-strategy period. Between 1993 and 1999 the salinity at Morgan has been less than 800 EC 92 per cent of the time. However, an increase from an average salinity of 570 EC to 790 EC in 50 years and 900 EC in 100 years indicates that the outcomes of the strategy will be overtaken unless new action is taken.

There has been significant improvement in our understanding of the challenges salinity presents to public policy. There is a better capacity to predict future impacts of salinity on a Basin and catchment scale. There is accumulated knowledge that points to the limits of most current farming systems to control salinity, even at the level of best practice. There is a greater appreciation of economic and social impediments to the scale of land use change now advocated for dryland catchments and there is a track record of policy initiatives, such as the Salinity and Drainage Strategy.

The Salinity Audit is a major advance in our predictive capacity. It provides the basis for framing a Basin-wide salinity management strategy. What has the Audit told us?

- The salt mobilisation process across all the major river valleys is on a very large scale. The annual movement of salt in the landscape will double in the next 100 years.
- There is a future hazard for some rivers and those people dependent on them as a source of water. Average river salinities will rise significantly, exceeding the desirable thresholds for domestic and irrigation water supplies in many tributaries and exceeding critical levels in some reaches.
- Sources of salt that impact on the Murray–Darling system are better identified and quantified but our capacity to estimate land areas impacted by future salinity is inadequate and current understanding of environmental impacts is inadequate.
- There is a priority for investment in better estimation of cost impacts and the benefit:cost ratios of taking action.

The Salinity and Drainage Strategy has gained us a 20-year reprieve against rising salinity in the lower Murray. Land and Water Management plans and adoption of best practices in irrigated agriculture have brought a level of salinity control. There is a sound basis for deciding on future investments in associated engineering works.


The Salinity Audit clearly identifies the severity and scale of the salinity threat to the Murray–Darling Basin if there are no new management interventions. The Audit has identified where improvements can be made and the National Land and Water Resources Audit’s dryland salinity monitoring program will provide further guidance. Across the Basin the government support for integrated catchment management, including regulatory and financial capacity, offers a path forward for a Basin Salinity Strategy.
Areas Studied for the Audit

- Salt loads study based on groundwater rise
- Land & Water Management Plans SA
- Salt loads study based on groundwater flow

Areas Excluded

- NSW Alluvial areas
- Other areas
- Irrigation Areas
- Wetlands of Importance
- Murray–Darling Basin

Figure 1. Key Geographical features and locations referred to throughout this publication
Introduction

The Salinity Audit brings together for the first time our knowledge of the extent of the salinity threat in the Murray-Darling Basin. The Audit considers the impacts of salinity on economic and environmental values and reviews the achievements of policy and management responses over the past decade are reviewed.

The Salinity Audit follows the 1995 Water Audit that set in train the development of a new policy by the Murray-Darling Basin Ministerial Council, which resulted in the ‘Cap’ on diversions of the Basin’s water resources.

The Audit is more than a report on salinity levels and trends. In fact, a Salt Trends report for the Basin’s rivers was published in 1997. The Audit does not estimate the location and area of salt-affected land. That can only be reliably done with more cost-intensive technologies on a local or small catchment scale. First and foremost, the Salinity Audit establishes a trend line, river valley by river valley, for salt mobilisation in the landscape and its expression at the land surface and in rivers. This is the predicted rise in salinity if there are no new management interventions to prevent it.

Knowing this trend line is only part of the story. Salinity management strategies and implementation of new ‘action plans’ to follow will be measured for their achievement in reducing salinity impacts below the trend lines. The Audit will be the foundation of development and implementation of these strategies and plans.

The Murray–Darling Basin Commission has the charter to coordinate and monitor sustainable management of natural resources in the Basin. It is a multilateral authority with statutory powers on behalf of State and Commonwealth governments to address issues of water sharing and water quality. In doing this, the Commission operates consistently with national conventions and policies, including principles of ecologically sustainable development and natural resources management.

Salinity is a major water quality issue for the Murray–Darling Basin. With high dependence on the river systems for consumptive water use, strategies have been in place to address both salinity and nutrients. However, because of its pervasiveness in the landscape, salinity is more than just a threat to water quality. It also impacts on environmental values for rivers and wetlands. It causes damage in terrestrial environments — to land, built infrastructure, agricultural production and the environment. The rise of salinity in the landscape is symptomatic of current land uses, which have taken the place of natural systems, resulting in a massive hydrological imbalance that will take up to several hundred years to stabilise.

Salinity is a major natural resource management issue, and successful measures to reduce its impact will have broader benefits for natural resources. The management challenge is to achieve a beneficial salinity outcome while not putting at further risk economic, social and environmental sustainability.

In undertaking the Basin Salinity Audit, the Commission has embarked on a ‘knowledge-driven path’ to a new Basin Salinity Management Strategy. There are four key steps:

- improving our capacity to predict salinity impacts under the ‘no new intervention’ scenario
- conducting a thorough ‘audit’ of existing knowledge about impacts now and in the future
- canvassing and developing management and policy options for controlling salinity on a Basin and catchment scale, and estimating their impact on salinity control
- incorporating these into a comprehensive new strategy.

The Ministerial Council has requested a draft strategy for June 2000. Meanwhile, the Basin Salinity Audit is highly relevant to current catchment management. It includes trends and salinity thresholds that will allow regional catchment management organisations to assess their own options for addressing salinity, and to measure achievements. It is a sufficiently comprehensive document to better inform policy and strategy development, yet is highly relevant to community, industry and government organisations that depend on the Murray–Darling Basin’s natural resources.

1. Williamson et al. (1997).
Salinity in the Murray-Darling Basin

Source of Salt

The Murray-Darling Basin is geologically and climatically prone to concentrating salt in the landscape. The generally flat terrain, combined with low rainfall and high evaporation, combine to concentrate salt in the groundwater.

Before European settlement, the native vegetation assisted in the concentration of cyclic salt from rainfall by transpiring the pure water while leaving salt-enriched water to leach below its rootzone. Natural groundwater is often as salty as the sea. Natural salt lakes occur throughout the lower Basin, causing further concentration of salts. The very limited rainfall, the capacity of native vegetation to use almost all the rain that infiltrates and sluggish groundwater flow regimes preclude thorough flushing of the accumulated salts. The rivers generally collect groundwater in their lower reaches and carry it to the sea. During periods of low flow, the salinity of the streams and rivers rises dramatically.

The aquatic ecosystems have become accustomed to these significant variations in salinity.

Land use changes since European settlement mean that less of the rainfall that soaks into the ground is used by vegetation, in dryland areas, causing a gradual filling of shallow aquifers, bringing this natural salt to the surface (see Dryland Salinity below). The clearing of vast tracts of land and the introduction of annual crops and pastures has resulted in reduced consumption of the rainfall by plants and consequently increased recharge to the aquifers. In some regions the impact is felt over decades; elsewhere, particularly in the Mallee, the recharge has yet to significantly influence the deep, regional water tables.

While these salt accumulation and discharge processes occurred naturally, the increasing regulation of rivers by dams and weirs and the diversion of water for consumptive uses have further compounded the lack of natural flushing.

The use of water for irrigation not only reduces dilution flows but also adds to the natural salt loads. Irrigation has exacerbated the salinity issues by causing rapid rises in local groundwater levels, bringing salt to the surface, concentrating it there through evaporation and causing increased discharge to the rivers. The 1995 Water Audit confirmed the extent of diversion for consumptive uses under current development conditions.

Dryland Salinity

Salt occurs naturally in the Australian landscape where it has accumulated over geological time. Salt often occurs at the land surface in the form of salt lakes or salinised land supporting salt-tolerant native vegetation.

However, in areas of more reliable rainfall where we now practice agriculture and where most of our roads and buildings are, salt used to be stored deep enough in the soil not to affect plants.

Clearing of native vegetation and the introduction of agriculture and urban development starts off the process of secondary salinisation (Figure 2).

When a saline water table rises to within 2 metres of the land surface, salt impacts start to show. From that point, capillary action in the soil, transpiration by plants and evaporation at the land surface draw up the saline water and concentrate the salt.

Depending on land relief, whole broad valleys or the footslopes of hilly areas may be affected. In a growing proportion of the land with shallow water tables, saline water can be seeping from the ground, and washing off to creeks making them more salty. With or without high salt concentrations, waterlogging of soil affects its structure and chemistry and reduces its productivity.
Among other things, the levels of water diversion have significantly reduced flows in the lower reaches of the River Murray, so much so that the median annual flows from the Basin to the sea are only 21 per cent of those that would have occurred prior to development.²

The decision in 1997 by the Murray–Darling Basin Ministerial Council to place a Cap on water diversions is an important step towards arresting the rising trends in the salinity of the Basin’s rivers.

Groundwater Salinity

The process of concentration of salt in the groundwater systems varies across the Basin and there are differences in the location and mobilisation of salts.

The largest store of salt has accumulated in the sedimentary Murray Groundwater Basin. Groundwater, often approaching seawater salinity, extends as much as 600 metres below the surface. The fractured rock regions around the margins of the Murray–Darling Basin contain thinner lenses of saline groundwater and often contain a significant salt store in the partially saturated zone above the water table. The alluvial sediments of the plains contain complex zones of saline and fresh groundwaters. In many of these areas the fresher water is exploited for irrigation and water supply. In such circumstances the groundwater levels are often in decline and landscape salinisation will not occur.

When land has a saline water table within 2 metres of the surface, several forms of damage occur.

AGRICULTURAL LAND

Typically, crop failures are experienced in wetter years and on more waterlogged areas. There is a succession of plant life changes in farm paddocks. Nitrogen-fixing clovers and medics are the first to disappear, replaced by barley grass and volunteer salt-tolerant species and, finally, bare soil with poor structure. Salt-affected land is usually defined as land where productivity is reduced by 50 per cent. Bare-scalded areas are a small proportion of all salt-affected land. It is possible to establish a grazing enterprise on land re-planted to salt-tolerant forage shrubs but this is not as profitable as cropping. Typically, farmers underestimate areas of salt-affected land.

REGIONAL INFRASTRUCTURE

Rising saline water tables under roads, buildings and other concrete structures cause damage. One of the earliest recorded impacts of dryland salinity was the loss of local water supplies for steam trains. The average life of a road on well drained soil is four times that of one whose base is waterlogged and salinised. The sulphates in saline groundwater quickly destroy the strength of older concrete structures. For older buildings without adequate damp-coursing, rising saline dampness erodes mortar and bricks.

URBAN AREAS

There are towns and cities across Australia where house foundations are suffering decay and it is no longer possible to grow fruit trees and maintain lawns and gardens. Older plumbing is corroded, septic systems become ineffective, cellars require regular pumping, and even the cemetery may have to be relocated.

Saline high water tables and saline water supplies affect farmers, urban and rural households, commercial businesses, public utilities and local councils. Water tables near the surface can enhance run-off, resulting in a higher flood risk.

THE ENVIRONMENT

The Murray–Darling Basin is home to significant biodiversity, much of which is found nowhere else. The plants, animals and the ecosystems of which they are a part are generally unable to cope with the increases in salt associated with secondary salinity. This applies to both freshwater and terrestrial organisms. There are increased impacts on endangered species and ecological communities. This is compounded by the highly fragmented natural environment in the Basin. Salinisation affects both conservation reserves, and remnant vegetation on public and private land.

2. MDB (1999).
River Salinity Trends

The Salt Trends report\(^2\) has demonstrated how these processes are causing gradual changes to rivers around the Basin (Figure 4).

While the study indicated the historic trends, it was recognised that these were often the result of increasing water diversion from the rivers. However, the Salt Trends study was an important catalyst for the current Salt Loads study where emphasis has been put on the groundwater mobilisation process.

There is a considerable time lag between land use changes and the mobilisation of salt to rivers and in the landscape. In irrigation districts where the recharge rates are very high and the sources are close to the rivers, the salt mobilisation process is much more rapid.

Land Salinisation

Salinisation in the landscape is a naturally occurring process in the Murray-Darling Basin.

Two hundred years ago, salinity was restricted to particular locations and times of the year. The extensive salt lakes in the Victorian and New South Wales Mallee region are indications of this primary landscape salinisation. However, it has become increasingly apparent that secondary salinisation as a result of land use changes is accelerating. Their effects over the past 150 years are just beginning to express themselves in salting of the valleys and low-lying landscape.

Land salinisation not only affects vegetation in the immediate area, but also contributes directly to erosion, as soil structure declines and stream banks are made less stable. There is also a phase-lag in the effects of salination, such that by the time they are apparent, they will intensify before any remedial action can reduce their impacts.

A 1993 study\(^3\) identified only 20,000 hectares as grossly affected by secondary salinisation, but it was probable that 200,000 hectares were actually affected at that time. The report indicated the likely future hazard for the Basin was of the order of 1 million hectares.

Another study in 1995, by the National Dryland Salinity Program, estimated 300,000 hectares of land within the Basin as salt-affected in the form of dryland salinity (Figure 5).\(^4\)

When we compare the conclusions of these reports with the current Salt Loads study, it is clear just how fast our knowledge of this emerging threat has grown. Typically, no concern is shown about rising water tables until they actually break the surface.

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\(^2\) MDBC (1999).

\(^3\) Beal (1993).

This Salinity Audit came about because of the Murray-Darling Basin Commission's decision to review the Salinity and Drainage Strategy (see Salinity and Drainage Strategy, p.11).

In the process of that review, it became apparent that the dominant source of salinity would shift from irrigation areas to dryland catchments. Consequently, the Commission took a further decision, with the agreement of the States, to assess the salinity hazard Basin-wide.

Most other recent studies predicting future salinisation have focused on estimating the extent of land at risk of declining productivity or degradation. Such studies rely on extrapolating future salinisation on the basis of current observations, using landform and land use as the prime indicator. However, such studies do not provide for estimates of future salt loads to streams. Nor do they account for future salinisation where none is observed today. Accordingly, it was agreed to undertake the new study using groundwater observations as the basis.

Salt Loads Study

Given the complexity of groundwater systems in the Murray-Darling Basin, the Salt Loads study required a simplified approach.

It concentrated on the shallow surface aquifers, which have the capacity to discharge to the surface or direct to streams as groundwater levels rise. This assumption allows preliminary estimates of the salinity hazard. It has an important advantage over other contemporary predictive approaches in that it can be used to predict salinity outbreaks and can be useful for making time-based estimates.

Each Basin State — South Australia, Victoria, New South Wales and Queensland — has modelled the groundwater process, where data were available, and drawn on existing trend data to predict the degree of salt mobilisation in the landscape, the resultant salt loads and salinity levels in the major Basin tributaries, and the extent to which land is threatened by rising water tables.

To make such hydrogeologic predictions, the modelling draws on available data for each dryland catchment, specifically:

- The observed rate of groundwater rise
- The current depth to groundwater and
- The salinity of the groundwater.

The Murray–Darling Basin as a whole covers 100 million hectares. The Salt Loads study focused on 54 million hectares of the southern and eastern regions of the Basin. Of this, 25 million hectares are in New South Wales, 5 million in Victoria, 3 million in South Australia and the preliminary studies for Queensland covered 21 million hectares (see Figure 1). Within the study area, at least 16 million hectares have been identified as experiencing rising groundwater levels.

From these data the quantity of saline groundwater and salt load now moving within the landscape can be estimated. This salt load will ultimately discharge at the land surface or directly enter streams and rivers as groundwater seepage. In the future, the surface flow of saline water in the upstream reaches of rivers will become more dominant. Figure 6 illustrates the hydrological process modelled and the relationship between the two mobilisation processes contributing to river salinity — increases in surface ‘wash off’ of accumulated salt and increased seepage into rivers.

It is important not only to estimate the salt load involved but also the time over which this process will occur. The Salt Loads study provides estimates for 2020, 2050 and 2100. The precision of estimates from such modelling is limited by the data available; in particular the density of groundwater bores across the landscape and the time over which records have been kept.

**Figure 6:**

Hydrological Processes Modelled in the Salt Loads Study
The methodology used in this study included correlating the modelled predictions with current salinity regimes in rivers.

Interstate differences in data availability and interpretation, and existing modelling have meant that each State differs in the assumptions it makes and the way it applies the methodology. Recognising these differences in approach and the paucity of data from some parts of the Basin, the Commission had the methodology and findings independently assessed by CSIRO scientists working for the Cooperative Research Centre for Catchment Hydrology. Their advice was that the estimates of salt loads and river salinities were valid, but that these data alone should not be relied on to estimate the amount of salt-affected land.

For every geologic unit in each State, there is an estimate of the current salt load and the load 20, 50, and 100 years into the future. This is aggregated for each major tributary of the Murray–Darling system. Total salt exported to these rivers is estimated, and from a knowledge of their flow characteristics and water diversion rates, average river salinities are estimated.

The Salt Loads study has provided quantified estimates of critical importance to this Audit:

• The salt load mobilised in the landscape (tonnes per year)
• The area of land with rising groundwater, whether saline or not (hectares)
• The salt export through rivers (tonnes per year)
• The rivers’ salinity levels (EC units).

Other Data Sources
While the Audit draws most heavily on the Salt Loads study, it also brings together new and existing data from other sources.

The Salinity and Drainage Strategy review provides up-to-date information on the cost impacts of salinity along the reaches of the River Murray (see Productivity and Infrastructure Impacts) and on altered trends in river salinity (see Decade of Salinity and Drainage Strategy). A 1997 Salt Trends report has provided data on salt loads and river salinities over a recent 20-year period, for reaches of all major Basin rivers. These data have been correlated with outputs of the Salt Loads study. Other work (specifically, Environmental Impacts and Salinity Management Interventions) has been commissioned for the Audit, and data from existing sources have been used. These sources are acknowledged.

LIMITATIONS OF THE AUDIT
This Audit should be regarded as the best available estimate of the mobilisation of salt export through the rivers and as a reasonable indication of the locations of dryland salinity hazard. The fact that this Audit draws only from a calibrated groundwater study implies that it cannot readily identify complex salt mobilisation processes that occur on the local scale. Consequently, the Audit should be regarded as an overall collation of the best available Basin-wide data. If more detailed information becomes available it can be readily incorporated into the Basin-wide database. In areas where the Audit identifies a future area with a high hazard, then a site-specific study is warranted to improve local understanding prior to taking remedial action. The State Salt Loads reports provide detailed information on specific limitations to data interpretations (see Information Sources, p.38).
Future Salt Mobilisation

Catchment Salt Loads

Although there were significant amounts of salt moving through land and rivers before European settlement, the quantity involved has been exacerbated under the land use changes that have occurred since that time.

Much of this mobilised salt has yet to reach the ground surface. The fundamental premise of the Salt Loads study is that salt mobilisation can be predicted by extrapolating the current trends of rising groundwater levels in elements of the landscape. Not all of the salt that is mobilised actually gets exported out of the system through the rivers. Large-scale re-storage of salt occurs in the lower sections of valleys through diversions and entrapment, while sections with poor drainage retain much of the salt delivered to the surface from groundwater.

The Salt Loads study estimates that Basin-wide, the salt mobilised to the land surface will increase from 5 million tonnes a year in 1998 to 10 million tonnes in 2100. Table 1 shows predicted salt loads for river valleys and States.

Given that the salt enters rivers by two processes — washed off the land surface and direct seepage to rivers — Table 1 identifies those salt loads that directly enter the River Murray.

Salt Loads to the River Murray

Along the River Murray main stem, the salt accessions have been monitored under the Salinity and Drainage Strategy.

In the reach from Tocumwal to Swan Hill, current salt accessions of around 715,000 tonnes per year are recorded. Data from the Murray–Darling Basin Commission’s models indicate that about 525,000 tonnes per year are contributed from the southern (Victorian) side of the Murray with the remainder from New South Wales. The additional salt loads from Victorian tributaries will increase the River Murray salt loads in this reach.

In the Mallee zone from Swan Hill to the South Australian border, the existing salt inputs are 280,000 tonnes per year. In this reach the current Victorian contribution is estimated as 190,000 tonnes per year with 90,000 tonnes per year from New South Wales. This is based on data available from the Murray–Darling Basin Commission, and included in the 1988 benchmark conditions under the Salinity and Drainage Strategy. The Victorian estimates indicate a further 110,000 tonnes per year by 2050, mostly around Mildura.

Groundwater level observations and modelling in the New South Wales section of the Mallee, where there is significantly less clearing and development, suggest that there will be no significant increase in salt load discharge within the Audit’s time frame.

The irrigation districts in Victoria and New South Wales have access to salinity credits for drainage. Both Victoria and New South Wales will need to dispose of an additional 20,000 tonnes per year from the irrigation districts over and above the Salinity and Drainage Strategy allowance.

In the Mallee zone, through South Australia from the border to Morgan, salt loads will increase from 330,000 tonnes per year to 610,000 tonnes per year by 2050. Predictions that the extensive clearing of the Mallee in South Australia more than 50 years ago will have significant future consequences for salt loads in South Australia have been made for the last 15 years. The Salt Loads study provides a revised assessment. While it is still difficult to assess when these impacts will occur, the results indicate that salt load increases are still very significant over the coming 20 years or more.

Salt Loads to Other Rivers in the Basin

The Murrumbidgee River and Lachlan River catchments are dominant among river valleys in their salt mobilisation, with quite different consequences.

The salt loads currently observed in the Murrumbidgee are significant but still considerably less than the estimates of salt mobilised within the catchment. The Murrumbidgee is a highly regulated river with augmented flow from the Snowy Mountains Scheme and a major source of irrigation water supplies. Despite the prevailing high salt loads, the dilution flows available maintain low salinities in the river. The Lachlan rarely provides significant flows to the Murrumbidgee and Murray; rather the mobilised salt in the river itself will be stored in the floodplain, irrigation districts and the Great Cumbung Swamp.

Estimation of the cost and environmental implications of these different impacts is a major concern for this Audit. While salt mobilised in the landscape is an important predictor of salt impacts, it is where this salt is ‘re-stored’ that determines the impacts.

Figure 7 summarises the estimated changes in these salt exports for river valleys and States, with the Basin-wide total increasing from 2 million tonnes per year now to 4 million tonnes by 2100. Currently the River Murray exports an average of 2.1 million tonnes a year to the ocean. Clearly, this will rise, with a major contribution from the Mallee zone to the Murray, and significant additional loads from the Namoi, Macquarie, Murrumbidgee and Goulburn-Broken Rivers. Given that these rivers account for more than half of the Basin’s water resources consumed, such increases in salt loads are of concern.
**Table 1: Estimated Quantity of Salt Mobilised to the Land Surface, 1998–2100, Murray–Darling Basin**

<table>
<thead>
<tr>
<th>River valley</th>
<th>Salt mobilised to land surface (tonnes per year)</th>
<th>1998</th>
<th>2020</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Australia</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>River Murray</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barrages to Lock 2</td>
<td></td>
<td>105,000</td>
<td>190,000</td>
<td>260,000</td>
<td>335,000</td>
</tr>
<tr>
<td>Lock 2 to Border</td>
<td></td>
<td>329,000</td>
<td>450,000</td>
<td>610,000</td>
<td>685,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>434,000</strong></td>
<td><strong>640,000</strong></td>
<td><strong>870,000</strong></td>
<td><strong>1,020,000</strong></td>
</tr>
<tr>
<td>Victoria</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>River Murray &amp; Tributaries</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mallee zone</td>
<td></td>
<td>190,000</td>
<td>240,000</td>
<td>300,000</td>
<td>365,000</td>
</tr>
<tr>
<td>Upstream Swan Hill</td>
<td></td>
<td>525,000</td>
<td>545,000</td>
<td>545,000</td>
<td>545,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>740,000</strong></td>
<td><strong>825,000</strong></td>
<td><strong>1,150,000</strong></td>
<td><strong>1,370,000</strong></td>
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<tr>
<td>New South Wales</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>River Murray &amp; Tributaries</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mallee tributaries</td>
<td></td>
<td>90,000</td>
<td>90,000</td>
<td>90,000</td>
<td>90,000</td>
</tr>
<tr>
<td>Upstream Swan Hill</td>
<td></td>
<td>190,000</td>
<td>270,000</td>
<td>290,000</td>
<td>450,000</td>
</tr>
<tr>
<td>Murrumbidgee</td>
<td></td>
<td>2,170,000</td>
<td>2,920,000</td>
<td>3,250,000</td>
<td>3,960,000</td>
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<tr>
<td>Lachlan</td>
<td></td>
<td>710,000</td>
<td>850,000</td>
<td>1,280,000</td>
<td>1,780,000</td>
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<tr>
<td>Darling and other NSW catchments</td>
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<td>n.a</td>
<td>n.a</td>
<td>n.a</td>
<td>n.a</td>
</tr>
<tr>
<td>Macquarie</td>
<td></td>
<td>240,000</td>
<td>490,000</td>
<td>660,000</td>
<td>790,000</td>
</tr>
<tr>
<td>Castlereagh</td>
<td></td>
<td>161,000</td>
<td>180,000</td>
<td>320,000</td>
<td>330,000</td>
</tr>
<tr>
<td>Namoi</td>
<td></td>
<td>60,000</td>
<td>100,000</td>
<td>120,000</td>
<td>150,000</td>
</tr>
<tr>
<td>Gwydir</td>
<td></td>
<td>7,000</td>
<td>20,000</td>
<td>50,000</td>
<td>60,000</td>
</tr>
<tr>
<td>Macintyre</td>
<td></td>
<td>80,000</td>
<td>80,000</td>
<td>80,000</td>
<td>80,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>3,707,000</strong></td>
<td><strong>5,000,000</strong></td>
<td><strong>6,140,000</strong></td>
<td><strong>7,690,000</strong></td>
</tr>
<tr>
<td>Queensland</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warrego</td>
<td></td>
<td>27,000</td>
<td>55,000</td>
<td>56,000</td>
<td>56,000</td>
</tr>
<tr>
<td>Balonne–Condamine</td>
<td></td>
<td>109,000</td>
<td>139,000</td>
<td>139,000</td>
<td>139,000</td>
</tr>
<tr>
<td>Border Rivers</td>
<td></td>
<td>50,000</td>
<td>61,000</td>
<td>61,000</td>
<td>61,000</td>
</tr>
<tr>
<td>Remainder of Queensland</td>
<td></td>
<td>n.a</td>
<td>n.a</td>
<td>n.a</td>
<td>n.a</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>&gt;186,000</td>
<td>&gt;255,000</td>
<td>&gt;256,000</td>
<td>&gt;256,000</td>
</tr>
<tr>
<td><strong>BASIN TOTAL</strong></td>
<td></td>
<td>&gt;5,070,000</td>
<td>&gt;6,720,000</td>
<td>&gt;8,420,000</td>
<td>&gt;10,340,000</td>
</tr>
</tbody>
</table>

Notes:

a Where the salt loads mobilised were estimated by direct observation of salt loads in the River Murray, they are shown in italics.

b The map, figure 1, indicates that nearly 50 per cent of the Basin has not been assessed.

c In South Australia irrigation loads are derived from recent Land and Water Management Planning studies AWE 1999.

d Data from Victoria and New South Wales State report combined with Commission Salinity and Drainage benchmark models.

e The New South Wales study assumes that salt load contributions to the Darling other than those from its eastern tributary catchments will not increase.
Salt Retained in the Landscape

A very important finding of this Audit is the estimation that much of the salt mobilised does not get exported through the rivers and on to the sea. It stays in the landscape or gets diverted into irrigation areas and floodplain wetlands.

Currently, of the 5.1 million tonnes mobilised, about 3 million tonnes is retained. By 2050 the salt mobilised will reach 8.3 million tonnes. However, 3.3 million tonnes will be exported to the rivers. This will rise to 3.8 million tonnes per year by 2100, resulting in build-up of salt in the landscape of about 5 million tonnes per year.

It is one thing to know the quantity of salt moving in a landscape or in a river, it is quite another thing to estimate its impact on productive and environmental assets.

Impact studies and cost estimates for salinity across Australia have identified four key areas of concern:

- Declining water quality in rivers
- Loss of productive land
- Damage to built infrastructure such as buildings and roads
- Degradation of the environment, including loss of biodiversity.

This Basin Salinity Audit draws implications for all these community- and privately-owned assets.

Figure 7: Salt Mobilised and Exported to Rivers, 1998, 2020, 2050 and 2100
River Salinity

The level of salinity in a river at any time is a consequence of the salt load and the flow. Australian landscapes are naturally saline which, together with the climatic variation, means that extremes of salinity were common.

The regulation of rivers for water supply has moderated these extremes. However, as diversions have risen, together with increases in induced salt accessions, the rising trend of salinity in rivers is of growing concern. Previously, salinity in rivers was considered to be a downstream problem and this continues to be so for the River Murray. However, a major finding of this Audit is the extent to which salinity levels are rising in tributaries of the Murray–Darling system.

A critical challenge for the Salinity Audit has been the need to estimate how much of the salt mobilised in each catchment actually reaches the rivers and then to estimate the likely diversions of salt from the rivers that will be re-stored in irrigation districts and wetlands. This has involved carefully examining the existing salt export processes and how these might change in the future. Readers are referred to the State reports on which this Basin Salinity Audit is based for further explanation.

Suffice it to say that less than half of the salt mobilised today is actually reaching the rivers and that overall, a similar ratio is expected to prevail into the future. The State Salt Load reports have identified local variations to this assumption. Importantly, in the Mallee zones of Victoria and South Australia where salt inflows are through direct seepage to the rivers, all of the salt mobilised is expected to reach the rivers. Elsewhere, in catchments with poor drainage features, salt is expected to accumulate in the landscape.

Using estimated salt exports into the future and modelled flow regimes for rivers under Cap conditions, it is possible to predict salinity levels at key stations in the rivers. This is highly relevant to water users, who experience salinity levels rather than salt loads.

The 1997 Salt Trends report confirmed the increasing salinity in many rivers of the Basin, based on actual measured data for 1975–95. The Salt Loads study correlates these data with its modelled outputs, and estimates river salinities for 2020, 2050 and 2100.

Figure 8 gives a Basin-wide summary of predicted river salinities, with the Macquarie, Namoi, Bogan, Condamine–Balonne, Border (Queensland) and Warrego Rivers exceeding an 800 EC threshold within 20 years; the Lachlan and Castlereagh Rivers exceeding 800 EC within 50 years; and the lower River Murray above 800 EC, on average, in 50–100 years. The Avoca and Loddon Rivers already exceed 800 EC, on average. However, these projections require further interpretation. Much of the cost of rising salinity is borne by the water users of the Basin, in particular producers of high value crops such as horticulture, and the urban water users of the River Murray. Environmental impacts are not so readily estimated.

The River Murray

The three States of New South Wales, Victoria and South Australia are the primary stakeholders of the Murray, but as the most developed river resource and because of its importance to ecosystems, it has national importance. Salinity has been a critical water quality constraint since the earliest stages of development.

CUMULATIVE IMPACT OF BASIN SALINITY AT MORGAN

It is in the nature of catchment processes that downstream water resources are impacted by land and water quality degradation and ameliorated upstream by ecological systems. Throughout the history of the Murray–Darling Basin Initiative, there has been a strong focus on the lower River Murray and its water quality. This is a key feature of the current Salinity and Drainage Strategy — a range of measures with a notional target of improving salinity at Morgan to less than 800 EC 95 per cent of the time while at the same time preventing salinisation of up to 869,000 hectares of irrigated land in Victoria and New South Wales. The threshold for desirable drinking water quality is 800 EC. In the previous decade, 1975–85 (Figure 9), salinity exceeded 800 EC 42 per cent of the time. Currently the exceedence is 8 per cent as a result of the Salinity and Drainage Strategy.

Current best knowledge of the cumulative impact of Basin-wide river salinity is summarised in Table 2. It is important to understand the sources of this salinity, and what component of the salinity trend is not accountable under the current Salinity and Drainage Strategy. The key indicator site for monitoring and projecting these salinity trends is Morgan in South Australia. It is located upstream of the major off-takes of water to Adelaide and the industrial ‘Iron Triangle’, but downstream of the major irrigation developments, including those in South Australia.
Salinity and Drainage Strategy

The aim of the Salinity and Drainage Strategy is to improve the water quality of the River Murray against a trend of increasing salinity levels, while providing irrigation districts with protection against waterlogging and salinisation.

The Salinity and Drainage Strategy is a unique development in public policy whereby two essentially conflicting aims are met through financial transactions. Simply put, irrigation districts can acquire the right to dispose of saline drainage water, provided they collaborate financially in building and operating salinity mitigation works and measures further downstream. These initiatives are required to reduce salinity levels there by at least twice as much as the disposal increases salinity.

In the mid-1980s, studies showed that 96,000 hectares of irrigated land in the Basin were showing visible signs of salinisation, and it was estimated that the area affected by high water tables could increase from 559,000 hectares in 1985 to 869,000 hectares in 2015.

At the same time, it was estimated that the average salinity at Morgan would increase by 30 to 75 EC within 30 years. It was thought that this increase in river salinity was largely due to contributions from increased drainage and groundwater discharges from irrigation areas along the length of the Murray. At that time, the relative contribution from dryland areas was thought to be very small.

Clearly, river managers faced a dilemma. This downstream impact had become the basis of court action between South Australia and New South Wales. On the other hand, it was helpful that the hazards could be reasonably well quantified in economic terms. Engineering schemes, which could effectively intercept salt, could be shown to be economically viable. Some schemes had already been constructed. However, the more economically attractive opportunities had been taken up and later schemes were becoming increasingly expensive. Also, downstream users were not keen to build new schemes while salt discharges from upstream continued to be allowed.

The then River Murray Commission adopted an interim objective to maintain salinity levels at Morgan at less than 800 EC 95 per cent of the time.

With this in mind the Murray–Darling Basin Ministerial Council approved the Salinity and Drainage Strategy shortly after its formation. This Strategy commenced operation on 1 January 1988. It provides a framework for reducing salinity while at the same time meeting some of the demands of upstream irrigators to drain areas with limited disposal rights to the river. These rights were negotiated by providing financial support for salinity reduction works further downstream. The rights have become known as salinity credits; they are a tradeable ‘pollution right’.

The essential features of the Salinity and Drainage Strategy are:

- river salinity levels over the period 1975 to 1985 are adopted as the benchmark for attributing impacts of all future actions that affect river salinity
- each State is responsible for its actions affecting river salinity
- no actions that increase salinity are allowed unless they are offset by works to ameliorate them.

At the time the Strategy was initiated, increased salt loads from current commitments and from developments undertaken before 1988 were accepted as part of the baseline, even though they were not well defined.

The Strategy provided for a package of actions that would reduce salinity immediately through river dilution flows (about 35 EC), jointly-funded engineering works (80 EC) and provide 30 EC in salinity credits for actions that would exacerbate salinity levels, such as drainage works and further irrigation development. The expected net improvement, once river dilution flows were incorporated into the benchmark river salinity, was 50 EC. Further, any State can undertake additional salinity interception works, and the accrued credits may offset other actions contributing to salinity.

This Strategy provides a clear distinction between accountability for past and future actions. States are fully accountable for future actions but not accountable for past actions or the ‘background’ trend. Because of this, the Strategy is an effective policy in contemporary terms but it is not a long-term solution. However, it has precipitated identification and implementation of solutions by creating a real value and accountability for salt pollution.

The projections on which the Salinity and Drainage Strategy is based are shown in Figure 8.

Estimations of future salt loads in the Audit indicate that these trends are more severe than had been anticipated. To acknowledge this is not a criticism of the Salinity and Drainage Strategy; it underscores the fact that we face a greater dilemma than that predicted a decade ago. Since the implementation of the Strategy, river salinity has improved markedly, despite the underlying trend of rising salinities. The Commission has now built up a sound record of experience upon which to determine a strategy of salinity management for the coming decades.

![Figure 8: Forecast of Salinity at Morgan](image-url)
In 1988 when the Salinity and Drainage Strategy was agreed, the average salinity at Morgan adopted as the benchmark after allowing for agreed changes to river operations was 583 EC. Under the provisions of the Strategy, which include joint interception schemes and drainage works, States have agreed to a program that achieves a net improvement of 50 EC while offsetting the salinity impacts of irrigation and drainage developments after 1988.

At that time it was acknowledged that an underlying trend of increasing salinity prevailed. The results of this Audit suggest that for the past decade this amounted to 40 EC. The Audit indicates a further increase of 218 EC over the coming 50 years (see Table 2). The average salinity at Morgan will be 791 EC by 2050 and 900 EC by 2100, an increase of 330 EC from 1998 without consideration of the impacts of diversion increases since 1988.

It is evident that the Salinity and Drainage Strategy program of works has yet to achieve the target that would keep salinity levels below ‘800 EC for 95 per cent of the time’. Within 20 years, the salinity regime of the 1970s and 1980s will return, with salinity levels again exceeding 800 EC 40 per cent of the time.

The important estimate to be considered in the context of this Audit is the expected 218 EC increase at Morgan that is not accommodated within the Salinity and Drainage Strategy. Only 28 EC of this increase in attributable to irrigation and drainage developments from before 1988. While the table is incomplete (it lacks estimates for salinity attributable to some sources in Victoria, New South Wales and Queensland), it does point to a changing balance in sources of salt over the next 50 years. Future salt exports will shift from irrigation-induced sources to dryland catchment sources. In general, irrigation-induced salinity tends to stabilise over a few decades whereas dryland processes take much longer. Of the projected increase of more than 218 EC by 2050, 115 EC arises from the cleared dryland region of the Mallee zone of South Australia and Victoria and 75 EC from the dryland tributary catchments of Victoria, New South Wales and Queensland. That is, 60 per cent of the salinity increase in the lower River Murray is attributable to dryland sources, 37 per cent from the Mallee zone and 24 per cent from other catchments. Unlike the irrigated regions, these dryland sources and older irrigation sources are not offset by any actions under the Salinity and Drainage Strategy.

The data presented in this table have been calculated using the Commission's hydrologic model of the Murray System on the basis of predictions of the salt load contributions from each valley in the Basin provided by the State Salt Loads studies. The future impacts from irrigation and drainage developments that were installed before 1988 are excluded from the provisions of the Salinity and Drainage Strategy. Estimates are not yet available for Victoria and New South Wales. The reductions due to salinity mitigation works and measures reflect current schemes or future commitments of the States to be accountable for increases in salinity arising from actions since 1988. The table also reflects an indication of a need for future drainage works within Land and Water Management Plans resulting in a need for salinity credits beyond those provided from the initial program of works designed to achieve a net reduction of 50 EC.

**Table 2: Estimated Change to Average Salinity of the River Murray According to Source of Salt Load, Morgan, South Australia, 1998–2050**

<table>
<thead>
<tr>
<th>Source of salinity change</th>
<th>Irrigation areas</th>
<th>Dryland</th>
<th>Net change</th>
<th>Average salinity at Morgan</th>
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<tbody>
<tr>
<td></td>
<td>Salinity mitigation works and measures</td>
<td>Post-1988 developments</td>
<td>Pre-1988 developments</td>
<td>Mallee zone</td>
</tr>
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<td></td>
<td>All figures are average EC Units at Morgan</td>
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<td></td>
<td></td>
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<tr>
<td><strong>Salinity and Drainage Strategy</strong></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Benchmark 1988</td>
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<td>583</td>
</tr>
<tr>
<td>Expected net outcome</td>
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<td></td>
<td></td>
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<tr>
<td>Joint works</td>
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<td>-50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>State actions</td>
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<td></td>
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</tr>
<tr>
<td>South Australia</td>
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<td></td>
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<tr>
<td>Victoria</td>
<td>-26</td>
<td>26</td>
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<td></td>
</tr>
<tr>
<td>NSW</td>
<td>-20</td>
<td>20</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td>-142</td>
<td>92</td>
<td>-50</td>
<td>533</td>
</tr>
<tr>
<td><strong>Salinity outcome</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Background change since 1988</td>
<td>40</td>
<td>40</td>
<td>573</td>
<td></td>
</tr>
<tr>
<td>Projected change from 1998, not accountable within S&amp;D Strategy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South Australia</td>
<td>26</td>
<td>82</td>
<td>–</td>
<td>108</td>
</tr>
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<td>Victoria</td>
<td>2</td>
<td>33</td>
<td>18</td>
<td>53</td>
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<td>47</td>
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<tr>
<td>Queensland</td>
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<td>10</td>
</tr>
<tr>
<td>Totals</td>
<td>28</td>
<td>115</td>
<td>75</td>
<td>218</td>
</tr>
<tr>
<td><strong>Future Salinity 2050</strong></td>
<td></td>
<td></td>
<td></td>
<td>791</td>
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</tbody>
</table>

Note: The data presented in this table have been calculated using the Commission's hydrologic model of the Murray System on the basis of predictions of the salt load contributions from each valley in the Basin provided by the State Salt Loads studies. The future impacts from irrigation and drainage developments that were installed before 1988 are excluded from the provisions of the Salinity and Drainage Strategy. Estimates are not yet available for Victoria and New South Wales. The reductions due to salinity mitigation works and measures reflect current schemes or future commitments of the States to be accountable for increases in salinity arising from actions since 1988. The table also reflects an indication of a need for future drainage works within Land and Water Management Plans resulting in a need for salinity credits beyond those provided from the initial program of works designed to achieve a net reduction of 50 EC.
River Salinity Levels, Thresholds and Exceedances

Salinity is defined as the amount of dissolved salts in water, typically measured in milligrams per litre or mg/L total dissolved salts (TDS).

Normally this is done by evaporating off the water and measuring the weight of the residue.

THE EC UNIT

However, the most widely used and convenient method of estimating the salinity concentration in water is by electrical conductivity, using highly portable and inexpensive equipment. One measure of electrical conductivity is micro-Siemens per centimetre or µS/cm. The shorthand expression used in Murray–Darling Basin Commission databases and communications is the electrical conductivity unit, EC Unit or just plain EC.

To convert one EC unit to mg/L (TDS), a conversion factor of 0.6 generally applies. This factor varies for very high salinity water or water with unusual chemical composition.

THRESHOLD SALINITY LEVELS

As an easy aid to the interpretation of the Basin Salinity Audit’s findings, all river salinities are gauged against three tolerance levels — threshold levels where options for consumptive use or impacts on the environment change significantly. These are:

- **800 EC units**: 1,500 EC units 5,000 EC units.

**800 EC threshold**: This is a figure of special significance to the Salinity and Drainage Strategy, with its focus on reversing salinity in the lower River Murray. The notional target in 1989 was to improve the salinity at Morgan, South Australia, to less than 800 EC 95 per cent of the time. According to the World Health Organisation, 800 EC is considered to be the upper salinity limit for drinking water desirability. Although water with more TDS can be safely consumed for short periods, it is less desirable. Yield reductions can occur for irrigated crops at salinity levels lower than 800 EC, but this very much depends on crop sensitivity, irrigation technology and soil type. From 800 EC it becomes increasingly difficult to manage irrigation and at this level, damage to tree crops has occurred.

- **1,500 EC**: At this salinity concentration, the options for consumptive use of water start to be restricted. Irrigation of most leguminous pastures and forage crops is very risky. Rice, maize and grain sorghum should not be irrigated at this salinity, and soybean only on well drained soils.

- **5,000 EC**: This is generally accepted by aquatic ecologists to be the value that divides fresh water from saline water. Above this level, saline ecosystems are quite different in species composition and restricted in species richness and diversity. While adult freshwater fish can tolerate salinities much greater than this, most aquatic fauna and young fish cannot, except for short periods.

From the point of view of irrigation, the recommended upper limit for water quality is 2,300 EC, and for mixing with herbicides it is 4,700 EC. Few crops can be irrigated; and those that can — cotton, barley, wheat, canola and sunflower — only on well drained soils with best practice irrigation technology.

**SALINITY CHANGE TRIGGERS**

The draft Australian and New Zealand guidelines for fresh and marine water quality (ANZECC, 1999) provide triggers for salinity change. They include a 500 EC increase for lowland rivers and a 110 EC increase for upland rivers. Increases of these magnitudes are ecological warning signals.

**VARIABILITY AND EXCEEDANCES**

It is usual for river salinities to be reported as average or flow-weighted values, and that is the case in this Audit. Yet it is the variability in salinity levels that makes management and use more difficult. When interpreting the figures of the Salt Loads study for future years, it is important to predict how often and how long salinities are likely to exceed these tolerances.

Figure 9 is a record of River Murray salinity at Morgan for two periods in time. It shows that for 1975–85, river salinity exceeded the 800 EC threshold for desirable drinking water quality 42 per cent of the time. Following the implementation of the Salinity and Drainage Strategy between 1990 and 1999, exceedance was reduced to 8 per cent. This variability was moderated by river operations (dilution flows) guaranteed flow entitlements to South Australia and salt interception schemes. The extreme of 1,500 EC was no longer experienced.

Predicted river salinities in river valleys away from the highly regulated southern rivers will have even greater variation around the average. For key rivers in the Murray–Darling Basin, exceedances of the 800, 1,500 and 5,000 EC tolerance levels are estimated for 2020, 2050 and 2100.

**Figure 9: Morgan Salinity Before and After the Salinity and Drainage Strategy**

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**THE MURRAY-DARLING BASIN COMMISSION**
Table 4 provides an indication of the current and future flow-weighted average salinity levels at the end-of-system junction with the Murray and for selected reaches of some tributaries. In Victoria the risks and consequences of rising salinity are in the valleys themselves, although the Avoca and Loddon Rivers already exceed the 800 EC threshold on a flow-weighted basis. Table 4 is based on modelling of the 1998 situation and accounts for the partial implementation of the Strategy. Consequently, it estimates river salinity at Morgan to rise to 900 EC on average by 2100. This reflects the increased diversion in the Basin since 1988.

While rising salinity through the main stem of the rivers from the border to Wellington is of concern because of impacts on consumptive use of river water, there are serious implications for the lower lakes Albert and Alexandrina, and the many anabranches and billabongs. As the feedwater salinities rise and the consequences of reduced ‘whole-of-system’ flow equilibrate, these water bodies will become regularly saline. Symptoms are already apparent in off-river water bodies. Salinity levels above the 1,500 EC threshold at Goolwa occur occasionally.

VICTORIA

The Victorian region of the Murray–Darling Basin comprises a Mallee zone from the border to Swan Hill. In this region the Murray is still the major water course and there are no significant tributaries. Salt loads direct to the River Murray in this Mallee zone are significant.

The Western catchments, Avoca, Loddon and Campaspe, are already salinised and stream salinity levels reflect this.

The riverine plain region is low-lying flat land that has been subjected to dramatic changes in the hydrologic regime to support the extensive irrigation regions of Shepparton through to Kerang. Water is transferred westwards through canal systems that transect the lower reaches of the catchments. Drainage collection and disposal also complicate the hydrology.

Beyond the riverine plain the geology changes abruptly from the Murray sedimentary groundwater basin and becomes the fractured rock regions of the uplands. It is at this break of slope between these geologic and topographic regions that dryland salinity was first observed. Further upstream the tributary catchments become increasingly important in their contribution to flow but less significant for their contribution to salt loads and salinity. Water from these catchments originates in the alpine regions above the snow line.

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NEW SOUTH WALES

New South Wales represents 57 per cent of the catchment of the Murray–Darling Basin. Despite the Murray forming part of the border with Victoria, there is little natural contribution of flow and consequent salinity direct to the Murray below the Hume reservoir at Albury. The main contribution of flow and salinity from New South Wales is from the Murrumbidgee and Darling catchments.

progressively, the additional loads induced from the Mallee dryland will begin to dominate. Without intervention, the combined salt loads will more than double by 2050.

The Salt Loads study estimates future salinities to rise above the 1998 levels by 330 EC units at Morgan over the next century if there are no new interventions other than those of the existing Salinity and Drainage Strategy. Significantly, the salinity of the lower Murray is already moderated by a special dilution flow, a minimum entitlement under the Murray–Darling Basin Agreement and major salt interception schemes. Yet some reaches are predicted to experience average salinities exceeding the 800 EC threshold for desirable drinking water quality. Table 3 is based on modelling of the 1998 situation and accounts for the partial implementation of the Strategy. Consequently, it estimates river salinity at Morgan to rise to 900 EC on average by 2100. This reflects the increased diversion in the Basin since 1988.

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A HUNDRED-YEAR PERSPECTIVE

Above Albury the inflows are very fresh and are supplemented with good quality water through the Snowy Mountains Scheme. The potential for salinity increases in this region is expected to be low and has not been studied.

Further downstream of the Hume Reservoir, the Edward and Wakool Rivers divert flow away from the Murray, which is mostly used in the irrigation districts of Berriquin, Denilmein and Cadell. At Torrumburry water is diverted to Cadell, Denibootta, Tuliaakool and Wakool. Tailwater from these districts returns modest flow but significant salt accessions to the Murray.

The Yanco Creek and Billabong Creek draw Murumbidgee flows towards the Murray and Yanco irrigated districts. Salt accumulation occurs throughout these regions and discharges back to the Murray.

In the context of the Basin Salinity Audit, the Darling and its tributary catchments, together with the Murumbidgee, are of most significance to water users of the lower Murray below Wentworth. The Lachlan catchment is expected to become heavily salinised but will not discharge significant salt to the Murumbidgee or Murray except during the most severe flood flows.

The Salt Loads study has estimated river salinities at 2020, 2050 and 2100 for each river valley supplying water to the River Murray or Darling River. The Murumbidgee River currently carries very high salt loads, second only to the River Murray, and this is predicted to more than double over the next 100 years. Yet its salinity level will remain modest. In contrast, the Bogan, Macquarie, Castlereagh and Namoi Rivers face sharp rates of increase in salt loads and salinity levels, to a point where thresholds for consumptive use of water are exceeded on average (Table 5).

Specifically, the average salinities for the Macquarie, Namoi and Bogan Rivers exceed the 800 EC threshold within 20 years and the 1,500 EC level within 100 years. The Lachlan and Castlereagh Rivers exceed the 800 EC threshold within 50 years. These rises clearly have serious implications for future irrigation use and for environmental values. The salinity levels for reaches of the River Murray in New South Wales are included in Table 4.

QUEENSLAND

Almost 25 per cent of the Murray–Darling Basin lies north of the Queensland border. The major river systems include the Border Rivers, Condamine–Balonne, Warrego and Paroo Rivers. The Salt Loads study has estimated river salinities at 2020, 2050 and 2100 for the Border Rivers, and Condamine–Balonne and Warrego river valleys where sufficient groundwater data were available to predict salt loads mobilised to the land surface. Estimates were only undertaken for the Weir River and the Macintyre Brook catchments within the Border Rivers, which represent the majority of the land area of this catchment within Queensland.

This information has yet to be independently reviewed and should be considered preliminary in nature. The major assumptions used to estimate river salinity levels for the Queensland catchments include: all salt mobilised to the surface will reach the river system, either as surface wash-off or groundwater inflows; there are no major losses from the system below the source of additional salts; and flow regimes represented in the ‘current’ estimates will remain the same after the Water Allocation Planning processes for the Condamine–Balonne and Border Rivers and the Water Allocation Planning processes for the Warrego, Paroo and Moonie systems have been finalised.

A sharp increase in salt loads and salinity levels is predicted for the Condamine–Balonne, Border and Warrego Rivers, with estimated impacts by the year 2020. Once the rising groundwater trend has intercepted the land surface, then a uniform rate of salt discharge will enter the river system. Salinity levels will, on average, exceed the 800 EC threshold in all modelled catchments by the year 2020, and the 1500 threshold will be exceeded from 14 to 60 per cent of the time. After an initial sharp increase, the exceedance levels will not alter significantly for the next 100 years. Any variation in the current levels of inflow and diversion would require revision of the river salinity projections.

BASIN OVERVIEW

To date the focus on the threat of rising river salinity has been on the lower River Murray. The Salt Loads study predicts that average salinity at Morgan will exceed 800 EC in 50 to 100 years’ time. The dryland component of the Basin, particularly the Mallee region of South Australia and Victoria, will be a dominant source of future salt. Other tributary catchments will add about 25 per cent of the increment to the year 2050.

The Audit predicts, however, that even greater rises in river salinity will occur within other river valleys — specifically the Macquarie, Namoi, Lachlan, Castlereagh and Bogan Rivers of New South Wales and the Condamine–Balonne, Border and Warrego Rivers of Queensland. The Avoca and Loddon Rivers of Victoria already have high salinities. It is known that some tertiary streams feeding these rivers are experiencing even higher salinities, but they are not the subject of this Audit.

Table 5: Estimated River Salinity, New South Wales, 1998–2100

<table>
<thead>
<tr>
<th>River valley</th>
<th>Average river salinity (EC)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1998</td>
</tr>
<tr>
<td>Murrumbidgee</td>
<td>250</td>
</tr>
<tr>
<td>Wagga Wagga</td>
<td>140</td>
</tr>
<tr>
<td>Lachlan</td>
<td>530</td>
</tr>
<tr>
<td>Cowra</td>
<td>330</td>
</tr>
<tr>
<td>Darling River</td>
<td>360</td>
</tr>
<tr>
<td>Menindee</td>
<td>730</td>
</tr>
<tr>
<td>Bogan</td>
<td>620</td>
</tr>
<tr>
<td>Macquarie</td>
<td>440</td>
</tr>
<tr>
<td>Narromine</td>
<td>640</td>
</tr>
<tr>
<td>Castlereagh</td>
<td>680</td>
</tr>
<tr>
<td>Namoi</td>
<td>580</td>
</tr>
<tr>
<td>Gunnedah</td>
<td>560</td>
</tr>
<tr>
<td>Gwydir</td>
<td>450</td>
</tr>
</tbody>
</table>

Note: Data refer to the end of the system except the figures in italics, which indicate river reaches.

Table 6: Estimated River Salinity, Queensland, 1998–2100

<table>
<thead>
<tr>
<th>River valley</th>
<th>Average river salinity (EC)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1998</td>
</tr>
<tr>
<td>Warrego River</td>
<td>210</td>
</tr>
<tr>
<td>Condamine–Balonne</td>
<td>210</td>
</tr>
<tr>
<td>Border Rivers</td>
<td>310</td>
</tr>
</tbody>
</table>
Figure 10: Future Salt Loads and Salinities for Rivers of the Murray-Darling Basin
Landscape Salinisation

There have been countless studies, reports and observations on the amount of and trend in salt-affected land in parts of the Murray-Darling Basin.

More important for predictions of salt-affected land into the future, there have been groundwater monitoring and mapping of high water tables. However, this has generally been on a local basis, and usually carried out in irrigation areas. While this mapping has been important for local planning and action, it does not aggregate to Basin-wide trends and reliable estimates of future salinity cannot be made.

The Salt Loads study makes a further contribution to this predictive capacity by allowing the classification of geologic units across the Basin according to their rate of groundwater rise and identifying those areas where water tables are likely to reach 2 metres from the land surface. While these are not estimates of salt-affected land, such as, they do give a relative indication of the hazard in dryland catchments.

Irrigation Areas

Problems of rising water tables and soil salinisation arose soon after the establishment of the first irrigation schemes in the 1890s.

The process occurs much more quickly than in dryland areas, because the contribution of rainfall to recharge of groundwater is compounded by the application of large quantities of irrigation water. By 1987 it was estimated that 96,000 hectares of the Basin’s irrigated land were salt-affected and 560,000 hectares had water tables within 2 metres of the land surface. Water tables were continuing to rise rapidly in many areas. It has been predicted that all irrigation regions within the southern Basin will have water tables within 2 metres of the surface by the year 2010, without new interventions.

The Basin Salinity Audit provides no new estimates for salinity hazard to irrigation areas. Rather, the Salt Loads study estimates groundwater rise and salt mobilisation under entire catchments, including those parts irrigated. However, to complete the picture on salinity in the Murray-Darling Basin, current knowledge of hazards to irrigation areas is summarised here, acknowledging that continued adoption of improved practices will reduce these estimates of land requiring drainage in the future. The Queensland studies for this Audit have not yet considered the likelihood of rising groundwater levels beneath irrigation areas.

SOUTH AUSTRALIA

Within the Basin about 52,000 hectares of irrigated agriculture occur largely in ribbon development along the River Murray. Around 12,500 hectares are waterlogged and have been drained to relieve the build-up of salt and water. Without further intervention, the area at risk is likely to increase to 20,000 hectares.

VICTORIA

Of the 1 million hectares of irrigable land in Victoria, about 440,000 hectares have already suffered high water tables, and a major drainage program has been implemented. Without further intervention, the area at risk will increase to about 600,000 hectares.

NEW SOUTH WALES

In New South Wales a similar proportion of irrigated land (about 40 per cent) is prone to shallow water tables. For instance, of the 1 million hectares of irrigated land in the Murray and Murrumbidgee Valleys, around 160,000 had been drained by 1990 and 412,000 hectares will require drainage to manage waterlogging and control salinity by 2020.

Dryland Catchments

BASIN-WIDE

As recently as 1996 the area of salt-affected land in the basin was estimated to be 300,000 hectares, rising to as much as 6 million hectares when a new hydrologic equilibrium was reached. These figures were revised in late 1998, and reported to the Prime Minister’s Science, Engineering and Innovation Council as extending to about 9 million hectares in the future.

It is evident when examining these previous estimates that the terminology has varied. In particular, the definition of salinised area needs careful interpretation. As a general rule, the term ‘salinised’ is used when accumulated salt begins to cause significant reductions in yield with an increasing tendency to prefer salt-tolerant species, for example barley grass. This does not necessarily mean the salt-scarred landscapes so often dramatically depicted in photographs. In undulating landscapes, severe salinisation will often only occur in the valleys and at the break of slope. Milder salinisation causing reduction in yield will be more widespread. Often it is waterlogging rather than severe salinisation that causes tree death for native vegetation.

On the other hand the Salt Loads study featured in this Audit is based on an analysis of the groundwater regimes within selected geologic units. The Study was specifically designed to assess the likely future salt loads exported from the dryland landscape towards the rivers. However, in an Audit of likely salinity hazards to all productive and environmental assets it is important to also estimate land impacts. To do this it has been necessary to apply considerable professional judgement to the task. The following estimation process was adopted in the Salt Loads study:

- The area of each geologic unit that currently has water tables at or close to the surface
- The area of each unit that is currently experiencing rising water tables
- The proportion of that area that is likely to experience waterlogging in 2020, 2050 and 2100
- The proportion of the waterlogged area that is likely to experience salinisation in 2020, 2050 and 2100.

This approach suffers from progressive reductions in confidence about the predictions, and conclusions about salinised land areas need to be heavily qualified.
The variations in data available within each State have also made the task more challenging. Victoria has the best available data-sets for groundwater observations. The study for Victoria also had access to a digital elevation model that is very useful in improving the estimates. Such elevation data will soon be processed for New South Wales; however, its groundwater data cannot be rapidly improved. A similar limitation applies to Queensland and South Australia.

The Salt Loads study’s Basin-wide estimates for land with high water tables are presented in Table 7. These estimates need careful interpretation, and this is provided in the State reports below.

SOUTH AUSTRALIA
Dryland salinity occurs in most agricultural regions of the State, with the Murray Basin area a significant proportion. The rising watertable in the regional aquifer has affected low-lying areas on the Coastal Plain around Lake Alexandrina and Lake Albert, with additional areas of salinisation in the Mallee at the Noora–Yamba groundwater discharge zones near Loxton. Both these areas will not increase salt loads to the River Murray. Table 8 shows the areas at risk in each Basin sub-catchment.

Currently, about 68,000 hectares are salt-affected and this will increase to 116,000 hectares without intervention by 2050. The area for the largest potential increase is the flat terrain in the Cooke Plains–Coomandook area. Elsewhere, the spread is constrained by steep undulating dune-swale topography in the Noora–Yamba area, and the high groundwater discharge from already salinised areas close to the lakes. These areas protect the lakes from salinity increases due to regional water table rise and have limited the impact of the elevated lake levels following barrage construction.

The floodplain along the South Australian River Murray is also significantly affected, with an estimated 25,000 hectares salinised of a total area of 100,000 hectares. This is predicted to increase to about 40,000 hectares, mostly adjacent to highland irrigation areas.

The tributary valleys of the eastern Mt Lofty Ranges are heavily cleared with some showing isolated areas of salinisation. The affected tributaries flow into the river or lakes only in very wet years.

In summary, 1 per cent of the land area is currently at risk of rising groundwater and this is predicted to rise to 2 per cent. Given the relatively flat terrain, the very high groundwater salinities and the low rainfall in South Australia, it is likely that most of the area

<table>
<thead>
<tr>
<th>Region</th>
<th>Sub-catchment area (ha)</th>
<th>Area salinised (ha)</th>
<th>Area at risk of salinisation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1998</td>
<td>2020</td>
<td>2050</td>
</tr>
<tr>
<td>Mallee</td>
<td>5,850,000</td>
<td>4,000</td>
<td>4,100</td>
</tr>
<tr>
<td>Coorong &amp; Districts</td>
<td>350,000</td>
<td>25,000</td>
<td>37,000</td>
</tr>
<tr>
<td>Murray Floodplain</td>
<td>100,000</td>
<td>25,000</td>
<td>32,000</td>
</tr>
<tr>
<td>Irrigation areas</td>
<td>52,000</td>
<td>12,500</td>
<td>20,000</td>
</tr>
<tr>
<td>Eastern Hills</td>
<td>550,000</td>
<td>1,500</td>
<td>3,000</td>
</tr>
<tr>
<td>Total</td>
<td>6,900,000</td>
<td>68,000</td>
<td>96,100</td>
</tr>
</tbody>
</table>
suffering waterlogging will become salinised soon after. In this study it is presumed that 80 per cent of the area waterlogged will become salinised.

MALLEE REGION

The Mallee is a unique geomorphic region that straddles South Australia, Victoria and New South Wales. It is country of very low rainfall (250 mm/year) and the native vegetation has evolved to capture all but 1 per cent of rainfall. The very deep-rooted trees allow just enough percolation past their rootzone to leach salts to the lower depths. Under agricultural land uses, the net recharge has increased to 20–40 mm/year. Given the great depth to regional groundwater, it is likely that salinisation of the land surface will not occur for more than 100 years. It is estimated that ultimately 5 per cent of the cleared Mallee will be salt-affected.

VICTORIA

Salt storage in dryland catchments is increasing now and will continue for at least 100 years in some areas. The amount of saline discharge to the land surface is greatest in the Avoca catchment. The saline discharge to the River Murray is greatest in the Goulburn–Broken catchment, and there are already significant areas with high water tables. Projections are that in 20 years, all of the riverine plains will have water tables at 2 to 5 metres and in 50 years, all water tables will be within 2 metres.

The Salt Loads study has contributed to more precise and reliable estimates of salinity hazard, because of the inclusion of digital elevation modelling. The land areas with elevated water tables can be differentiated and mapped (Figure 11).

A high proportion of the cleared land is experiencing rising groundwater. It is predicted that 36 per cent of Victorian dryland catchments outside the Mallee will have a high water table (within 2 metres of land surface) by 2050. Much of this area of 1.1 million hectares will be at risk of saline discharge or soil salinity by 2100, and of the 843,000 hectares predicted to be salt-affected, 254,000 hectares will be severely salt-affected (Table 9).

In summary, an average of 5 per cent of Victorian river valleys will be severely salt-affected, and 17 per cent will be less affected within 50 years.

NEW SOUTH WALES

In the Salt Loads study for New South Wales, the bore data indicated that there are now potentially 5.4 million hectares with groundwater at or near the land surface. Since much of this area is on the western slopes with significant topographical relief, the areas of saline discharge are limited to the lower parts of the landscape and break of slope locations. The proportion of land area likely to be waterlogged and discharging groundwater will have to be determined through the application of a high-resolution digital elevation model (DEM). In terms of future areas of salinised land, the low groundwater salinity in some geologies and the effective landscape flushing rate will determine how much less this salinised area will be compared with the waterlogged area.

It is estimated that up to 12.3 million hectares are experiencing rising groundwater levels, or about 20 per cent of land area within the Basin. For individual catchments east of the Bogan and Darling Rivers, 40 to 80 per cent of their areas have rising groundwater levels.

It is not yet possible to provide a more precise estimate of land area with high water tables and the land area that is potentially salt-affected. However, an ultimate waterlogged area of some 5 to 7 million hectares would be a realistic order of magnitude, while serious salinisation would be experienced in a significantly smaller area; perhaps in the order of 2 to 4 million hectares. Figure 12 shows higher rates of groundwater rise in the southern Basin and groundwater falls in some parts of the northern Basin. Importantly, elevation data are now being brought into the modelling that supports this study and this will allow future estimates of land at risk of salinisation.

QUEENSLAND

Secondary salinity associated with rising water tables has been observed within the upland land systems of the eastern Darling Downs since 1958. Isolated occurrences of soil salinity have also been noted in the Inglewood district. Some 60 sites in the Toowoomba–Clifton–Pittsworth–Brymoo region of the eastern Darling Downs have been indentified, totalling more than 1,000 hectares affected by dryland salinity within the Queensland portion of the Murray–Darling Basin (predominantly on the basaltic landscapes of the eastern Darling Downs).

It is not expected that dryland salinity in Queensland will dominate the landscape within the next 100 years, as observed in some catchment of southern and western Australia. This is due to the combination of groundwater regimes, landscape characteristics, soil types, land use and climate in Queensland. However, we may see a significant increase in the frequency and extent of localised salinity outbreaks, which may impact on agricultural productivity, infrastructure and stream salinity. Salinity hazard mapping has been trialled in three sub-catchments in Queensland, but no state-wide assessment of salinity risk has been undertaken.
The Salinity Audit has allowed an estimation of land areas at risk of waterlogging and, potentially, salinisation, based on observed rates of groundwater rise. Given that the current expression of salinity in Queensland is associated with localised groundwater systems and landscape features, the actual area likely to be waterlogged and discharging groundwater or eventually salinised will need to be estimated using more refined techniques than those used for a catchment scale audit.

Estimates indicate that there will be potentially 633,000 hectares (2.4 per cent) of the Queensland Murray–Darling Basin with water tables within 2 metres of the surface by the year 2020. This area stabilises at this level due to the ‘at risk’ hydrogeomorphic units filling and no additional units filling within the modelled time frame.

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**Figure 12:** Annual Salt Contribution to Rivers, New South Wales, 2050, tonnes/km²
Productivity and Infrastructure Impacts

It has been estimated that dryland salinity costs $250 million per year nationally. While this provides a useful measure of the scale of the problem and the priority for a policy response, it does not inform what actions might be taken.

Such estimations are based, in part, on income foregone and therefore are of questionable validity. There is a contradiction in assessing the costs to agriculture when it is precisely that land use that contributed to salinity. Also, over time, technologies advance and management adapts to salinity. A cost at one time may not be a cost at a later time. Few comprehensive studies of the impacts of salinity incorporate a means of estimating the benefits and costs of policy, and management responses.

The Murray–Darling Basin Commission has undertaken two key investigations to better validate costs and to indicate the net benefits of managing salinity:

- salinity cost modelling for consumptive use of water resources of the River Murray
- cost impacts to rural and regional infrastructure from rising water tables and salinity.

The results are reported in this Audit, although they are still preliminary estimates.

Cost Impacts to River Murray Users

There are four main areas where river salinity has an impact: irrigated agriculture, domestic and commercial water supply, industrial water supply, and environmental water dependencies.

In developing and implementing the Salinity and Drainage Strategy for the River Murray, the Commission linked its hydrological modelling to economic modelling based on cost impacts to users along the length of the River. Studies dating back to 1970 have estimated incremental costs of or benefits from changes in average salinity. The most recent of these ‘cost functions’ studies was completed in February 1999.

This study examined the costs associated with actions within a river reach that cause salinity to users along the reaches of the River Murray downstream of Tocumwal, and the Darling downstream of Menindee Lakes. The agricultural impacts covered all crop types dependent on the River Murray and took into account the different irrigation technologies and soil types involved. The domestic and industrial water supply impacts considered costs associated with water treatment, soap and detergent use, plumbing and hot water systems, and inconvenience (taste and odour). Not all of these impacts were sensitive to rising salinity within the range examined (550–700 EC).

The study found that under current conditions, the value of one EC unit change in river salinity at Morgan in South Australia lies in the range of $93,000 to $142,000 per year. Assumptions regarding long-term toxicity impacts on fruit trees and grapevines account for this range. This estimated impact concurs with a 1984 figure of $140,000 per EC per year. More than 90 per cent of the salinity impacts are experienced in South Australia, even though the events leading to rising salinity occur along the length of the rivers. Aquatic environment impacts were assessed through a literature study and it was concluded that up to 1,500 EC, it was unlikely that impacts would be measurable.

Total cost varies significantly, depending on the location of the action that causes the change in river salinity and, therefore, the number and mix of downstream users. At current salinity levels, the cost could vary from $65,000 per EC if the increase is due to an action near Lock 3 in South Australia, downstream of major irrigation areas, to $151,700 per EC for an increase caused by an action near Swan Hill in Victoria. Further, the marginal cost per EC will increase in the future if river salinity increases; from $151,700 per EC for actions at Swan Hill and a median 550 EC at Morgan, to $200,000 per EC when salinity at Morgan rises to 660 EC.

The total economic impact due to current levels of salinity in the $46.2 million per year. This will increase further if no new actions are taken.

The distribution of economic impacts has changed over time, and this is largely attributable to technological changes, land use changes and adaptation by consumers. For instance, this most recent study found that the cost to agricultural users, especially horticulturalists, is much higher than previously estimated, while domestic and industrial costs are lower than previous estimates. In contrast to earlier times, the use of soaps and detergents, and the costs to water supply infrastructure and treatment did not vary with salinity levels.

The ratio between agricultural and non-agricultural impacts varies, depending on where the salt is discharged to the river. Similarly, the ratio of impacts on States varies with the location of the salt discharge. For an increase in salinity at Morgan due to an
action near Swan Hill, the agricultural impacts are 61 per cent of total impacts.

These contemporary estimates of cost impacts — how they are shared across consumptive users and how they vary according to the location of an action contributing to an incremental rise in salinity — establish a basis for future investment decisions about mitigating river salinity in the Murray.

Cost Impacts in Other Catchments

Studies in selected areas of the Basin, namely the Loddon–Campaspe catchments in Victoria and the Upper Macquarie catchment in New South Wales, have determined that the two most common types of cost to infrastructure from rising water tables and salinity are:

- those associated with the use of saline river water, usually in urban areas, for example, increased production costs for urban businesses; internal damage to council water supply and reticulation systems; and internal damage to urban household water reticulation systems and household appliances and equipment.
- those associated with rising water tables, in both urban and rural areas, for example, damage to urban streets, buildings and recreation areas; external damage to underground infrastructure such as sewerage, water supply, telephone, gas and electricity supply systems; damage to rural roads, farm buildings and infrastructure; and reduced farm productivity.

Rising water tables can be exacerbated in urban centres by over-watering of parks and gardens and old leaky stormwater and sewerage systems. Rising water tables in new urban estates that were once agricultural land can be due to a combination of high water tables, were estimated at $430,000.

People who bear the impact costs of rising water tables and salinity may be grouped into five main categories — local councils, state agencies and public utilities, urban businesses, urban households, and farmers. Salinity may also indirectly affect people by reducing the quality of the natural environment.

Impact costs borne by the above stakeholders may be grouped into four main classes.

- additional repair and maintenance costs of infrastructure and equipment. These relate to the additional cost of maintaining assets in an undamaged state in saline areas. For example, the annual cost of maintaining a sportsground may increase by 25 per cent when it is affected by high water tables.
- the cost of undertaking protective works or actions. This relates to the additional cost incurred to minimise the impacts of rising water tables and salinity. For example, it could include the up-front cost of purchasing rainwater tanks to avoid the damage to household water reticulation systems and appliances, or the cost of using higher specification materials in the construction of roads and buildings to increase tolerance to rising water tables and salinity.
- the cost associated with shortened expected lifespans of infrastructure and equipment. This relates to the need to replace infrastructure earlier than normal because of damage caused by saline or wet conditions. For example, a council bears extra costs if it has to resurface roads affected by rising water tables and salinity more frequently than roads unaffected by these problems.
- revenue foregone because of reduced capacity to use, or charge for, salinised infrastructure or services. These costs include the reduced net value of agricultural production from salt-affected farms. For example, rising water tables and salinity can decrease crop production and, in extreme cases, close production down altogether.

The two case studies below are the most comprehensive attempts to date to quantify the full range of costs of rising water tables and salinity. For both the Loddon–Campaspe and Upper Macquarie catchments, the annual costs were approximately $1 million per year in impact costs for every 5,000 hectares visibly affected by salinity. As these catchments are similar to other regional and local flow system catchments at risk of salinity, one way of estimating the likely future magnitude of impact costs is to adopt the $1 million in costs for every 5,000 hectares visibly affected as a rule of thumb. If it is assumed that up to five million hectares will become visibly affected by salinity by 2100, this coarse analysis suggests that Basin-wide impact costs could total about $1 billion per year by that time.

LODDON–CAMPASPE

The project assessed salinity costs in 1993–94 to farm and non-farm businesses, local governments, other government agencies and public utilities, and urban households.

On-farm costs in dryland areas, represented by the reduction in net value of agricultural production as a result of salinity and high water tables, were estimated at $430,000.

Most non-farm businesses considered that they were not affected by rising water tables and dryland salinity. Those that were affected reported increased repair and maintenance costs, while some also reported increased capital works expenditures. The total cost to non-farm businesses was estimated at almost $244,000.

Local governments spent an average of $77,000 on salinity-related repairs and maintenance to roads and buildings. A majority of local governments attributed a proportion of their capital works expenditure over a five-year period to salinity problems. They also incurred additional expenditure (over $56,000) on salinity-related research, community education and extension and they lost income from reduced rate levies on salinity-affected farmland.

Salinity costs to other government agencies and public utilities were reported at more than $1.9 million, with over 70 per cent of these costs being for research, education, planning and extension. Most agencies and utilities considered that their repair and maintenance costs had increased due to salinity, but they were unable to provide estimates. However, one agency reported that a $10 million wastewater treatment plant which would normally have a lifespan of 100 years was expected to have a life of only 16 years. The annual cost due to the reduction in lifespan was estimated to be equivalent to $450,120.
Urban households reported that the greatest salinity-related costs were due to action taken to improve water quality. More than half had installed a rainwater tank, with 13 per cent installing a water filter and 6 per cent buying bottled water.

In summary, the Loddon–Campaspe catchments had 11,400 hectares visibly affected by salinity at the time of the study, river water quality was also affected, and salinity-related annual costs were estimated to total $1.974 million.

**UPPER MACQUARIE**

This study refined the methodology developed in the Loddon–Campaspe study by examining impact costs of rising water tables and salinity on communities in the Talbragar and Little River catchments in the Upper Macquarie catchment in New South Wales. The identifiable annual costs due to rising water tables and dryland salinity in the Little River and Talbragar catchments are summarised in Table 11 below.

The major costs for repairs, maintenance and preventative works were borne by farmers. The significant cost to the agencies was largely their funding of education and research on the salinity problem. The Little River and Talbragar catchments had 16,000 hectares visibly affected by salinity at the time of the study, river water quality was also affected, and salinity-related annual costs were estimated to total $3.3 million.

**ROAD INFRASTRUCTURE**

It has been widely reported that about 34 per cent of State roads and 21 per cent of national highways in south-western New South Wales are affected by high water tables, causing damage costs of $9 million per year.\(^7\)

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**Table 11: Estimated Annual Costs of Rising Water Tables and Salinity, Selected Catchments**

<table>
<thead>
<tr>
<th>Annual costs</th>
<th>Little River $</th>
<th>Talbragar $</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farmers</td>
<td>770,743</td>
<td>918,653</td>
</tr>
<tr>
<td>Households</td>
<td>177,943</td>
<td>269,567</td>
</tr>
<tr>
<td>Businesses</td>
<td>39,097</td>
<td>15,368</td>
</tr>
<tr>
<td>Councils</td>
<td>74,188</td>
<td>80,390</td>
</tr>
<tr>
<td>Agencies</td>
<td>329,816</td>
<td>302,491</td>
</tr>
<tr>
<td>Total</td>
<td>1,454,786</td>
<td>1,586,469</td>
</tr>
<tr>
<td>Reduced property</td>
<td>212,777</td>
<td>25,952</td>
</tr>
<tr>
<td>values (per year)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total Costs</strong></td>
<td><strong>1,667,563</strong></td>
<td><strong>1,612,421</strong></td>
</tr>
</tbody>
</table>

---

\(^7\) Department of Industry, Science and Resources (1998).

Salinity causes damage to both public and private infrastructure.
Environmental Impacts

Salinity impacts on the environment in a number of ways; but for purposes of this Audit we distinguish between the riverine environment and the terrestrial environment, and focus on what is known or can reasonably be predicted for loss of biodiversity.

There have been few studies on the impacts of salinity on individual species, and thus this discussion must remain at a general level, drawing on observed effects in other regions (notably the south-west of Western Australia) and what is known of in-stream and terrestrial ecological processes and biodiversity.

While some Australian organisms are remarkably salt-tolerant, it is probably accurate to state that the vast majority are adversely affected by the salt levels associated with secondary salinisation. Apart from the direct impact of salinity on ecological processes (river banks, for example, are more susceptible to erosion), there are secondary impacts on ecological processes as the more salt-intolerant species are removed from the landscape. Where, for example, trees die, the physical structure of the ecosystem changes and habitat for a range of flora and fauna disappears.

There are impacts on local endemic species (restricted to the Murray–Darling Basin) and threats to Ramsar sites. (The Murray–Darling Basin includes many significant wetlands, some of which are internationally recognised under the Ramsar Convention.) These threats can to some extent be quantified; it would, for example, be possible using current data to project the impacts of rising aquifers on endangered species.

There are also less easily identified impacts that are exacerbated by the highly fragmented nature of the natural environment in the Murray–Darling Basin. Formerly widespread species are in many cases now restricted to a few localities, and entire ecosystems (such as many types of box-woodland) now have very limited extent. Given that the biodiversity of these is at best only partially known, measuring impacts is very difficult. Given that some species are restricted to the Basin, natural resource managers in the Basin have a special responsibility for these organisms.

Floodplain Impacts — South Australia

The River Murray floodplain in South Australia covers an area of about 100,000 hectares.

It supports a diverse and distinctive biota. The majority of the species found there are unique and restricted to floodplain habitats. These habitats are a thin thread of wetlands in an otherwise arid environment. Already substantial areas of degraded riparian vegetation have been identified and mapped.

Floodplain salinisation is brought about in a number of ways: river regulation, irrigation-induced groundwater rises, increased extractions from the river, floodplain disposal of saline drainage water, and groundwater rises in dryland catchments. These threats differ significantly from upstream wetlands where in-stream salinity levels are the dominant factor. Here, the highly saline groundwater adds to the hazard.

About 26,000 hectares or 25 per cent of the floodplain is currently influenced by salt. Best estimates are that a further 10 per cent may be salt-affected in 30 years. It is likely that 30-50 per cent of the River Murray floodplain of South Australia will be adversely affected within 50 years.

CHOWILLA WETLANDS

The Chowilla and Lindsay Island area around the tri-state borders is under significant threat. It is a wetland of international importance for migratory birds under the Ramsar Convention and is one of the few floodplain habitats that has not been intensively developed. It has retained the natural attributes of a meandering anabranch complex and endemic floodplain vegetation. This makes it a highly valued low impact recreational area and park management endeavours to retain those values.

Chowilla is the single largest natural salt inflow zone along the River Murray. The salt load has changed little since European development. However, flow regimes have changed as a result of river regulation. Saline accessions accumulate in floodplain soils during the years of low and moderate flows that now predominate. In recession after large floods much greater loads are released. The users on these river reaches maintain elevated groundwater levels under these areas, promoting direct discharge onto low-lying areas. The operation of Lake Victoria and river weirs also impact on the region in the same way.

The extent of vegetation in the Chowilla floodplain likely to be damaged by salinity has been estimated and mapped. Without new interventions, more than half of the 20,000 hectares will be lost.

Figure 13: Chowilla Wetlands, Vegetation at risk of Salinisation.
Wetlands Impacts — Victoria

Wetlands on the Victorian riverine plains will need to be monitored closely.

Being in the lower parts of the landscape, they will be subjected to the direct effects of the high regional water tables. In addition, streams that flow across the plains, and which could be the source of supply to wetlands on the plains, are those most likely to experience substantial rises in salinity.

AVOCA MARSHES

The Avoca Marshes are already being impacted by salinity, particularly Third Marsh. The underlying mechanism is believed to be a rising regional water table lying beneath the Marsh, which restricts recharge from the periodic floods. Hence, salt is accumulating from above and below the Marsh. With a projected increase in river salinity downstream of Third Marsh, from 1,440 EC in 1998 to 2,220 in 2050 and 2,990 EC in 2100, further damage is highly likely. These increases, on average, greatly exceed the 1,500 threshold for in-stream biota and the 500 EC trigger. Compounded by sub-surface processes whose significance is not yet known, the Avoca Marshes will be quite degraded within 50–100 years.

Wetlands Impacts — New South Wales

Wetlands affected by in-stream salinity levels vary from terminal systems to flow-through systems.

Often wetlands can be considered as partially terminal (the area of the depression that hold water when flood flows recedes) and partially flow-through systems.

The implications of salinity levels are more important when water is trapped in the wetland and, under evapo-transpiration, the water quantity is reduced while the salinity increases. This can lead to extremely high salinity levels in the wetland and critical salinity levels for remaining biota in the central or deeper areas of the wetlands. These effects can lead to severe salt scalding within a wetland and lead to a build-up of salt within the wetland system if flushing does not occur in subsequent flooding or filling events. If flushed, these areas could also be considered as temporary salt sinks on the floodplains, adding to the salinity levels in the flood-waters during subsequent floods.

If the current floodflow salinity levels are increased even slightly by contributions from dryland salinity, the implication for floodplain wetlands could be significant. A change in floodflow salinity from 500 to 750 EC may not appear to impact on a range of biota. However, a concentration from 3,000 EC to 10,000 EC at the end of one summer has been observed. If concentrations can treble, then at 500 EC this would lead to salinities within the wetland approaching 1,500 EC, at which some changes might be expected to be detected in the biota. And at 750 EC, this would lead to salinity levels of 2,250 EC, at which level changes in the biota might become significant.

The interaction of wetlands with groundwater is not clearly understood. In some locations there may be a direct discharge or recharge connection between river and groundwater levels, while in other areas groundwater levels may be the result of regional flow. Groundwater mounds (caused by a range of factors) could be influencing the water source of particular wetlands and either directly contributing water (and hence salinity) into the wetland or preventing the water from entering the natural groundwater and causing salinity to increase as the water is concentrated under evapo-transpiration.

GREAT CUMBUNG SWAMP

Although this is considered to be a terminal basin, the salinity level within the wetland is not significantly higher than the receiving waters from the Lachlan River. This is generally explained by the seepage of water into the shallow groundwater table. This results...
in the subsequent leaching of salt from rootzones. This process appears to have been operational during the period of the swamp’s development and maintenance.

The end-of-year average annual salinity level for the Lachlan (based on data from the gauging stations at Forbes) is expected to rise to 1,460 EC in the year 2100, as a result of dryland salinity alone. This exceeds a trigger level of 500 EC increase. Other factors may also lead to increasing salinity levels. Based on monthly salinity levels, the probability of exceeding the 1,500 EC threshold in the Lachlan at Forbes changes from nil in 1998 to 13 per cent in 2100. Note that daily or weekly variations in salinities could also be significant, depending on flow regime and source of saline inputs.

Given these average variations, the impact on the Great Cumbung Swamp could be a potential change in species composition (particularly in the macrophyte communities) and a reduction in species diversity. The Common Reed (Phragmites australis) would probably continue to exist in the swamp given the salinity levels expected. However, the area’s breeding potential (particularly for colonial species that rely on fresh water for drinking and invertebrates for feeding) could be reduced.

This would change significantly if the groundwater mound in the area prevented further seepage into the groundwater and led to the area becoming a truly terminal system with increasing salinity due to evapo-transpiration.

MACQUARIE MARSHES
The Macquarie Marshes are a predominantly flow-through system as opposed to a terminal basin and the impacts will be localised to individual areas within the system as the water evaporates and salts are concentrated into pools or depressions.

The expected average salinity for the Macquarie River on entering the Macquarie Marshes is expected to rise to 2,110 EC in 2100. This exceeds the 1,500 EC threshold and the 500 EC net increase trigger level. Based on monthly salinity data, the probability of exceeding 1,500 EC in the Macquarie River at Narromine changes from approximately 4 per cent in 1998 to 23 per cent in 2100. This could be assumed to occur in low flow periods but could still significantly affect in-stream biota (and hence the recruitment of biota into and between wetland areas).

This would have a significant impact on the Marshes with expected loss of species diversity and composition. This would begin to have an impact at 1,500 EC or lower, beginning in 2020 or later. The high salinity levels would also lead to increasing salinity within wetlands isolated from the main river channel with potential salt scalding occurring in these areas as the saline waters are further concentrated.

One implication of this change in salinity levels in the Macquarie River could be that the current 50 GL environmental water allocation for the Marshes might have to be used for water quality control for flushing these saline areas if they occur.

GWYDIR WETLANDS
The Gwydir wetlands are a flow-through system as opposed to a terminal basin and the impacts will probably be localised to individual areas within the system as the water evaporates and salts are concentrated into pools or depressions.

The anticipated average salinity for the Gwydir River entering the Gwydir wetlands is expected to rise to 740 EC in 2100. Based on monthly salinity data, the probability of exceeding the 1,500 EC threshold in the Gwydir at Pallamallawa changes from 3 per cent in 1998 to 12 per cent in 2100. Again, daily or weekly variations in salinity levels could also be significant, depending on flow regime and source of saline inputs.

This rise in the probability of exceedance of the 1,500 EC level (3 to 12 per cent) is significant. This would occur predominantly in low flow situations and would have impacts on the in-stream biota. Given these values, there could be a potential change in species composition (particularly in the macrophyte communities) and a reduction in species diversity.

High salinity levels, if allowed to enter the wetland areas, would also lead to increasing salinity within them, with potential salt scalding occurring in some areas as the saline waters are further concentrated.

Terrestrial Impacts — Basin-wide
No estimate of the likely impact of increasing salinity on the biodiversity of terrestrial ecosystems of the Murray-Darling Basin has been made.

In the absence of information it might seem unwise to speculate, but there are some pointers to the likely effects available from other parts of Australia.

The wheatbelt of Western Australia is experiencing a more rapid spread of dryland salinity than is the Murray-Darling Basin. Now that such salinity covers some 2 million hectares, its impacts on remnants of native vegetation scattered across the farming landscape are becoming clear. Some 18 million hectares of the 25 million hectares constituting the agricultural zone of south-western Australia have been cleared of their native vegetation. Of the 7 million hectares left as remnant vegetation, about 4.5 million hectares are in the public estate (including hundreds of nature reserves). The remainder, on private land, is highly fragmented with large proportions already degraded. A substantial proportion of this vegetation lies in the lower parts of landscape, including most wetlands and creeks, where it is more likely to be destroyed by salinisation. Up to 80 per cent of the susceptible remnants on private land and up to 50 per cent of those on public land are estimated to be at risk.

In the absence of accurate knowledge of the biodiversity of the Murray-Darling Basin, it is necessary to make some use of surrogates. While surrogates have often proved inadequate as a means of precisely informing management decisions, they may at least be able to provide a general guidance as to how to approach a problem. In the case of the Basin, vegetation type is likely to prove an important surrogate. Again, using the Western Australian data, the estimates from south-west Western Australia suggest that certain vegetation types confined to low-lying parts of the country (for instance, salmon gum woodlands) were the most highly cleared because they occupied soils better suited to agriculture. Yet these are at severe risk of destruction by land salinisation, and the biodiversity they represent goes with them. Although we are unable to offer quantitative projections for the impact of salinity on biodiversity in the Murray-Darling Basin, it seems that vegetation types occupying similar landscape positions to those at risk in the West will face an uncertain future.
Local Impacts in the Catchments

The Salinity Audit has indicated the Basin-wide implications of salinity for water quality in major rivers, landscape salinisation, agricultural productivity and infrastructure and environmental impacts.

Yet, the results of the State Salt Loads studies are capable of estimating impacts along the tributary rivers, associated wetlands and in the landscape in greater detail. This section summarises these local implications of salinity under a ‘no further intervention’ scenario.

Readers are directed to the individual State Salt Load reports for further detail on impacts at the various time frames of 2020, 2050 and 2100. State reports include maps and tables.

South Australia

The Salinity Audit indicates an increase of salinity at Morgan of 330 EC over 100 years, bringing average salinity levels to 900 EC. At these levels, it will exceed the threshold for desirable drinking water quality and there could be substantial losses in horticultural productivity.

Morgan is 320 km from the Murray Mouth. Downstream, salinity levels rise significantly through to the Lower Lakes. The average salinity at Murray Bridge, a major off-take to Adelaide, will be 980 EC by 2100, a rise of 390 EC.

The salinity regimes of the lower lakes would jeopardise the use of the Murray as a source of water for Adelaide and users in the lower Murray such as those around Lake Alexandrina and Lake Albert.

The many anabranches and billabongs will be particularly at risk. As the feedwater salinities rise and the consequences of reduced ‘whole-of-system’ flow equilibrate, these water bodies will generally become regularly saline. Specifically, at Chowilla in the Riverland (a Ramsar site discussed in Environmental Impacts), the damage to floodplain vegetation will become acute. Lake Albert and Lake Alexandrina are also a Ramsar site. The Coorong section below the Barrages and connected to the sea is already hypersalinated.

Victoria

In general, the future salinity increases for Victorian rivers are modest.

Apart from the Kiewa and the Ovens, these are highly regulated rivers with inter-catchment transfers. For the Goulburn, Campaspe and the Loddon there are high diversions to irrigation and other uses, and hence the delivery of salt loads to the River Murray is considerably less than the salt loads generated within the catchments. Also, for various physical reasons, very little of the Avoca flow actually reaches the Murray, and this is the case too for its salt load.

The Salt Loads study has estimated river salinities in 2020, 2050, and 2100 at or close to where the tributaries enter the River Murray (Table 4).

The Mallee Zone

No estimates of water table levels have been made in the dryland Mallee because of the sparse coverage of bores and the difficulty of characterising the undulating land surface in a systematic way.

River salinities are expected to increase as follows:

<table>
<thead>
<tr>
<th>Location</th>
<th>Flow-weighted average salinity (EC)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Present</td>
</tr>
<tr>
<td>Merbein</td>
<td>360</td>
</tr>
<tr>
<td>Euston</td>
<td>270</td>
</tr>
<tr>
<td>Swan Hill</td>
<td>270</td>
</tr>
</tbody>
</table>

Off-river wetland systems are already suffering a salt accumulation which will be further exacerbated. An example of this is Lake Bonney, which was once used as an irrigation water supply. Since 1950 it has fluctuated between 3,000 and 6,000 EC. A 50 per cent increase is quite likely and if it occurs the critical freshwater ecosystem threshold of 5,000 EC will be exceeded most of the time.
AVOCA RIVER
High water tables are predicted to spread throughout the catchment as follows:

Table 13: Spread of High Water Tables through the Avoca Catchment

<table>
<thead>
<tr>
<th>Land Unit</th>
<th>Present</th>
<th>2020</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plains</td>
<td>—</td>
<td>5,000</td>
<td>153,000</td>
<td>293,000</td>
</tr>
<tr>
<td>Foothills</td>
<td>3,000</td>
<td>3,000</td>
<td>3,000</td>
<td>3,000</td>
</tr>
<tr>
<td>Hills proper</td>
<td>1,000</td>
<td>1,000</td>
<td>1,000</td>
<td>1,000</td>
</tr>
</tbody>
</table>

The pattern shown is one of fairly modest current outbreaks in the foothills (EL 140m to EL 220m) and hills proper (EL greater than 220m) remaining static well into the future. The future area of expansion will be the plains after 2020, with high water tables first appearing close to watercourses. By 2100 the whole of the northern half of the catchment is expected to have a high regional water table.

The Avoca is an intermittently flowing river. Because the salinities are ‘flow weighted’, they reflect salinity conditions during the periods of flow. River salinities are expected to increase as follows:

Table 14: Increase in Avoca River Salinity

<table>
<thead>
<tr>
<th>Location on Avoca River</th>
<th>Flow weighted average salinity (EC)</th>
<th>Present</th>
<th>2020</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coonooer</td>
<td>840</td>
<td>840</td>
<td>840</td>
<td>920</td>
<td></td>
</tr>
<tr>
<td>Quambatook</td>
<td>970</td>
<td>980</td>
<td>1,480</td>
<td>2,040</td>
<td></td>
</tr>
<tr>
<td>Downstream of Third Marsh</td>
<td>1,440</td>
<td>1,470</td>
<td>2,220</td>
<td>2,990</td>
<td></td>
</tr>
</tbody>
</table>

LODDON RIVER
High water tables are predicted to spread throughout the catchment as follows:

Table 15: Spread of High Water Tables through the Loddon Dryland Catchment

<table>
<thead>
<tr>
<th>Land Unit</th>
<th>Area with high water table (ha)</th>
<th>Present</th>
<th>2020</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plains</td>
<td>47,000</td>
<td>76,000</td>
<td>134,000</td>
<td>347,000</td>
<td></td>
</tr>
<tr>
<td>Foothills</td>
<td>1,500</td>
<td>1,500</td>
<td>1,500</td>
<td>1,500</td>
<td></td>
</tr>
<tr>
<td>Hills proper</td>
<td>2,200</td>
<td>2,200</td>
<td>2,200</td>
<td>35,000</td>
<td></td>
</tr>
</tbody>
</table>

In the irrigation areas in the northern end of the catchment, there is already a high water table across most of the area.

River salinities are expected to increase as follows:

Table 16: Increase in River and Stream Salinity in the Loddon Catchment

<table>
<thead>
<tr>
<th>Location on Loddon Catchment</th>
<th>Flow-weighted average salinity (EC)</th>
<th>Present</th>
<th>2020</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downstream of Loddon Weir</td>
<td>610</td>
<td>610</td>
<td>610</td>
<td>610</td>
<td></td>
</tr>
<tr>
<td>Downstream of Kerang Weir</td>
<td>870</td>
<td>880</td>
<td>900</td>
<td>970</td>
<td></td>
</tr>
<tr>
<td>Wandella Creek at Reedy Creek</td>
<td>800</td>
<td>880</td>
<td>1,040</td>
<td>1,540</td>
<td></td>
</tr>
<tr>
<td>Mt Hope Creek at Kow Swamp</td>
<td>520</td>
<td>620</td>
<td>800</td>
<td>1,360</td>
<td></td>
</tr>
</tbody>
</table>

The main stem of the Loddon is surprisingly unaffected. The reasons are that the Loddon has many effluent streams, which pick up the salt load, and the Loddon itself has a small catchment area where it travels north across the plains. Also, the Loddon is diluted with good quality water from the cross-country channel system, at Loddon Weir and Kerang Weir.

CAMPASPE RIVER
High water tables are predicted to spread throughout the catchment as follows:

Table 17: Spread of High Water Tables through the Campaspe Dryland Catchment

<table>
<thead>
<tr>
<th>Land Unit</th>
<th>Area with high water table (ha)</th>
<th>Present</th>
<th>2020</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plains</td>
<td>0</td>
<td>1,000</td>
<td>1,000</td>
<td>1,000</td>
<td></td>
</tr>
<tr>
<td>Foothills</td>
<td>33,000</td>
<td>45,000</td>
<td>57,000</td>
<td>76,000</td>
<td></td>
</tr>
<tr>
<td>Hills proper</td>
<td>1,000</td>
<td>1,000</td>
<td>1,000</td>
<td>1,000</td>
<td></td>
</tr>
</tbody>
</table>

In this dryland catchment the main area of expansion of the high water table is the ‘foothills’. However, the part of the foothills most affected is immediately adjacent to the plains. The predicted pattern of expansion is a steady coalescing of the high water table areas within the hilly country, and encroachment onto the flatter country from the south and east.

To the north are the Campaspe Irrigation District and the part of the Shepparton Irrigation Region north of Rochester. These may be considered as having high water tables, now or in the not-too-distant future, in those parts without sub-surface drainage.

River salinities are expected to increase as follows:

Table 18: Increase in Campaspe River Salinity

<table>
<thead>
<tr>
<th>Location on Campaspe Catchment</th>
<th>Flow-weighted average salinity (EC)</th>
<th>Present</th>
<th>2020</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downstream of Eppalock</td>
<td>570</td>
<td>570</td>
<td>570</td>
<td>570</td>
<td></td>
</tr>
<tr>
<td>At Campaspe Pumps</td>
<td>540</td>
<td>550</td>
<td>560</td>
<td>560</td>
<td></td>
</tr>
<tr>
<td>Upstream of River Murray</td>
<td>600</td>
<td>600</td>
<td>610</td>
<td>610</td>
<td></td>
</tr>
</tbody>
</table>

The pattern is one of expansion of high water tables southwards across the plains, until in 2100 the ‘front’ of the expansion is expected to be about 20 km south of Bears Lagoon.
GOLDBURN-BROKEN RIVERS
High water tables are predicted to spread throughout the catchment as follows:

Table 19: Spread of High Water Tables through the Goulburn-Broken Dryland Catchment

<table>
<thead>
<tr>
<th>Land Unit</th>
<th>Area with high water table (ha)</th>
<th>Present</th>
<th>2020</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plains</td>
<td></td>
<td>65,000</td>
<td>74,000</td>
<td>538,000</td>
<td>538,000</td>
</tr>
<tr>
<td>Foothills</td>
<td></td>
<td>5,200</td>
<td>109,000</td>
<td>117,000</td>
<td>125,000</td>
</tr>
<tr>
<td>Hills proper</td>
<td></td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

As shown here, the plains area experiences a dramatic expansion in the area of high water tables 20 to 50 years into the future. However, this study was rather broad brush in nature. The current Broken and Northern Goulburn Plains Study, which is repeating the work, but using 33 instead of six land units, is showing that there are some extensive areas of the plains that will still have water tables deeper than 2 metres in 50 years’ time.

To the north is the Shepparton Irrigation Region, which may be considered as having high water tables now or in the not-too-distant future, in those parts without sub-surface drainage.

River salinities are expected to increase as follows:

Table 20: Increase in River and Stream Salinity in the Goulburn-Broken Catchment

<table>
<thead>
<tr>
<th>Location</th>
<th>Flow-weighted average salinity (EC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downstream of Goulburn Weir</td>
<td>Present</td>
</tr>
<tr>
<td>Upstream of River Murray</td>
<td>120</td>
</tr>
<tr>
<td>Broken River downstream of Casey’s Weir</td>
<td>130</td>
</tr>
<tr>
<td>Broken Creek upstream of River Murray</td>
<td>130</td>
</tr>
</tbody>
</table>

An important conclusion is that the Goulburn River at Goulburn Weir, the diversion point for major deliveries to irrigation in the Goulburn, Campaspe and Loddon Catchments as well as further west, is largely unaffected by the expansion of high water tables in the catchment. This is because of the large volumes of high quality water released from Eildon and the fact that the expansion of high water tables occurs largely downstream of the Goulburn Weir diversion point.

OVENS AND KIEWA RIVERS
High water tables are predicted to spread throughout the catchments as follows:

Table 21: Spread of High Water Tables through the Ovens and Kiewa Catchments

<table>
<thead>
<tr>
<th>Land Unit</th>
<th>Area with high water table (ha)</th>
<th>Present</th>
<th>2020</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ovens</td>
<td></td>
<td>35,000</td>
<td>42,000</td>
<td>59,000</td>
<td>91,000</td>
</tr>
<tr>
<td>Kiewa</td>
<td></td>
<td>12,000</td>
<td>13,000</td>
<td>17,000</td>
<td>23,000</td>
</tr>
</tbody>
</table>

In both the Ovens and the Kiewa, the high water tables occur mainly around the breaks of slope. Even in 2100 the plains areas, for the most part, have water tables 2 to 5 metres deep. Because of the comparatively low salinities of groundwater in these catchments, the problems posed by high water tables are likely to be caused by waterlogging as much as by salinisation.

River salinities are expected to increase as follows:

Table 22: Increase in River Salinity in the Ovens and Kiewa Catchments

<table>
<thead>
<tr>
<th>Location</th>
<th>Flow-weighted average salinity (EC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ovens River</td>
<td>Present</td>
</tr>
<tr>
<td>Kiewa River</td>
<td>45</td>
</tr>
</tbody>
</table>

New South Wales
The significant rivers for New South Wales are the Murrumbidgee, which flows to the River Murray, and the Lachlan in the southern Basin. The tributaries of the Darling River have a significant potential to mobilise salt.

Table 5 summarises the end-of-valley salinity levels from the Salt Loads study for these major rivers and some river reaches. The salinity trends for reaches of the River Murray are reported in Table 4. The contribution of salt from upper River Murray tributaries in New South Wales has not been fully assessed. Salt exports from the Tooma River, Jingellic Creek and Billabong Creek above Walbundary have been calculated.

Billabong Creek flows into the Edward River before entering the River Murray. The Coleambally outfall drain and Yanco Creek also influence the flows in the lower reaches of the Billabong Creek. Salinity in the Edward River is heavily influenced by diversions coming from the River Murray and diversions out again to the irrigation districts. Worsening conditions in Upper Billabong Creek may have adverse affects on the irrigation areas downstream, but it is not possible to quantify the impact from this assessment.

MURRUMBIDGEE RIVER
The Murrumbidgee River is a highly regulated river with high water allocation commitments. Substantial irrigation diversions are fed from the Murrumbidgee below Wagga Wagga and there are also significant wetlands in the lower reaches of the system. Of the average annual Cap flow of 4,592 GL at Wagga Wagga, 2,424 GL is diverted for irrigation, 19 GL is used for stock and domestic water supply, 799 GL is absorbed in wetlands and 1,350 GL flows out to the Murray River at the end of the system.
What distinguishes the Murrumbidgee from all rivers other than the River Murray is its very high current salt loads (around 400,000 tonnes per year at Wagga Wagga), moderated by high flow rates. Of the 17 tributary sub-catchments above Wagga Wagga in the Murrumbidgee Basin, several currently contribute the highest average annual salt loads per land area found anywhere in the New South Wales portion of the Murray–Darling Basin.

Tributary catchments such as Muttama Creek and Jugiong Creek already exceed 800 EC 35 per cent and 77 per cent of the time and 1,500 EC 20 per cent and 33 per cent of the time, respectively.

The Salt Loads study estimates the Murrumbidgee’s salinity at its junction with the River Murray to increase from 250 EC currently to an average of 315 EC in 2020 and 403 EC in 2100. At Wagga Wagga threshold values of 800 EC and 1,500 EC will remain well above the range of average monthly EC predicted for the coming century, but the end-of-valley increase to 286,000 tonnes of salt load per year will increase salt accumulation in irrigated areas. Currently, more than 200,000 tonnes per year is stored in the landscape of the irrigation areas. Quite large populations, including centres such as Canberra and Wagga Wagga, rely on river supplies and aquifers in close connection to the river. However, as the 800 EC threshold will not be exceeded in any but some smaller tributaries, urban water supplies can be regarded as safe into the future.

LACHLAN RIVER

The Lachlan is a generally considered to be a terminal river system only flowing out of the Great Cumbung Swamp to the Murrumbidgee in exceptionally high flood flows (approximately one in 20 years). All salt generated in the upland tributary catchments above Forbes is redistributed back into the landscape, either in irrigation diversions, floodplain entrapment or into this significant wetland environment. Roughly 23 per cent of all diversions occur below Forbes, mainly to the Jemalong Plains.

One town draws water from the Lachlan above Wyangalla Dam, five towns with a total population of 17,500 draw water from the Lachlan in the downstream reach to Forbes and three towns with a total population of 5,800 in the reach to Hillston. Three towns draw water separately from the Boorowa River, the Crookwell River and the Burrangong River. The average annual flow at Forbes is 1,147 GL. Of this amount 196 GL is estimated to be diverted for irrigation below Forbes, with the remainder feeding the wetlands.

The Salt Loads study predicts that salt mobilised within the catchment will more than double in 100 years, second only to the Murrumbidgee. Average annual salinity and its monthly distribution at Forbes is indicative of the concentrations experienced downstream. The current salinity is predicted to increase from 530 EC now to 780, 1,150 and 1,460 EC in 2020, 2050 and 2100, respectively. The probability of exceedence of the 800 EC threshold is currently 5 per cent but will deteriorate to 8 per cent, 35 per cent and 60 per cent on an average monthly basis in 2020, 2050 and 2100.

Further upstream at Nanami above the reach feeding the Jemalong Plains irrigation area, the distribution is very similar. Average monthly salinities at Forbes, which currently do not exceed 1,500 EC, are predicted to experience higher levels 5 per cent and 12 per cent of the time 2050 and 2100. The Boorowa River at Prossers Crossing currently experiences average monthly salinities greater than 800 EC 57 per cent of the time and this is predicted to be greater 66 per cent, 90 per cent and 100 per cent of the time in 2020, 2050 and 2100. At Narawa North, on the Crookwell River, the corresponding probabilities jump from 18 per cent to 32 per cent, 55 per cent and 64 per cent.

MACQUARIE RIVER

The Macquarie River valley includes the Bogan River. The outflow from both rivers to the Barwon–Darling system was 150GL and 235GL, respectively. Twenty-one defined sub-catchments contribute to flow and salt load in the Macquarie River above the Narromine irrigation district. Downstream, substantial diversions for irrigation redistribute a significant proportion of the salt load back into the landscape and a somewhat greater proportion is deposited in the Macquarie Marshes before the remainder is exported from the valley.

Groundwater-driven rates of salt load change are high, with salt loads in the rivers expected to double in 20 years and increase by more than three times the current base value in 2100.

The Salt Loads study estimates the end-of-valley salinity for the Macquarie to rise from the current 623 EC to 1,284 EC in 20 years, 1732 EC in 50 years and 2106 EC in 2100 and for the Bogan to rise from 727 EC to 1,501 EC, 1,954 EC and 2319 EC, respectively. At Narromine the benchmark water quality value of 800 EC for human consumption and irrigation of sensitive crops is currently exceeded on an average monthly basis 10 per cent of the time but is predicted to exceed it 30, 55, and 83 per cent of the time in 2020, 2050 and 2100. The threshold of 1,500 EC critical for the health of wetland ecosystems is currently exceeded less than 5 per cent of the time but this exceedence probability is predicted to deteriorate to 10, 15 and 20 per cent of the time. In some tributary streams the scenario is predicted to be worse.

Twelve urban centres with a combined population of 65,000 use water from rivers and creeks within the valley. This includes Dubbo, with a population of 34,500. With these projected salinity increases, water quality will deteriorate below safe levels for town water supply as well as irrigation and wetland ecosystem health.

CASTLEREAGH RIVER

Current average salinities are similar to the Macquarie — 640 EC in its middle reaches at Coonamble. Although groundwater trends indicate moderate rates of change and dryland salinity has not yet become widespread, the Castlereagh will experience a doubling of salt mobilised in the landscape and exported in the river over the next 100 years. The Salt Loads study estimates a rise in salinity at the end of the valley to 760 EC in 2020, 1,104 EC in 2050 and 2100. The threshold of 1,500 EC critical for the health of wetland ecosystems is currently exceeded less than 5 per cent of the time but this exceedence probability is predicted to deteriorate to 10, 15 and 20 per cent of the time. In some tributary streams the scenario is predicted to be worse.

The Castlereagh Basin contains two towns with populations of 3,500 and 600 people who take their water supply from the river. A further two towns with more than 3,000 people use water from bores in alluvial aquifers. There are no significant diversions of water for irrigation and no significant losses to wetlands in the basin. Redistribution of salt into the landscape is almost all associated with flooding.
The threshold of 800 EC is currently exceeded at Coonamble 30 per cent of the time but will exceed it 32 per cent of the time in 2020 and 45 per cent in 2050 and 2100. The probability of average monthly salinity exceeding 1,500 EC is currently 20 per cent, increasing to 21 per cent in 2020 and 30 per cent in 2050 and 2100.

**NAMOI RIVER**

Dams on this river commit much of the water resource to irrigated agriculture (240 GL/year) although it is not as highly regulated as southern rivers. Flow at the end of the Namoi System adjusted for Cap scenario conditions is on average 503 GL per year.

High quality floodplain aquifers are subject to groundwater pumping in the Namoi, and levels are generally static or falling. These aquifers are recharged during flood flows and their future salinity will be influenced by the water salinity during these flood events.

Current average salinities for the Namoi River are 680 EC at the end of the system and 634 EC at Boggabri. The Salt Loads study estimates a more than doubling of the salt export from the valley, to exceed the Murray Bridge (see Figure 7). River salinity at the end of the valley will rise from 680 EC now to 1,050 EC in 20 years, 1,280 EC in 50 years and 1,550 EC by 2100.

Five towns with a total population of 49,900, including Tamworth with a population of more than 35,000, draw their water supply from the river and tributaries. A further six towns draw their water from alluvial bores potentially influenced by the quality of recharge.

The distribution of average monthly water salinity at Boggabri can be used as a basis to assess the probable impacts on irrigation diversions and urban water supplies. Here, a threshold salinity of 800 EC is currently exceeded 20 per cent of the time and is predicted to overstep this value 39 per cent, 48 per cent and 63 per cent of the time in 2020, 2050 and 2100. The critical threshold of 1,500 EC is presently exceeded 6 per cent of the time, rising in probability to 11 per cent, 20 per cent and 27 per cent of the time. Further upstream at Gunnedah the picture is much the same. At a point below Keepit Dam, 800 EC is now only exceeded 2 per cent of the time but this is predicted to deteriorate to 28 per cent, 36 per cent and 42 per cent of the time in 2020, 2050 and 2100.

Salt exports are generated mainly from tributary streams above Boggabri. The Peel River at Chaffey Dam is not expected to exceed 800 EC during the coming century. By contrast, Goonoo Goonoo Creek and Timbumburi exceeds 800 EC 42 per cent of the time now and is predicted to exceed it 50 per cent, 55 per cent and 65 per cent of the time in 2020, 2050 and 2100.

**GWYDIR RIVER**

The Gwydir River, like the Namoi, is heavily committed to irrigated agriculture, with an average annual diversion of 319 GL. Further, it contains wetlands of high environmental significance and considerable areas of irrigation development below Pallamallawa. The average flow of the Gwydir and Meehi Rivers into the Barwon Darling Systems is 56 GL/year.

Salt accumulating in the down stream reach, with further additions from Tycannah Creek, is redistributed back into the landscape via irrigation and in wetlands. Overall rates of change are relatively low — intermediate or no change in the adjacent Border Rivers and moderate rates predicted in the Namoi. Most of the salt generated in the upland catchments is redistributed back into the landscape between Tycannah Creek and the end of system.

The estimated current average salinities for the Gwydir are 560 EC at Pallamallawa and the end of the valley. The Salt Loads study estimates only a modest rise in salinity over the next 100 years. End-of-valley river salinity will rise to 600 EC in 20 years and 743 EC by 2100.

The distribution of salinity values calculated at Pallamallawa is expected to be representative of the water quality available in diversions, entering the wetlands and available for stock and domestic use in the lower reaches of the system. A threshold salinity of 800 EC for irrigation and drinking water is currently exceeded 14 per cent of the time and is predicted to exceed it 27 per cent of the time by 2100. A critical salinity for wetland eco-system health of 1,500 EC is currently only exceeded infrequently but it may be exceeded 8 per cent of the time by 2100.

Four towns with a total population of 10,000 draw water supplies directly from rivers and creeks or from bores influenced by them.

The Warialda Creek catchment exceeds 800 EC 52 per cent of the time and 1,500 EC 33 per cent of the time, with the predicted situation deteriorating to 60 per cent and 40 per cent in 2100. Warialda, however, does not take its water from this creek.

**NSW BORDER RIVERS**

About 60 per cent of flow in the Border Rivers comes from New South Wales, including the Macintyre River with an average annual flow of 760 GL. The Macintyre does have consumptive use (average 209 GL/year) but at lower levels than the Gwydir and Namoi Rivers.

No groundwater-driven change to river salt loads has been predicted for the Border Rivers catchment in New South Wales. Current patterns of salt generation and redistribution in the Macintyre River system are expected to continue throughout the coming century.

Gil Gil Creek lies within the Border Rivers catchment, but receives water from the Gwydir via Carole Creek in the Gwydir catchment to its outlet on the Barwon River. Increasing salt trends in the Gwydir are resulting in modest rises in salt load from the Barwon River to Gil Gil Creek.

The Salt Loads study predicts no significant increase in salinity over the next 100 years, the end-of-valley median salinity remaining at the current 449 EC.

Water quality is expected to remain well below the critical threshold level of 800 EC almost constantly, except in Ottleys Creek and the Beardy River where it currently exceeds this value 30 per cent of the time.

Seven towns with a population of 20,300 use water from rivers and creeks within the valley.

**OTHER AREAS**

On the basis that rising water table trends are not evident in groundwater systems underlying areas north of the Darling upstream of Bourke, it is considered that these areas will not contribute additional salt loads to the Murray in the future.
Queensland

For Queensland, the Salt Loads study methodology was applied only recently. Queensland features large catchments where bore data are not well distributed or available for long time periods.

Three river valleys could be assessed and future salinity levels predicted. These findings will be independently reviewed, as has been done for the other States.

WARREGO RIVER
The Warrego River catchment covers an area of approximately 5,000,000 hectares with an average annual discharge of 400,000 ML. The river flows through a semi-arid and arid zone of generally low relief, and the flow is characterised by low and highly variable runoff conditions. Current average river salinity is 210 EC units, although data are only available for the last seven years.

Salinity levels are predicted to rise to 1260 EC units by 2020 as the system becomes influenced by continuous groundwater inflow. Predicted salinity levels will exceed the 800 EC threshold approximately 70 per cent of the time as the system becomes dominated by groundwater baseflow. As for the Condamine–Balonne and the Border River systems, the salinity levels stabilise within a relatively short time period.

Salt loads have been generated in mid- to upper slope units so there is potential for significant storage of salts in the system upstream of the gauging station at Cunnamulla. This requires further validation and estimates should be regarded as indicative only. Limited data are available to assess the behaviour of shallow sub-artesian systems in the Warrego, Paroo and Moonie River systems, with groundwater data only utilised in the Warrego catchment. Recent observations of localised outbreaks of salinity in these catchments have highlighted the need for a more refined monitoring and assessment approach than that utilised for the Salt Loads study.

CONDAMINE–BALONNE
The Condamine–Balonne River catchment covers an area of approximately 8,730,000 hectares in southern Queensland. The Condamine–Balonne system has a highly variable annual discharge, which averages 95,000 ML at Warwick and 1,300,000 ML at St George. Surface flow is regulated in some sections due to the significant development of surface water storages within regions, particularly for irrigation and urban supplies. Total storage capacity, for both town water supply and irrigation areas, within the catchment is 230,000 ML, which represents 21 per cent of the average annual flow measured below St George.

The estimated current mean salinity for the Condamine–Balonne is 210 EC based on flow-concentration relationships at Whyenbah and Hastings. The Salt Loads study estimated a sharp rise in salinity within 2020 years. End-of-valley river salinity is predicted to rise to 1040 EC by 2020 and remain at this level over the next 70 years. A threshold salinity value of 800 EC for drinking water and irrigation is currently not exceeded, but this is predicted to be exceeded 58 per cent of the time by 2020. Similarly, the 1,500 EC threshold for wetland ecosystem health is predicted to be exceeded 40 per cent of the time by 2050.

Average salinity levels will increase significantly as a result of groundwater inflows changing the characteristics of the river system from ephemeral flow to permanent flow. These estimates do not take account of the potential for storage of salts within the catchment, hence they should be considered indicative only.

BORDER RIVERS
The Border Rivers catchment covers an area of approximately 4,950,000 hectares, including the Severn, Dumaresq, Macintyre and Barwon rivers downstream to Mungindi. The Salt Loads study was undertaken for the Queensland component of the Border Rivers catchment and focused on the Weir River and Macintyre Brook sub-catchments. This has meant that salt loads from the Pike Creek and Severn River catchments within Queensland have not been included in this assessment. The current combined average annual flow from the Weir River and the Macintyre Brook systems is 307,474 ML with a salinity level of 310 EC. This compares to an average annual flow of 1,126,000 ML for the Macintyre River at Goondiwindi.

Predictions from the Salt Loads study are that mean salinity levels are estimated to rise to 1010 EC by 2020, and the 800 EC threshold will be exceeded 66 per cent of the time. However, as there has been no discrimination of salt inputs from the contributing hydrogeomorphic units into the Weir River and Macintyre Brook sub-catchments, this outcome provides an average for both systems. These results contrast with predictions for the New South Wales section of the Border Rivers catchment and will require further validation and refinement. They are based on observed rising water table trends in the Queensland section of the catchment, hence additional salt loads may reasonably be expected to contribute to the Darling system in the future.

The Condamine Valley east of Killarney in south-east Queensland.
Salinity Management Interventions

For more than 20 years the salinity threat has been addressed in State salinity programs, in community Landcare activities and, more recently, supported by Commonwealth government funded programs. Within the Murray-Darling Basin there has been a focus on irrigation areas, both controlling irrigation-induced salinity and ameliorating rising river salinity. For areas under dryland agriculture, typically the response has been catchment planning and management at a local scale, as part of the Landcare programs.

Given the current salinity trends and the estimated future impacts, what impact has this past and current investment had? In this section, the Basin Salinity Audit offers a factual account of ‘on-the-ground’ achievements of salt action programs, and where changes in natural resource condition cannot be estimated, then the level of implementation of strategies, plan and best management practices.

The Salinity and Drainage Strategy

After ten years of implementation, the Salinity and Drainage Strategy is being reviewed. Already its achievement is self-evident.

There has been an improvement in River Murray salinity without limiting the rehabilitation of degraded lands and the undertaking of drainage works to control the rise of groundwater tables. This was made possible by reducing the amount of salt entering the river through construction of salt interception schemes and using some of the salinity action plans by the States.

SALT INTERCEPTION SCHEMES

Given that the indicative target was to keep river salinity at Morgan (South Australia) below the 800 EC threshold at least 95 per cent of the time, a key indicator of achievement is the distribution of salinities before and after the strategy period. A frequency plot is shown in Figure 9. It shows that salinity levels in the lower Murray have been much lower in the post-Strategy period compared with the pre-Strategy period. In fact salinity levels are currently less than 800 EC 92 per cent of the time.

The magnitude of change in salinity levels at Morgan on average, and against the threshold level of 800 EC is summarised in Table 23. These figures show that while the target may not have been met, the Strategy has still been effective.

<table>
<thead>
<tr>
<th>At Morgan</th>
<th>Pre-Strategy</th>
<th>Post-Strategy</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average river salinity (EC)</td>
<td>721</td>
<td>569</td>
<td>152</td>
</tr>
<tr>
<td>Proportion of time exceeding 800 EC thresholds (%)</td>
<td>42</td>
<td>8</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 23: River Salinity at Morgan Before and After the Salinity and Drainage Strategy

Under the Strategy the States and Commonwealth constructed four salt interception schemes and upgraded two State schemes. Taking into account some river operation actions that added to river salinity, the net reduction in average salinity at Morgan was 61 EC. This is a significant achievement against an indicative target of 80 EC. The initial capital cost of these schemes was $43 million and the annual operating cost is more than $1.8 million. These schemes pump about 134,000 tonnes of salt per year.

The States have also constructed salt interception and drainage diversions schemes, some before and some after the Strategy. They pump another 482,000 tonnes of salt per year.

RIVER OPERATIONS

When the Salinity and Drainage Strategy was being negotiated, it was recognised that there was an opportunity to improve flows during periods of low flow without significantly reducing the security of supply to water users. Changes to rules governing the operations of major storages were made to allow dilution flows, providing a 35 EC reduction in salinity at Morgan. The actual reduction has been about 28 EC.

Other developments with minor impacts on salinity have been allowed, but these have been more than offset by revised rules for operation in one of the Victorian schemes.

In summary, the Salinity and Drainage Strategy has achieved a reduction of approximately 10 per cent in River Murray salinity at Morgan. However, given the gradual deterioration that continues to occur from historical groundwater movement and the continued impacts of developments preceding the Strategy, this reduction is predicted to be eliminated in 20 years’ time.
IRRIGATION PRACTICES

This Audit attributes the mobilisation of natural groundwater salts to increased recharge in the landscape, whether that be under irrigated agriculture, dryland agriculture or other land uses (e.g. urban development). Clearly, irrigation is an extremely intense process for mobilising and re-storing salt loads. On the other hand, it provides a greater capacity to address the causes and consequences of salinisation either by controlling the water cycle or through capital investment. Reduction in losses of water under irrigated crops or from supply infrastructure is a critical factor in controlling salinisation.

A range of measures has been promoted and adopted over many years to address the threat — from drainage and groundwater pumping to more efficient water application techniques, water re-use and soil moisture monitoring. There is anecdotal evidence in some irrigation areas that groundwater movement has been stabilised or is now falling. Importantly, from the Commission’s standpoint, the major irrigation areas are covered by Land and Water Management Plans and Salinity Management Plans. As they evolve, these plans identify the local recharge processes, and propose to address them through works and best management practices, evaluated on an economic basis. These plans direct public and community investment, and guide landholder investment in salinity management options. They are the means by which salinity credits are allocated and used with account landholder investment in salinity management options. The interventions have been in the context of irrigation areas, and the potential impacts on land are more diffuse and will be realised incrementally over a longer time period.

Dryland Salinity

The recognition of the salinity threat associated with dryland agriculture has been more recent than for irrigation areas, and the potential impacts on land are more diffuse and will be realised incrementally over a longer time period.

Government, community and industry responses have been different in nature. The interventions have been in the context of natural resource management, with major public funding of the community capacity to plan and implement land management practices on a local catchment scale. This has been supported by research, development and extension of improved land use practices, with some further incentives under income tax provisions.

While there is some evidence of farm and revegetation practices controlling water tables on a site-specific basis, there is no indication yet that Landcare and natural resource management programs have altered the ‘no new intervention’ trend lines for rising salinity across the Basin.

NATURAL RESOURCE MANAGEMENT PROGRAMS IN THE BASIN

In 1988 the Murray–Darling Basin Ministerial Council approved the Natural Resources Management Strategy (NRMS) to develop a community-government partnership to:

- control land degradation and, where possible, rehabilitate degraded land
- maintain and, where possible, improve water quality
- conserve the natural environment
- conserve cultural heritage.

Managing dryland salinity was recognised as an important land and water degradation issue.

The NRMS incorporated and promoted the principle of integrated catchment management and the institutional arrangement of communities of common concern working in partnership with governments. It also established the basis for Commonwealth and States ‘matching’ of funding for community projects.

Over a decade, integrated catchment management, catchment management organisations and public funding arrangements have evolved markedly. The Basin is covered by several thousand Landcare and local action groups. There has been a dramatic increase in awareness and understanding of land degradation and its impacts. There have been thousands of on-ground projects. The Natural Heritage Trust, the Commonwealth’s major funding program since 1997, is now undergoing a mid-term review, including an evaluation of how it has addressed dryland salinity. In the Murray–Darling there have been 50–80 integrated catchment management plans that incorporate dryland salinity as a priority.

Under the Murray–Darling Basin Initiative, current planning indicates a total investment of $2.5 billion over the next three years to address natural resource management, including salinity.

State Dryland Salinity Management Plans

Over the past ten years, State governments, regional catchment management bodies and local action groups have planned and initiated a range of intervention actions within the major catchments of the Basin.

SOUTH AUSTRALIA

In South Australia, the combined Soil Boards/local action planning groups have been undertaking a dryland regional strategy. The Coorong and Districts Plan, covering 110,000 hectares, is well advanced with some important on-ground works in hand. There has been a very encouraging adoption of high water use farming practices driven by a thorough analysis of public investment based on a rational cost-sharing approach. The Eastern Hills and Murray Plains local action plan builds on some groundwork of the Bremer–Barker catchment group, which has initiated revegetation programs. The Murray Mallee local action plan has undertaken a priority analysis that includes assessment of impacts to the River Murray and is now moving towards implementation.

VICTORIA

In Victoria, Dryland Salinity Management Plans have been developed for all major dryland catchments of the Basin, and most have been approved by the Victorian Government for partnership arrangements. These plans have provided the groundwater data against which this Salinity Audit has been based. ‘Living with Salt’ is a feature common to most plans.
The Murray–Darling Basin Commission

...systems and other land uses to control salinity.

...a 'dryland salinity theme' of the National Land and Water Resources Audit, a report to the Prime Minister's Science, Engineering and Innovation Council.

...the National Dryland Salinity Program coordinated by the Land and Water Resources Research and Development Corporation.

...emphasises recharge control and increased productivity through perennial pastures in the north and pasture phases, minimum tillage and run-off reduction in the south.

...the Loddon Plan offers similar actions together with some emphasis on tree planting, floodwater management and groundwater management. The Campaspe Plan also covers these issues but then includes remnant vegetation retention, urban salinity (Bendigo) and the problem of rural subdivision. The Goulburn–Broken Plan was one of the first to be approved in 1990 and is currently under detailed review. Plans for the Ovens and Kiewa catchments are being incorporated into the North East Catchment Salinity Management Plan. The Mallee zone is covered by four Salinity Management Plans with their origins in irrigation management, a Mallee Dryland Plan covers the dryland hinterland.

...plans is subject to review. A stronger linkage between the dryland and irrigation plans is envisaged.

NEW SOUTH WALES

In New South Wales a Salt Action program has supported the development of salinity components for regional catchment plans. These plans covering the Murray, Lower Murray–Darling, Murrumbidgee, Lachlan, Central West, and North West regions mostly anticipate a 30-year program. Dryland salinity is considered in the context of a wider range of natural resource management issues. Currently New South Wales is committed to preparing a state wide dryland salinity strategy by mid-2000.

QUEENSLAND

In Queensland, dryland salinity is regarded as an emerging issue. The four catchment community groups have been preparing catchment strategies that include dryland salinity to varying degrees. Some 60 sub-catchment action groups have initiated an intensive mapping activity to identify actual and potential salinity outbreaks.

...in each of the Basin States, ‘salt action’ programs have supported regional and local actions, with technical and decision support to communities and catchment bodies, and matching funds under national and Basin initiatives.

...the Commission and Basin States have invested in ground-water mapping and modelling, assessment of impacts of land and stream salinity, best management practices for farming systems and novel uses or techniques for disposal of salt. Current studies include improved estimates of salinity costs, improved tools for salinity education and analysis of policy options.

NATIONAL AND STATE SALINITY PROGRAMS

The Commission invests and participates in a number of initiatives to address salinity nationally or in eastern Australia:

...the National Dryland Salinity Program coordinated by the Land and Water Resources Research and Development Corporation.

...a report to the Prime Minister’s Science, Engineering and Innovation Council.

...a ‘dryland salinity theme’ of the National Land and Water Resources Audit.

...the Cooperative Research Centre for Catchment Hydrology.

...joint projects with CSIRO.

...Significantly, the Commission is collaborating with CSIRO and other research bodies to evaluate the capacity of different farming systems and other land uses to control salinity.

EFFECTIVENESS OF FARMING SYSTEMS

...From our understanding of the salinisation process it is clear that farming systems capable of preventing dryland salinity will have to mimic natural vegetation in use of rainfall and reducing leakage to groundwater to a very low rate (1–2 mm/year or less than 1 per cent of rainfall). In a recent review of field studies CSIRO has concluded that current leakage rates under farming systems, even when practiced at best practice level, generally far exceed native vegetation.

...An understanding of the limits to effectiveness of current farming systems is essential to developing strategies to address salinity. In summary, the CSIRO review concludes that:

For grazing systems

...In high rainfall zones (> 600 mm) neither perennial nor annual pastures are capable of limiting leakage rates as much as trees. A high proportion of trees is the only option for salinity control.

...In medium rainfall zones (400–600 mm) perennial systems may significantly reduce leakage.

...In low rainfall zones (< 400 mm) the use of lucerne has mimicked natural Mallee vegetation in control of leakage.

For cropping systems

...In areas of the Southern Basin where rainfall is 250–500 mm, the removal of long fallow rotations and inclusion of lucerne in rotations (phased cropping) has reduced leakage to 5 per cent of rainfall and eliminated recharge in some areas.

For agroforestry systems

...In general trees in agroforestry formats can halve leakage rates but not mimic native vegetation. However, their performance varies with specific catchment characteristics.

...In many areas the low permeability of groundwater systems means that the impact of trees on lowering groundwater levels, extends little beyond the plots themselves.

For plantations

...In medium and low rainfall zones (< 700 mm) the leakage underneath the plantation is close to zero. In Basin-wide terms the monitoring and studies of the capacity of farming systems to effectively minimise recharge and control salinity indicate that:

...For irrigation areas a combination of works and improved farming systems under strategies allowing for tradeable pollution rights and accountable land and water management plans supported by public investment can achieve a level of control.

...For the wheat–sheep zone there are options which may achieve a level of salinity management that is close to or mimics native vegetation.

...For the winter and summer rainfall grazing zones, with more than 600 mm per year, there are no options for salinity control except large-scale tree plantings where the benefits are restricted to the areas under vegetation.

...For the rangelands, the current land uses dependent on native salt-tolerant vegetation are in equilibrium and there are no significant threats of off-site impacts.

...In conclusion, the management interventions in dryland catchments over the past 20 years have yet to demonstrate a level of salinity control such that future costs and impacts will be reduced below those predicted in this Audit. Clearly, this is a major challenge for a future salinity management strategy, as was more fully explained in the recent report to the Prime Minister’s Science, Engineering and Innovation Council.
Conclusion

Salt is a natural part of the Australian landscape. The Murray-Darling Basin, over geological time, has been a natural salt trap. The clearing of native vegetation and its replacement with annual crops and pastures, irrigated agriculture, town gardens and lawns has unleashed a hydrological disequilibrium that brings this vast salt store to the land surface and increases its seepage to river systems.

The impact on streams and rivers is exacerbated by the reduction in flow resulting from the high rates of diversion for irrigation, urban and industrial water supply. The cause and nature of the impacts of salinity have been known for decades. Policy and management responses, supported by major funding programs from Commonwealth and State governments, have been in place for 20 years. They range from the Murray–Darling Basin Commission’s Salinity and Drainage Strategy to catchment management and Landcare initiatives. In very recent times there has been significant and relevant improvement in our understanding of the challenges salinity presents to public policy.

- There is a better capacity to predict future impacts of salinity on a Basin and catchment scale
- There is accumulated knowledge that points to the limits of current farming systems in most zones to control salinity, even at the level of best practice
- There is a greater appreciation of economic and social impediments to the scale of land use change now advocated for dryland catchments
- There is a track record of policy initiatives, such as the Salinity and Drainage Strategy that are now under review.

The Basin Salinity Audit was born out of the latter review. Indications are that river salinity in the lower Murray would be increasingly impacted by salt exports from the dryland catchments. This shifted the focus on salinity hazard to a Basin-wide approach, and led to the agreement by States to participate in a new Salt Loads study to predict salinity impacts up to 100 years into the future.

WHAT HAS THE AUDIT TOLD US?

The salt mobilisation process across all the major river valleys is on a very large scale. The annual movement of salt in the landscape will double. The salt load exported to and through rivers will double.

There is a critical future hazard for some rivers and the people dependent on them as a source of water. Average river salinities will rise significantly, exceeding the critical thresholds for domestic and irrigation water supplies, and the riverine environment. The Macquarie, Namoi, Lachlan, Castlereagh and Bogan Rivers of New South Wales and the Condamine–Balonne, Border and Warrego Rivers of Queensland will experience drainage salinity rises. The Avoca and Loddon Rivers of Victoria already exceed a critical threshold, on average. Within 20 years the river salinity at the key monitoring station at Morgan in South Australia will have returned to the levels experienced in the 1970s and 1980s, overtaking the achievements of the Salinity and Drainage Strategy. The importance of variability of salinities over time and periodic exceedances of critical water thresholds, such as for irrigation water and ecosystem maintenance, is now better appreciated. This quantification of estimated salinities and their variability, and identification of river reaches most at risk, allows for better targeting of policy responses.

Sources of salt that impact on the Murray–Darling system are better identified and quantified. About half of the impacts in EC terms at Morgan will derive from salt movement from irrigation developments before the Salinity and Drainage Strategy together with salt from the dryland Mallee zone, and one-quarter from tributary catchments. The distribution of sources between irrigation areas and dryland catchments, and between and within river valleys clearly points to the need for a Basin-wide salinity management strategy that incorporates a revised Salinity and Drainage Strategy. The importance of salinity variability over time in relation to exceedances of critical water salinity thresholds, such as for drinking water, has been brought out and is now appreciated.

The capacity to estimate land areas impacted by future salinity is inadequate. The Salt Loads study has identified land units with rising saline groundwater, and the rate of rise. Yet, due to lack of monitoring data and surface contour data, the size and location of saline discharge areas cannot be reliably predicted. This is being corrected with initiatives in New South Wales, where predictive capacity is weakest.

There is a priority for investment in better estimation of cost impacts and the benefit:cost ratios of taking action. There is adequate current and historical knowledge of the costs and potential benefits of incremental changes in salinity of the lower Murray. The same cannot be said for other river valleys and dryland catchments. Inevitably, there will be trade-offs in policy responses and priorities for public investment. This is being addressed in a major ‘cost project’ by the Commission.

Current understanding of environmental impacts is inadequate. While there is some scope for estimating losses to floodplain wetlands and riparian values, on the basis of projected river salinities, the scale and nature of threats to terrestrial environments cannot be gauged. There have been no broad-scale studies. There is no basis for setting priorities or targeting investment.

There is some knowledge of the achievements of management interventions to date. The Salinity and Drainage Strategy has gained us a 20-year reprieve against rising salinity in the lower Murray. Land and Water Management Plans and adoption of best practices in irrigated agriculture has brought a level of salinity control. There is a sound basis for deciding on future investments, typically salt interception schemes. On the other hand, the prognosis for dryland catchments is not as good. Despite major investment in the development of improved farming systems and in catchment management programs, for some rainfall zones there are currently no farming systems capable of controlling salinity. The scale of land use change needed to address the hydrological imbalance, for instance forestry and revegetation, is beyond current resources and raises other dilemmas, including trading off salinity control and water yield.
WHAT ARE THE NEXT STEPS?
The Murray–Darling Basin Commission is preparing a draft Basin Salinity Management Strategy for Ministerial Council consideration by June 2000. The Commission is giving priority to refining the current framework for integrated catchment management to better accommodate a decade of evolution in catchment management organisations and government–community partnerships. The Basin-wide salinity threat is a major reason for updating the Natural Resource Management Strategy. The new integrated catchment management framework will include the following features:

- Adoption of the national principles of natural resource management
- Strengthening regional catchment planning, implementation and accountability
- Development of a long-term investment program, better suited to the nature of dryland salinity
- Evaluation of a range of policy options for government.

The draft Basin Salinity Management Strategy is likely to extend the principles of the Salinity and Drainage Strategy so that they apply Basin-wide. The key current feature of the Strategy is that States are accountable for actions that impact on salinity and there are incentives to take measures to achieve a common, agreed target. This approach could be applied to river valleys, beyond the River Murray ‘main-stem’, where ‘end-of-valley’ targets would be established. Integration of river valley and Basin salinity outcomes would be essential.

Clearly, broad-scale land use change has to be considered if there is to be salinity control that improves on the projected trends. At the national and state levels, consideration is being given to the multifunctional benefits of forestry and revegetation, the stimulation of innovation and development of new sustainable industries, assistance with rural adjustment in some regions and better application of planning principles. These are highly relevant to the prospective Strategy.

The Commission has already taken steps to improve the predictive capacity and decision support for the new Strategy. The Audit has identified where improvements can be made, and the National Land and Water Resources Audit’s dryland salinity monitoring program will provide further guidance. An integrating model is under development; one that can accommodate the trade-offs between Basin and river valley salinity targets to achieve optimum natural resource, economic and social outcomes. Better decision support at the regional level, including environmental impacts and benefit/cost analyses, is needed.

The Murray–Darling Basin Commission is a party to a number of national incentives on salinity and can work closely with them:

- The Commonwealth Government’s response to the PMSEIC report on dryland salinity
- The APMCANZ policy framework on dryland salinity
- The mid-term review of the National Heritage Trust, regarding dryland salinity
- The National Dryland Salinity Program.

The Salinity Audit clearly identifies the severity and scale of the salinity threat to the Murray–Darling Basin if there are no new management interventions. Yet it does not pre-empt what might be the Murray–Darling Basin Salinity Management Strategy. Rather, the Commission has identified a path forward for integrating the Strategy it will recommend to the Ministerial Council within the evolving integrated catchment management framework and national initiatives in dryland salinity.
### Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Alluvium Clays</td>
<td>Sands, gravels and other materials that are transported and deposited by running water and which typically form a floodplain.</td>
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<tr>
<td>Aquifer</td>
<td>Materials below the surface of the ground that can store and transmit groundwater. Aquifers generally occur in sands, gravels, limestone, sandstone or highly fractured rocks.</td>
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<tr>
<td>Aquitard</td>
<td>A layer that retards but does not prevent the movement of water to or from an adjacent aquifer. Aquitards usually comprise materials such as siltstone, mudstone, marl or clay.</td>
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<tr>
<td>Australian Height Datum</td>
<td>The reference point (very close to mean sea level) for all (AHD) elevation measurements, used for depths of aquifers and water levels in bores.</td>
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<tr>
<td>Baseflow</td>
<td>The component of flow in a river which has come from groundwater discharge.</td>
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<tr>
<td>Conjunctive use</td>
<td>The combined use of surface water and groundwater storage to optimise total available water resources.</td>
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<tr>
<td>EC</td>
<td>Electrical Conductivity unit. 1 EC = 1 micro-Siemens per centimetre, measured at 25 C. It is used as a measure of water salinity (see Salinity below).</td>
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<tr>
<td>EL</td>
<td>Elevation Level. Metres above Australian Height Datum (approximately sea level).</td>
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<tr>
<td>Fractured rock aquifers</td>
<td>These occur in igneous and metamorphosed hard rocks which have been subjected to disturbance, deformation, or weathering, and which allow water to move through joints, bedding plains and faults. Although fractured rock aquifers are found over a wide area, they contain much less available groundwater than surficial and sedimentary aquifers and, due to the difficulty of obtaining high yields, the quantities of water taken from them are relatively low.</td>
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<tr>
<td>Groundwater</td>
<td>Water that occurs beneath the ground surface and which is stored in an aquifer.</td>
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<tr>
<td>Impermeable layers</td>
<td>Layers of rock that do not allow water to pass through them.</td>
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<tr>
<td>Infiltration</td>
<td>The movement of water from the land surface into the ground.</td>
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<tr>
<td>Local groundwater systems</td>
<td>Aquifers that respond rapidly to recharge due to a shallow water table and/or close proximity of the recharge and discharge sites. These types of flow systems occur almost exclusively in unconfined aquifers.</td>
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<tr>
<td>Megalitre (ML)</td>
<td>One million litres.</td>
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<tr>
<td>Recharge</td>
<td>The process that replenishes groundwater, usually by rainfall infiltrating from the ground surface to the water table and by river water entering the water table or exposed aquifers; the addition of water to an aquifer.</td>
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<tr>
<td>Regional groundwater systems</td>
<td>Extensive aquifers that take longer than local systems to respond to increased groundwater recharge because their recharge and discharge sites are separated by large distances (&gt;10km), and/or they have a deep water table. Unconfined aquifers with deep water tables that are part of regional flow systems may become, in effect, local flow systems if there is sufficient recharge to cause the water table to rise close to the surface (&lt;5km).</td>
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<tr>
<td>Salinisation</td>
<td>The accumulation of salts via the actions of water in the soil to a level that causes degradation of the soil.</td>
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<tr>
<td>Salinity</td>
<td>The concentration of sodium chloride or dissolved salts in water, usually expressed in EC units or milligrams of total dissolved solids per litre (mg/L TDS). The conversion factor is 0.6mg/L TDS = 1 EC unit is used as an approximation.</td>
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<tr>
<td>Total dissolved solids (TDS)</td>
<td>A measure of the salinity of water, usually expressed in milligrams per litre (mg/L). Sometimes TDS is referred to as total dissolved salts, or as TSS, total soluble salts. See also EC.</td>
</tr>
<tr>
<td>Transpiration</td>
<td>The loss of water vapour from plants.</td>
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<tr>
<td>Water table</td>
<td>The upper level of the unconfined groundwater, where the water pressure is equal to that of the atmosphere and below which the soils or rocks are saturated. It is the location where the sub-surface becomes fully saturated with groundwater; the level at which water stands in wells that penetrate the water body. Above the water table, the sub-surface is only partially saturated (often called the unsaturated zone.)</td>
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