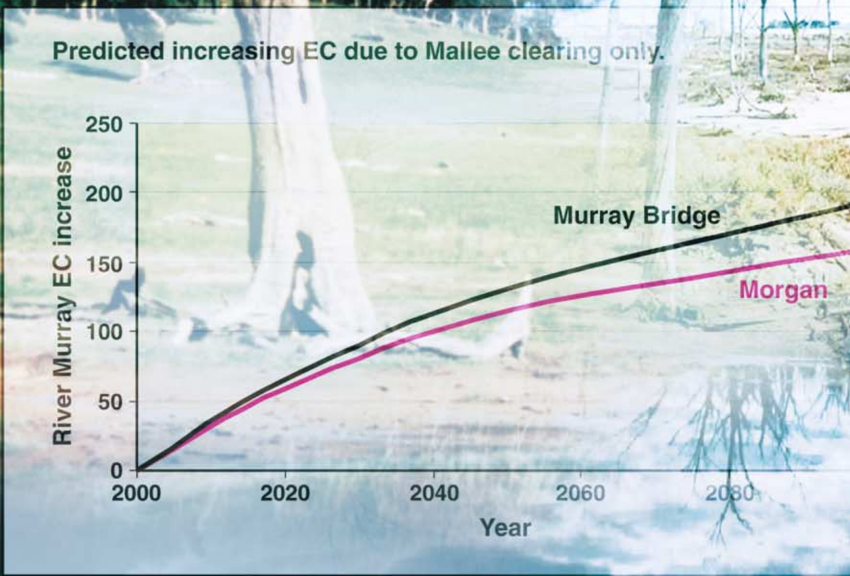
RB 2000/45

NATIONAL LAND AND WATER RESOURCES AUDIT

Extent and impact of dryland salinity in South Australia

Compiled by
S.R. Barnett



Department for Water Resources
Department for environment and heritage
PRIMARY INDUSTRIES AND RESOURCES SA
CSIRO
Government of South Australia

National Land and Water Resources Audit

Extent and Impacts of Dryland Salinity in South Australia

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Groundwater Resource Assessment

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Summary

Dryland salinity has been recognised in SA to be an important issue which presents unique challenges to land managers, policy makers and regulators. Estimates of areas affected have increased from 55 000 ha in 1982 to almost 393 000 ha in 1993 as a result of increased awareness and better recognition of the problem, as well as the actual expansion of salinisation. This Audit project has allowed the first mapping of dryland salinity to be carried out with consistent methodologies and guidelines. The assets currently affected, together with those considered at risk (after considering watertable trends, landforms and anecdotal evidence) are shown in Table 1. The areas of agricultural land affected are considered to be secondary salinity and do not include the estimated 84 000 ha of primary (pre-European) salinity.

Table 1. Summary of dryland salinity impacts

Assets	Current	2020	2050
Agricultural land (,000 ha)	326	421	521
Roads (km)	910	1260	1710
Rail (km)	35	40	46
Towns	0	0	2
Remnant vegn (,000 ha)	18	22	25
Rivers ephemeral (km)	160	190	210
Wetlands (,000 ha)	45	52	57
Wetlands of National Significance	4	4	4

The associated interim estimates of the economic impact are depicted in Table 2.

Table 2. Interim total costs of dryland salinity ($M/year)

Impacts	Current	2020	2050
Losses in agricultural production	26.1	34	42
Road and rail maintenance	17.1	23.5	30.5
Building maintenance	1.2	1.4	1.9
Costs of increase in River Murray salinity	0	8.2	17.4
Total Cost	**44.4**	**67.1**	**91.8**

While these estimates appear large, they represent even in 2050, less than 1% of the Statewide agricultural production. Consequently, dryland salinity is probably of less significance in SA than some other mainland states.

Because most of the groundwater trends are strongly controlled by rainfall, watertable levels have been falling throughout southern SA for the last 2 - 3 years up until the year 2000, due to well below average winter rainfalls. Some drier catchments have experienced falling groundwater levels since 1993. Obviously, future groundwater trends will depend on future rainfall patterns which are notoriously difficult to predict.

The regional groundwater systems of the Murray Basin are generally well monitored through various agencies, with the only improvements required being in the western area to monitor the watertable rise which will increase saline groundwater inflows to the River Murray. Although networks are restricted in areal extent in other regions where local flow systems in fractured rock aquifers predominate, it is thought that they are sufficiently indicative of regional trends that extra observation wells (which would require expensive drilling) are not necessary.

Increasing stream salinisation is occurring in Tod River (Eyre Peninsula) and Middle River (Kangaroo Island), although in both situations, alternative domestic supplies are available (limited groundwater on EP, desalination on KI), and there is little prospect of increased demand for domestic and stock water. However, there is little opportunity for increased industrial, mining and irrigation supplies in the future, which could have serious consequences for regional development in these areas. Elsewhere within SA, and particularly in the Mt Lofty Ranges, stream salinisation trends are not evident from the available data from catchments that have been monitored.

Perhaps the most widely felt impacts of watertable rise will be felt by the consumers of River Murray water. This resource is of vital importance to SA. Groundwater modelling has suggested that vegetation clearance in the Mallee will result in an increase in salinity of 118 EC by 2050, with an additional cost to consumers of $17.4M/year.

Biodiversity mapping has identified several areas at risk from rising watertables. These include extensive tea-tree shrublands and native grasslands in the Coorong District, and seasonal wetlands and watercourses in the Upper South East. On Kangaroo Island, the viability of sedgeland and tea-tree ecosystems protected in conservation parks or vegetation heritage agreements are threatened by extensive areas of shallow saline aquifers, while on Lower Eyre Peninsula, native vegetation on valley floors and in seasonal swamps have also been identified as being at high risk.

A whole-of-government approach to the management of the growing salinity problem in SA has been adopted with the formation of the State Salinity Committee. This body has overseen the formulation of the State Salinity Statement, and drafts of the South Australian River Murray Salinity Strategy and the State Dryland Salinity Strategy which has identified various management options to meet the challenge of dryland salinity. These involve:

- reducing the recharge (usually with the aid of deep-rooted perennial vegetation); and/or
- utilising the discharge (usually with salt-tolerant plants or in other industries that can use saline water); and/or
- disposing of surplus water (usually by drainage).

An economic analysis and cost sharing assessment of six revegetation options for the Lower Eyre Peninsula (LEP) found that broad-scale revegetation for dryland salinity management is not economically feasible given returns expected from the current land use options. There may, however, be site specific situations where targeted remedial works will deliver benefits which exceed costs. Similarly, dryland salinity management options will become more attractive if more profitable land-uses designed to reduce recharge are identified.

Significant action has already being undertaken to combat the impacts of dryland salinity through the Upper South East Dryland Salinity and Flood Mitigation Plan with associated drainage, revegetation, farm redevelopment and environmental initiatives. The Coorong and Districts Local Action Plan and associated on ground works has become a national model whereby a local community has led implementation of significant on-ground works to increase rainfall utilisation and reduce salinity threats. Similar projects are emerging in other parts of the State.

One of the more difficult challenges is dealing with the increased recharge from rainfall under dryland farming in the Mallee region which will cause significant future saline discharges into the River Murray.

Introduction

South Australia has recognised dryland salinity to be an important issue which presents unique challenges to land managers, policy makers and regulators. In 1990, the State Dryland Salinity Committee developed a Technical Strategy which was implemented over the following decade through coordinated research projects in five representative catchments from agricultural regions around the State. This has resulted in a much better understanding the nature of dryland salinity in the various regions of South Australia and has led to development of some very effective management tools.

The National Land and Water Resources Audit project to identify the extent and impacts of dryland salinity is very timely because the outputs presented an opportunity for the State program to be refocussed for the next decade, and also provided a solid foundation for the State Dryland Salinity Strategy which has recently been released.

Extent and trends in dryland salinity

Dryland salinity occurs in the southern half of South Australia which experiences a Mediterranean climate with cool to cold wet winters and hot dry summers. Rainfall exceeds evaporation only in the winter months. The main land use in the areas affected by dryland salinity is almost entirely annual crops and pastures which allow a much higher recharge to the underlying watertable than native vegetation that previously covered the area. Table 3 shows the previous estimates of the areas affected in the various agricultural regions of the State.

Table 3. Previous estimates of areas affected (hectares)

Region	**1982**	**1990**	**1993**
Upper Southeast		60 000	260 000
Murray Basin		16 000	57 000
Eyre Peninsula		60 000	50 000
Kangaroo Island		8 000	10 000
Mid North		8 000	8 000
Yorke Peninsula		10 000	5 000
Mt Lofty Ranges		2 500	2 500
Total	**55 000**	**224 500**	**392 500**

The dramatic increase in areas affected by dryland salinity in some regions is most likely the result of increased awareness and better recognition of the problem, rather than the physical expansion of salinisation (however in some areas, salinisation has increased significantly, especially after very wet years). These estimates did not have the benefit of being carried out with consistent methodologies and guidelines, but were the best available with the limited information and resources accessible at the time.

It is important that reasonably accurate mapping should be made of current areas affected to enable credible risk assessments to be made of future impacts, and also to allow accurate estimates of the current cost of dryland salinity. For the purposes of this study, the most recently available aerial photography (at a scale of 1:40 000) was used where possible to delineate the actual affected areas (methodologies are outlined in Appendix 1). A GIS coverage was created of the mapped current areas (both primary and secondary) affected for the year 2000. Regional maps from this coverage are presented in Appendix 2, and are also available on *www.saltcontrolsa.com* under Salinity in SA. An important contribution to this process was made by the PIRSA "Catchments back in balance" project which mapped salinised areas during the formulation of salinity management plans in various catchments throughout the State.

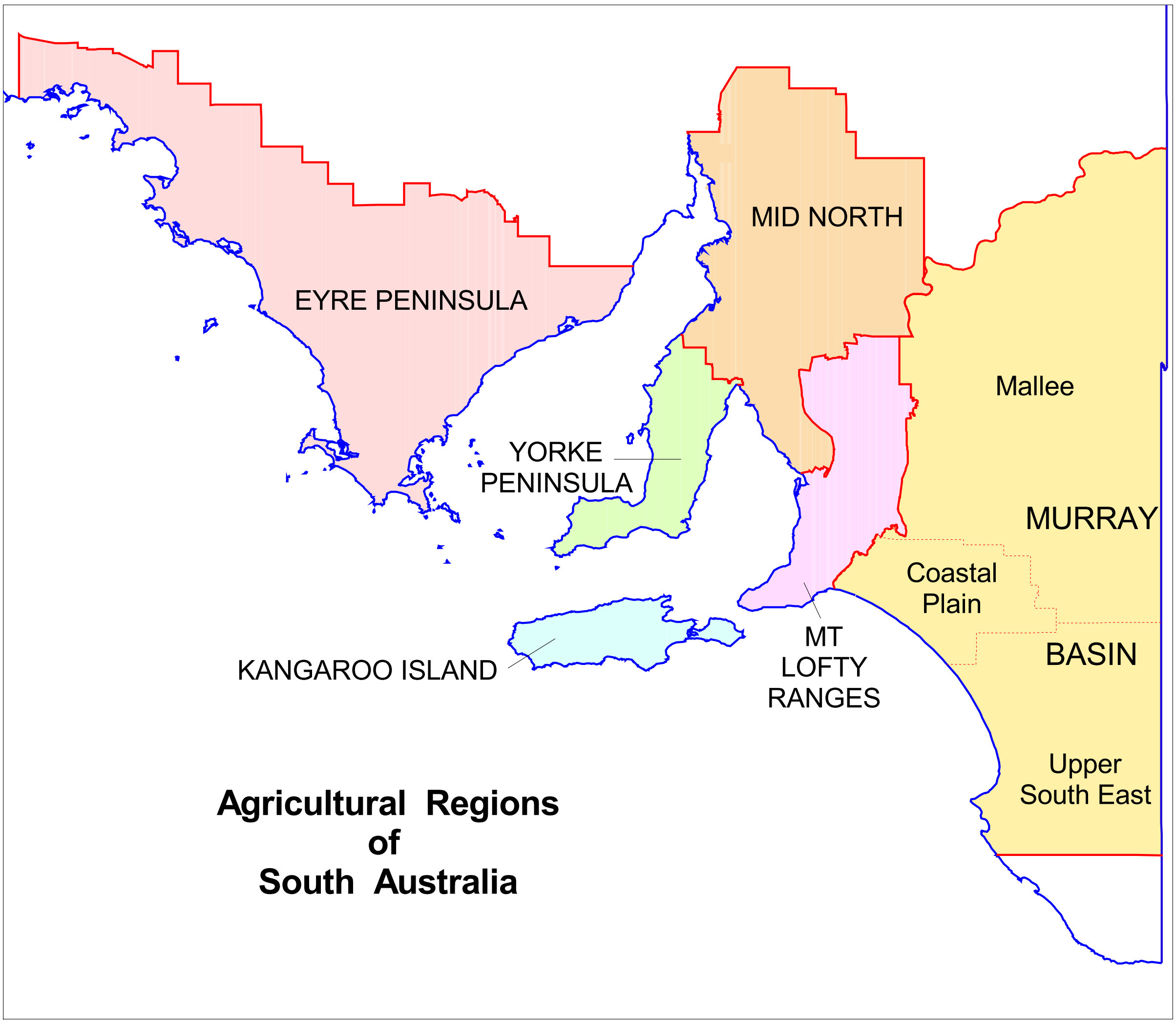

Figure 1. Agricultural regions of South Australia

Table 4. Current areas affected in 2000 (hectares)

Region	Primary	Secondary	Total
Upper South East	22 500	250 500	272 000
Murray Basin	16 700	19 800	36 500
Eyre Peninsula	35 200	20 400	55 600
Kangaroo Island	500	5 600	6 100
Mid North	300	14 800	15 100
Yorke Peninsula	8 000	13 900	21 900
Mt Lofty Ranges		1 200	1 200
Total	**84 000**	**326 000**	**410 000**

Despite the difficulty in determining when historical salinity occurred, an attempt was made to distinguish possible pre-European or primary salinity from secondary or human-induced salinity. Primary salinity has, and probably never will be considered for agricultural purposes, and therefore will not be included in the cost estimates of the impact on agricultural production. However, these areas will have an ongoing impact on infrastructure costs and were included in those estimates. Lagoons and wetlands which have, or may become salinised have been delineated and excluded from areas of secondary salinity because again, they are not used for agricultural production. Areas under tidal influence along the coast were also excluded from the mapping coverage.

Table 4 presents a summary of current areas which has been derived from the GIS coverage and professional judgement given some limitations in the available aerial photography.

Compared with Table 3, the actual salinised area as found by the Audit is less than previous estimates, however the area most affected was confirmed to be the Upper South East.

Groundwater Level Trends

All observation well data within the five agricultural regions were examined and analysed for any trends and relationships with rainfall. Because of the low utilisation of groundwater due to high salinities and low yields in most of these areas, data was only available from observation wells drilled in the five representative catchments in 1990/91. The exception is the Murray Basin where the early recognition of dryland salinity and the widespread use of groundwater for stock supplies enabled a regional observation network to be established in the Coastal Plain area in 1987. Further south in the Upper South East, regional groundwater monitoring has been carried out since 1975, but not specifically for dryland salinity.

The monitoring record in most areas is therefore only moderate in length, and is complicated by the atypical rainfall patterns, namely a very wet 1992/93 season and mostly below average rainfall up until the year 2000. However all of the observation wells could be categorised according to the following trends.

- Continually rising
- Episodic rise (in response to very wet years)
- Correlation with winter rainfall
- No discernible trend

A discussion of each trend follows, with a summary presented in Table 5. Examples of representative hydrographs depicting these trends are shown in Figure 2. The State-wide distribution of the observation networks and the location of each observation well categorised according to its water level trend is displayed in a GIS coverage available in the dynamic mapping part of the Australian Natural Resources Atlas. Each observation well is also hot-linked to its water level data presented as a hydrograph, together with rainfall data.

Continually rising trend

The continually rising trend is seen only in the regional flow systems of the Murray Basin. This trend is observed where there is no discharge from the system apart from lateral groundwater flow, ie where there is no major pumping for irrigation, or more importantly, where the watertable is too deep for evaporative discharge to occur.

In the Coastal Plain area where the depth to the watertable is greater than 5 m, consistent rises of 7- 10 cm/year are being observed beneath sandy soils despite significant variations in annual rainfall. Similar rises are also observed in the Upper South East where the depth to the watertable is greater than 20 m. Heavier soils in the Bordertown area restrict recharge from rainfall, with rises of the order of only 2 – 3 cm/year. Rises in the drier Northern Mallee area are also low, about 2 cm/year where watertable is greater than 10 m below the ground surface.

Episodic rise

Episodic rises in response to very wet years were found to occur in local and intermediate flow systems in lower rainfall areas (below 500 mm) and where lower permeability aquifers prevent the rapid dissipation of the high recharge volumes by lateral flow. These trends were observed in upper Eyre Peninsula, Yorke Peninsula, the Mid North and in part of the Murray Basin (Coastal Plain) where the normally permeable regional limestone aquifer changes to a calcareous marl (clay).

Because of the mostly below average rainfall since the last major recharge event in 1992-93, groundwater levels have been falling since then, often to levels lower than those preceding this event.

Winter rainfall

In some wetter areas, a very good correlation was found to occur between observed groundwater level trends and the cumulative deviation from the mean winter rainfall (May-August). This winter rainfall correlation was better than using the mean monthly rainfall deviation over the twelve months of the year. This suggests that in many areas, the winter rainfall alone is controlling watertables, irrespective of the rainfall in the other eight months of the year (except in very wet years such as 1992-93). This is not really surprising given the dominance of evaporation over rainfall for most of the year under the Mediterranean climate experienced in southern SA.

Close examination of hydrographs shows that even average, or slightly below average rainfall in winter is still sufficient to cause rising watertables, and several years of below average rainfall are required before watertables begin to fall. In some cases, it is difficult to distinguish between a continually rising trend and a winter rainfall correlation because winter rainfalls in some areas of the Upper South East and the Northern Mallee have been mostly above average since 1981, leading to consistent watertable rises.

Because of the this close relationship with winter rainfall, groundwater levels have fallen during the last 2 – 3 years over large areas of southern SA that experienced below average rainfall for the past three winters (up until the year 2000).

No discernible trend

Observation bores showing no discernible trend are mostly located in discharge areas where the watertable is less than 2 m below the ground surface. Although there are seasonal variations due to winter recharge and summer evaporative discharge, these processes tend to balance each other and consequently, any long term rising or falling trend is quite subdued or non-existent.

Future trends

Obviously, because of the strong relationship between groundwater levels and rainfall as demonstrated above, future groundwater trends will depend on the future rainfall patterns which are notoriously difficult to predict. The greenhouse effect is expected to lead to lower winter and higher summer rainfalls, however the degree to which other cyclical patterns (eg the eleven year solar cycle) will impact on these trends is unknown. It must be remembered that these natural variations in rainfall are only of the order of 10 – 20%, whereas recharge has increased by about 1000% since clearing.

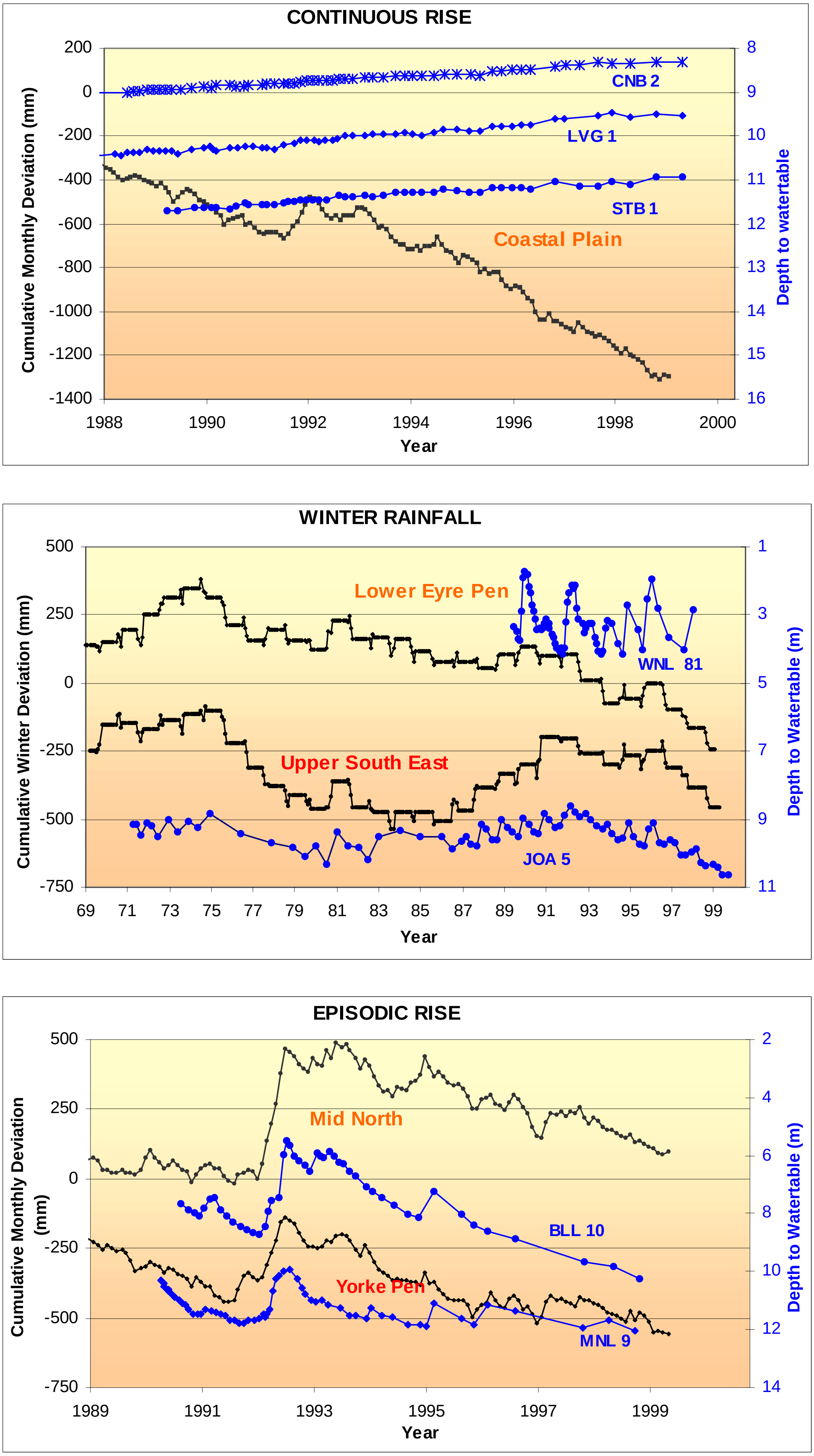

Figure 2. Representative groundwater level hydrographs

Table 5. Summary of groundwater level trends

Catchment	Hydrogeological Province (NLWRA)	Flow system (NLWRA)	Rainfall (mm)	Dominant trends	Comments
MURRAY BASIN					
Coastal Plain	Cainozoic marine sediments	Regional (iii)	450 - 500	Winter rainfall Continuous rise 8 cm/yr	SWL <5m SWL >5m
Upper South East	Cainozoic marine sediments	Regional (iii)	450 - 600	Winter rainfall Continuous rise 10 cm/yr	SWL <20m SWL >20m
Northern Mallee	Cainozoic marine sediments	Regional (iii)	275	Winter rainfall Continuous rise 2 cm/yr	SWL <10m SWL >10m
EYRE PENINSULA					
Cummins Basin	Cainozoic sediments	Regional (iii)	500	Winter rainfall Episodic rise	
Wanilla	Precambrian rocks (weathered)	Local (i)	550	Winter rainfall	
Darke Peak	Cainozoic sediments	Local (i)	385	Episodic rise	
KANGAROO ISLAND					
Narroonda	Palaeozoic rocks (weathered)	Local (i)	620	Winter rainfall	
MID-NORTH					
Jamestown	Cainozoic sediments	Intermediate (i)	460	Episodic rise	
Lochiel	Cainozoic sediments	Local (ii)	400	Episodic rise	
YORKE PENINSULA					
Minlaton	Palaeozoic glacial clays	Local (i)	400	Episodic rise	
MT LOFTY RANGES					
Harrogate	Palaeozoic rocks (weathered)	Local (i)	555	Winter rainfall	
Keyneton	Palaeozoic rocks (weathered)	Local (i)	540	Winter rainfall	

Risk Mapping

In determining areas at risk to dryland salinisation, there are two fundamental questions that need to be considered.

1. In a region where dryland salinisation has already occurred, is it possible that there will be **new** areas affected ? In other words, given similar geology and climate throughout the region, if salinisation is going to occur, would it have already happened by now ?
2. Are areas currently affected going to **expand** ? In other words, is it already as bad as it's going to get, and has a new equilibrium already been reached ?

Before European settlement, a natural hydrological balance existed between recharge and discharge. Land clearing lead to increased recharge which inevitably resulted in increased discharge in order to restore this balance. Eventually, a new equilibrium will be reached when the increased recharge is balanced by increased discharge, through evaporation from salinised areas and increased groundwater discharge. When this occurs, the areas affected by dryland salinity will stabilize. This stability of the system is dependent on length of time since clearing has occurred. Based on local experience, it is felt that on average for local flow systems, a post clearing period of 30-40 years is required prior to a new equilibrium being established.

When considering areas at risk, it must be remembered that about 80% of the agricultural regions in SA are almost completely devoid of native vegetation, with considerable areas cleared over 100 years ago.

In areas with regional flow systems such as the Murray Basin, where groundwater level trends were established, the areas at risk to dryland salinisation were assessed on the basis of where the rising groundwater would rise within 1 – 2 m of the land surface. Because the regional watertable elevation contours are generally well known, it is a relatively simple exercise to extrapolate the rising trend and determine where and when the watertable will intersect the ground surface. Accurate topographic maps or digital terrain models are required for the best results using this method, which was successfully used in the Upper South East using GIS modelling. Unfortunately, most areas of SA do not have sufficient data to do this type of modelling.

GIS coverages have been prepared showing the areas at risk in 2020 and 2050 for the Murray Basin and are available in Appendix 2. Broad areas with very low topographic gradients have more land affected for a given watertable rise, than steeper undulating country. Also, the watertable rise will be restricted close to discharge areas with a fixed water level eg the River Murray, the Coorong and Lakes Alexandrina and Albert. Similarly, any rise will also be limited in areas of significant salinisation because much of the recharge to the shallow aquifers will be lost by evaporative discharge.

Elsewhere in SA, fractured rock aquifers predominate with local flow systems. There are few watertable contour maps for these aquifers and even fewer detailed digital terrain models. Consequently, the trend extrapolation method cannot be used in these regions. A combination of anecdotal evidence and professional judgement has been used to determine areas at risk. Because the actual areas at risk are quite small compared to the scale of the mapping coverage, no attempt was made to map them. Instead, estimates of the percentage increase from the current extent were made to determine the risk areas.

The areas at risk assuming a non-intervention scenario are presented in Table 6. These figures exclude areas of primary salinity. The extrapolated areas were derived assuming an approach to an equilibrium of salinised land and not an indefinite linear rising trend in watertables.

Table 6. Estimates of areas at risk

Region	2000	2020	2050
Upper Southeast	250 500	324 000	409 500
Murray Basin	19 800	29 600	34 000
Eyre Peninsula	20 400	24 000	27 000
Kangaroo Island	5 600	6 500	8 000
Mid North	14 800	18 000	21 000
Yorke Peninsula	13 900	17 500	20 000
Mt Lofty Ranges	1 200	1 400	1 500
Total	**326 000**	**421 000**	**521 000**

Impacts of dryland salinity

Stream Salinity

South Australia's climate, with low and highly variable winter rainfall combined with long, hot and dry summers, has resulted in relatively small harvestable water resources, and heavy dependence on the River Murray which is central to the social and economic development of the State. In dry years, it supplies up to 85% of the State's urban water needs. One of the most significant threats to these resources is deterioration of water quality, in particular increases in salinity.

The causes of dryland salinity are well documented, namely the increase in recharge following clearing results in rising watertables. In the case of streams, lakes and dams, increased hydraulic gradients due to rising groundwater can result in greater movement of saline groundwater into these surface water resources (Figure 3).

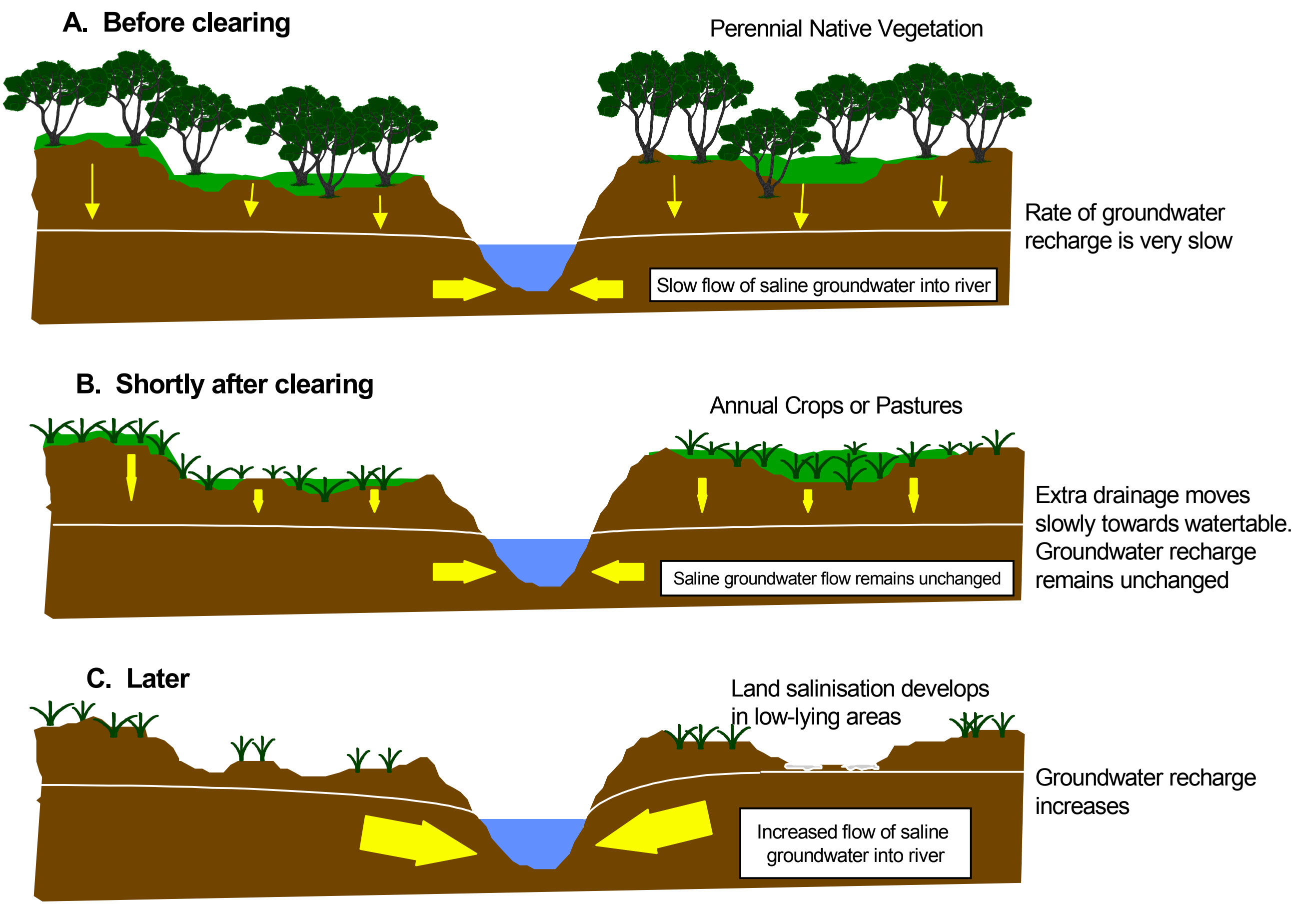

Figure 3. Processes causing stream salinisation

Two projects were carried out to determine the impacts of dryland salinity on the surface water resources of SA. A brief reconnaissance study of the likely impacts on water resources within SA was carried out by a team from CSIRO Land and Water and the Department for Water Resources, in addition to a groundwater modelling study by the Department for Water Resources and consultants Australian Water Environments to determine salinity increases in the River Murray due to clearing in the Mallee region.

Surface Water Resources within SA

Jolly et al (2000) used a three part process to identify which water resources are at risk:

- Review of relevant literature to determine which water resources were previously identified to be at risk from dryland salinisation.
- Interviews with key personnel in appropriate water supply and catchment management authorities throughout the various regions of South Australia with dryland salinity.
- Statistical analysis of historical stream salinity trends for stations in these areas where data were available. The maximum available length of record was 27 years, however many stations had less than this.

The investigation found the water resources to be at greatest risk were the Tod River Reservoir on Lower Eyre Peninsula, and the Middle River Reservoir on Kangaroo Island. While there is only limited duration data for the Tod River catchment, it was clear that salinities have significantly increased in the streams supplying the reservoir. Predictions of increases in areas of dryland salinity in the catchment means that further detrimental impacts on the salinity of streamflows may occur. The reservoir will no longer be an essential component of the reticulation system as the proposed additional output from nearby groundwater basins may offset the reservoir contribution if it is empty. However, for obvious economic reasons, and to relieve the demands on the groundwater basins, the reservoir will be used when water is available and is of acceptable quality (low salinity and there are no other water quality concerns).

Although there is insufficient data to determine salinity trends in the streams supplying Middle River Reservoir, dryland salinity has clearly impacted on this resource, as evidenced by need to manage its salinity by winter flushing. While both of these reservoirs are clearly under serious threat, alternative domestic supplies are available (limited groundwater on Eyre Peninsula, desalination on Kangaroo Island), and there is little prospect of substantially increased domestic and stock water requirements. However, there is little opportunity for future increased industrial, mining and irrigation supply, which could have serious consequences for regional development in these areas.

There was no clear evidence that stream salinities have increased overall in the Mid-North and Mount Lofty Ranges, however the high salinities (particularly on the eastern side of the ranges) and large fluctuations over time at many stations were disturbing but could not be fully investigated in this short-term reconnaissance study. It is clear from previous salt balance studies that many of the catchments of the Mount Lofty Ranges are exporting salt as a result of clearing. However, the statistical trends determined in this investigation suggest that the resultant stream salinisation has not worsened, at least over the last 20–30 year period where data are available. Presumably this is because many of the catchments have been cleared for many decades and may be at (or past) the peak of the salt export cycle.

The statistical analysis was constrained by lack of any data in some areas, and either short-term, irregular or sparsely sampled data in many areas. Also, the methodology used for collection of stream salinity data has changed over time and there is some concern that this may have, in some instances, introduced some bias in the results. Furthermore, over the last decade or so, the climate has generally been drier than average and so the full impact of dryland salinity in many areas may yet to be seen.

River Murray

Groundwater flow modelling was carried to predict the increase in groundwater inflows and salt loads to the River Murray in South Australia as a result of land clearing in the Mallee. Two models were developed – from Morgan to Tailem Bend by the Department for Water Resources, and Morgan to the SA Border by Australian Water Environments (Barnett et al, 2000). The models were calibrated against measured groundwater levels and previously calculated salt loads discharging into the river.

By using the increased recharge rates following clearing as determined by CSIRO Land and Water, and when the increased recharge would reach the deep regional watertable, the models predicted the rise in the watertable in the years 2020, 2050 and 2100. By knowing the groundwater salinity adjacent to the river, the modelled groundwater discharge could be converted to salt loads on a lock to lock basis.

Table 7 shows the modelled salt loads up to the year 2100 from Tailem Bend to the SA Border. These results take into account a range of complex processes within the river floodplain (storage of saline groundwater discharge in floodplain aquifers and evapotranspiration from the floodplain), which reduce and delay the entry of salt loads to the river itself.

Table 7. Modelled salt loads to the River Murray (tonnes/day)

River Reach	1995	2020	2050	2100
Tailem Bend - 1	70	111	160	237
Lock 1 - 2	240	275	307	344
Lock 2 - 3	500	350	214	226
Lock 3 - 4	145	210	275	331
Lock 4 - 5	90	150	198	237
Lock 5 - 6	210	300	382	440
6 - SA Border	70	125	179	218
Total	**1325**	**1521**	**1715**	**2033**

Figure 4 shows the impacts of these saltloads on the river salinity which will increase by 118 EC at Morgan by 2050 with an increased cost to the consumers in SA of $17.4M/year. The Salinity Audit of the Murray Darling Basin has established that this contribution from the Mallee will be three times that from the irrigation areas by 2100. The models were also used to determine the effectiveness of various land management strategies in the Mallee to reduce salt loads to the river. It was found that modifications to existing farming systems will not be sufficient to bring about significant reductions in river salinity, and that large-scale revegetation would be required in order to have any significant effect. However, the cost of traditional forms of revegetation is enormous and the benefits will not be realised for many years.

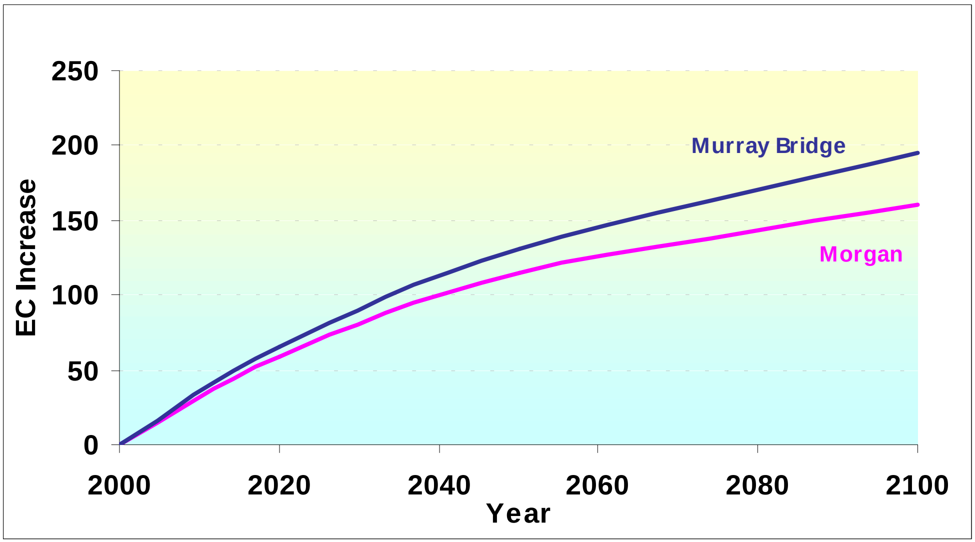

Figure 4. Increase in River Murray salinity due to Mallee clearing only

The draft *South Australian River Murray Salinity Strategy* outlines further work that is required to refine management options. More detailed groundwater modelling is recommended to prioritise areas for strategic on-ground works (revegetation, groundwater interception schemes) to achieve cost effective salinity reduction.

In many areas of the State where dryland salinity is threatening water resources, access to River Murray water is generally available. This present and future reliance on River Murray supply poses a significant threat to South Australia's water resources. Any major increases in salinity or changes in security of supply of the River Murray will have widespread and very serious consequences in the future.

Biodiversity

Apart from the well known impacts of dryland salinity on agricultural production, it is becoming increasingly recognised that rising watertables can have environmental consequences. A study by Grear and Moyle (2000), funded by the Audit, examined the threats to the biodiversity in the agricultural regions of SA by collecting biological data in a GIS format (vegetation associations, landcover type, threatened species, conservation tenures and wetlands), and then correlating them with similar GIS coverages of depth to watertable and shallow aquifer salinity. Ground-truthing was undertaken in selected areas to accurately determine factors such as dominant vegetation, vegetation health, pre-settlement vegetation systems, hydrology, halophytic species and surface soil/water levels. Results are shown in Table 8.

Table 8. Dryland salinity impacts on biodiversity

Impact	Current	2020	2050
Remnant vegn (,000 ha)	18	22	25
Rivers ephemeral (km)	160	190	210
Wetlands (,000 ha)	45	52	57
Wetlands of National Significance	4	4	4

The mapping identified extensive tea-tree shrublands and native grasslands in the Coorong District that are at risk from rising watertables. The conservation significance of much of these habitats is enhanced by close proximity to the Ramsar listed Coorong and Lower Lakes. Seasonal wetlands and watercourses in the Upper South East are at high risk from dryland salinity. Extensive clearance of vegetation and drainage of wetlands in this district has had particularly severe implications for sedgelands and seasonal wetland ecosystems. Those areas remaining are almost all at high risk and have high conservation significance, often recognised by inclusion in the protected area estate.

Similarly on Kangaroo Island, the viability of sedgeland and tea-tree ecosystems protected in conservation parks or vegetation heritage agreements are threatened by extensive areas of shallow saline aquifers. Native vegetation on valley floors and in seasonal swamps on Lower Eyre Peninsula, provide refuge for birds and mammals endemic to the region and have also been identified as being at high risk.

A summary of these findings is presented in Table 9, together with the several significant Conservation Parks and Wildlife Reserves which have been identified as having high potential for biodiversity degradation from rising watertables. In addition, numerous Vegetation Heritage Agreement Areas on Eyre Peninsula, the Coorong, Upper South East, Riverland and Kangaroo Island are at risk from a decrease in biodiversity.

Table 9. Risks to habitat from dryland salinity

Region	Habitat	Conservation Parks
Upper South East	Seasonal wetlands, watercourses	Messent and Gum Lagoon
Coorong District	Tea-tree shrublands, native grasslands	
Lower Eyre Peninsula	Native vegetation, seasonal swamps	Hincks and Bascombe Well
Kangaroo Island	Sedgeland, tea-tree ecosystems	Murrays Lagoon

Other areas such as the Murray Mallee and Lower Yorke Peninsula have problems associated with rising watertables, however the paucity of remnant vegetation in these areas lessens the biodiversity risk.

Economic Analysis

One of the fundamental steps in the management of dryland salinity is the determination of dryland salinity its cost to the community and the benefits (or otherwise) of various treatment options. An economic model has been constructed by CSIRO Land and Water (Hajkowicz and Young, 1999) to estimate the cost of dryland salinity through not only the most obvious component of losses in agricultural production, but also the previously overlooked impacts on infrastructure such as the increased costs of road and building maintenance.

- Losses in agricultural production were estimated by calculating the area of secondary salinity unfit for agricultural production in hectares, and multiplying this by changes in regional weighted mean gross margins for agricultural production.

- Increased maintenance costs of roads affected by dryland salnity were calculated at $800 per km per year for unsealed roads and $2000 per km per year for sealed roads. Roads affected by salinity were identified by overlaying road maps with areas of both primary and secondary salinity risk maps in a GIS.

- Increased maintenance costs for buildings were calculated at $250 per building per annum for moderately affected buildings, and $2135 per building per annum for severely affected buildings. Buildings affected by salinity were identified by overlaying statistical local area (SLA) maps, indicating the number of dwellings per SLA, with areas of secondary salinity in a GIS.

It must be pointed out that some important costs were not included in this study. The effects of the salinity of water supplies and the impacts on biodiversity because of the lack of appropriate data and the difficulty in obtaining appropriate measures of cost.

The project was carried out in two stages. An interim cost estimate was first carried out (Hajkowicz and Young, 1999) using the chosen economic model and an existing GIS coverage of land capability mapping which estimated the current areas affected by dryland salinity as percentages of various soil landscape units expressed as lower, middle and upper estimates for each salinity class (Appendix 1). Table 10 shows the results of this interim study covering the State.

Table 10. Interim total costs of dryland salinity ($ 000 / year)

Impacts	Lower Estimate	Best Estimate	Upper Estimate
Losses in agricultural production	10 888	46 730	95 274
Road maintenance	299	637	974
Building maintenance	3 499	6 184	8 869
Total cost	**14 686**	**53 550**	**105 117**

The more accurate mapping coverage of the current extent of dryland salinity provided by this Audit project was then used (Hajkowicz and Young, 2000a), together with the estimates of future extents (Table 6), to generate a more refined interim estimate shown in Table 11.

Table 11. Refined interim total costs of dryland salinity ($ 000 / year)

Impacts	2000	2025	2050
Losses in agricultural production	26 050	34 038	42 123
Road and rail maintenance	17 106	23 541	30 351
Building maintenance	1 251	1 361	1 905
Total cost	**44 407**	**58 940**	**73 665**

While these interim costs to agricultural production appear large, they represent less than 1% of the Statewide gross margin from production on all agricultural land of $4 545M.

Case Study

Hajkowicz and Young (2000b) discussed issues relating to cost sharing for dryland salinity management and presented an economic analysis and cost sharing assessment of six dryland salinity management options for the Lower Eyre Peninsula (LEP).

The management options are based on a recent study of the Wanilla catchment by Stauffacher *et al.* (2000). These options involve different revegetation and land-use scenarios in the catchment over a 20 year period. The major trade-off posed by each scenario is the amount of cropping land revegetated against the additional land prevented from becoming salt affected. The options were explored first for the Wanilla Catchment (where there are few off-site impacts on infrastructure and urban water users) and then for the entire LEP.

The results of the benefit cost analyses indicated that the dryland salinity management options proposed by Stauffacher *et al.* (2000) are not economically feasible. For the most favourable option to break even, the value of the non-market benefits (eg biodiversity, drinking water quality) of dryland salinity control would need to be around a minimum of $173M for the LEP and $10M for the Wanilla Catchment. Hajkowicz and Young (2000b) found that if these benefits accrue only to people living in the LEP region, each household (of which there are roughly 6600) would have to contribute roughly $26 600 or $2500 per year over 20 years. Costs of this magnitude would need to be carefully considered against other options for avoiding the negative impacts of dryland salinity.

For the LEP, results suggest that broad-scale revegetation for dryland salinity management is not economically feasible given returns expected from the current options. There may, however, be site specific situations where targeted remedial works will deliver benefits which exceed costs. Similarly, dryland salinity management options will become more attractive if more profitable land-uses designed to reduce recharge are identified.

These results have some implications for other parts of Australia but may differ if a major population centre such as Adelaide was incorporated into the study region. A large population such as Adelaide's would mean that infrastructure costs of salinity problems would rise dramatically. This would have the effect of increasing the Net Present Values for the management options and their economic feasibility.

Monitoring

The monitoring of groundwater and surface water resources is fundamental to the understanding of the processes, impacts and risk assessment of dryland salinity, and also the effectiveness of various treatment options. A State Water Monitoring Review is underway to develop an integrated statewide monitoring program and to specify data sharing mechanisms.

Groundwater levels

All groundwater monitoring data in SA is stored on OBSWELL administered by DWR. The system has been incorporated with the corporate drillhole database SA_GEODATA using Oracle. A web interface is being developed to allow convenient access to the data.

The regional groundwater systems of the Murray Basin are generally well monitored through various agencies, with the only improvements required being in the western area between Morgan and Karoonda where a more comprehensive network is necessary to monitor the watertable rise which will increase saline groundwater inflows to the River Murray.

In other regions where local or intermediate flow systems predominate, the representative catchment observation wells are the only monitoring sites. Although restricted in areal extent, it is thought that these networks are sufficiently indicative of regional trends that extra monitoring is not necessary (any additional observation wells would require drilling because of the lack of private wells due to poor groundwater quality). A stronger agency commitment is required to ensure regular monitoring of these existing networks.

A number of Landcare Groups have also been involved with installing piezometers, however these were usually installed in discharge areas, therefore not providing any significant additional information. Monitoring of these piezometers has been discontinued in most areas due to lack of funding and insufficient agency resources to provide support.

Recommendations for improved groundwater monitoring include ;

- Improved coverage in the northern Mallee and more consistent monitoring in the Riverland to help more accurate predictions of salinity impacts on the River Murray.

Stream Salinity

Monitoring and data collection of surface water quantity and quality has been undertaken by government agencies in SA for many decades. In the early 1970s, a network of surface water monitoring was established to meet the needs of water supply obligations. Surface water salinity monitoring in SA occurs in the form of grab samples, continuous monitoring and composite samples which have all been collected using different methods.

Jolly et al. (2000) analysed EC trends from 39 grab sample and continuous monitoring stations throughout the State (Appendix 2), and found the statistical analysis of stream salinities constrained by lack of data, with either short-term, irregular or sparsely sampled records in some areas. Recommendations to overcome these shortcomings include ;

- Chart salinity data for stations in the Mount Lofty Ranges that has not been analysed should be digitised, entered in the appropriate database and included in future analyses of stream salinity trends.

- Detailed studies are carried out to identify the causes of the observed stream salinity trends for all stations in the Mount Lofty Ranges. This should include updated salt balance studies for the previously studied catchments.

- A gauging station should be installed upstream of the Middle River Reservoir, and any decision on the long-term future use of the reservoir should also consider the viability of catchment rehabilitation and alternative uses of the resource.

- Detailed studies are carried out to identify the causes of the large variations in stream salinity trends with time that are observed for stations in the Wakefield and Broughton catchments.

- The current PIRSA investigations which are seeking to determine the viability of rehabilitating the Tod River catchment to reduce the effects of dryland salinity should continue. Meanwhile, all existing groundwater basins should be maintained until such time that the Tod River catchment is rehabilitated, if this is possible.

- Further salt balance studies in Mount Lofty Ranges catchments will require monitoring of rainfall salinity.

Land Management

Dryland salinity is fundamentally a water balance issue where recharge to a groundwater system exceeds the natural capacity for discharge. The management challenge must therefore include the following actions:

- reducing the recharge (usually with the aid of deep-rooted perennial vegetation); and/or

- utilising the discharge (usually with salt-tolerant plants or in other industries that can use saline water); and/or

- disposing of surplus water (usually by drainage).

Management options

The draft *SA Dryland Salinity Strategy* has identified various management options to carry out the above actions.

Reducing the recharge

The fundamental step in managing salinity should be to address the cause of the problem by reducing recharge. Local groundwater systems might be addressed at the individual farm scale or at least at the catchment scale. Regional systems, however, will be far more difficult to manage, because landholders with the recharge problem will rarely experience the discharge symptom and also because the time lag between intervention and meaningful response might span generations.

Native vegetation minimised recharge prior to clearance for white settlement, so the retention and enhancement of ***remnant vegetation*** should be the highest priority. Remnant vegetation, to function effectively, must be actively managed as it will deteriorate unless protected from grazing, weeds and rabbits. The conservation of remnant vegetation brings added benefits such as biodiversity enhancement and carbon sequestration. However the individual land managers share only a small fraction of these benefits, so that public investment in these assets is essential.

The very presence of dryland salinity reflects the fact that little remnant vegetation is to be found on agricultural land in SA. ***Revegetation*** using local native plants is a useful alternative for which the necessary establishment and management skills are well developed in South Australia. Once again, public investment will be necessary where private benefits are very limited.

The amount of revegetation required to arrest recharge will vary from catchment to catchment depending on the hydrogeology, soils and climate. In some instances, the loss of production from the revegetated land will exceed any gains from discharge reduction, and therefore would be impossible to justify economically. Even where this is not the case, it will be essential to target non-commercial revegetation for maximum impact and to optimise other potential benefits such as shade and shelter.

Commercial farm forestry offers an opportunity to intercept recharge in a cost effective manner. Although this has been successful in WA and Victoria with blue gum plantations, the options for low to medium rainfall regions (< 500mm/annum) are limited and in some cases still at the development stage. For this reason, and given the long time interval between establishment and harvest, it is important that government invest in the development of these alternatives.

TOPCROP programs are developing the opportunities to improve the water use efficiency of ***annual crops*** and deliver productivity gains to farmers, however the most optimistic improvements to annual cropping systems will be unlikely to reduce recharge by more than about five percent. It is probable that significant impacts on recharge will result only from development of new cropping systems that include a considerable component of deep-rooted perennial species. Fodder crops, phase farming and alley farming have already attracted some interest, but the results so far indicate that there is still much to do before these become commercially attractive options. Public investment in developing these new systems will be essential.

Perennial pastures provide some recharge control that can be further enhanced under sound management. The Sustainable Grazing Systems program has developed management guidelines (e.g., rotational grazing, liming acid soils) to optimise pasture growth and persistence, which should in turn minimise recharge. Native grasses should provide better recharge control than annual exotics in unimproved pastures. Lucerne is an excellent option for recharge control, with healthy stands performing as effectively as native vegetation. Whilst the commercial value of lucerne is an incentive for farmers, the opportunities for its use are limited by soil properties and climate.

In some catchments, discharge sites will also act as recharge sites. Saltbush has been shown to reduce recharge in some of these situations, lower the watertable locally and provide a more hospitable site for other salt tolerant species.

Significant recharge can occur in ***urban environments***, particularly if water is imported as occurs in many SA towns. Leaky septic tanks or sewerage settlement ponds and inefficient garden watering systems can contribute to the development of groundwater mounds and associated dryland salinity.

Managing discharge sites

Discharge sites are the visible aspect of dryland salinity. They are recognisable by salt or saline water lying on the surface, the presence of indicator plants, and the damage inflicted on native vegetation, crops and structures (e.g., fences, buildings, roads, etc). Salinity can also be responsible for the development of soil sodicity with the associated increased risk of erosion, and for significant off-site effects on surface water quality and native vegetation.

Simply ***protecting saline ground*** from livestock and traffic often allows native salt tolerant plants to colonise and protect the ground, reduce evaporation, lower the watertable locally and improve the visual appearance.

Recognition that recharge reduction comes at a cost, which may be impossible to justify in some cases, has stimulated further investigation of the productive use of saline land. Many plants are naturally adapted to saline conditions and some have commercial value, enabling landholders to turn adversity into opportunity.

Saltland varies from region to region depending on salinity levels, waterlogging, soil properties and climate. Not only might these variations affect the establishment of ***salt tolerant plants***, they might also limit their persistence. These variations must be mapped regionally and the implications understood for the appropriate treatments to be implemented.

Treatment of saline sites with non-local salt tolerant plants has the potential to expose native vegetation to weed threats. This risk should generally be assessed at the local level and appropriate monitoring and safeguard procedures established. Sites of particular environmental significance should be identified at the regional level and risk management procedures developed with local communities.

Managing surplus water

Engineering options will sometimes be required to complement recharge reduction and plant based management of discharge. These are generally costly and may require ongoing maintenance, however they can be justified for protection or restoration of high value assets such as town infrastructure, areas of environmental significance and highly productive agricultural land. It is essential that all engineering solutions are implemented as part of catchment plans and take into account inevitable off-site impacts. Clear general guidelines are needed to assist catchment groups in this regard.

Surface water drains, whilst often dealing with fresh water, can be a very effective means of reducing inundation of low lying areas which might otherwise cause plant death due to waterlogging. Drainage may therefore assist in both reducing recharge and enhancing safe discharge. There is evidence to suggest that surface drainage on saline sites, normally subject to seasonal inundation, may deny the normal flushing process that prevents salt accumulation in the root zone.

If the surface water is saline, as will generally be the case on discharge sites, much greater care must be taken with drainage. Soils might be sodic and therefore highly erodible and in some instances acid sulfate soils might be disturbed with serious off-site consequences.

Groundwater drains may be deep open drains or subterranean drains with the specific aim of lowering the local watertable. The effectiveness of these systems is very dependent on the soil properties, an inverse relationship often existing between soil permeability and stability. Furthermore, every drop of saline groundwater drained will be delivered further down the catchment with consequences that must be anticipated and managed. Given these constraints, it is essential that groundwater drainage only proceed after careful evaluation of site responsiveness and as part of a whole catchment plan.

Groundwater pumping is usually so costly that it is applicable only where it offers protection to high value assets. The cost of pumping can sometimes be offset if the water is harvested (e.g., for aquaculture or for salt extraction).

Management plans

In the light of the discouraging economic and social analyses of regional scale revegetation as a tool to **control** dryland salinity, the focus throughout SA on **management** of the problem is shifting toward improving the productivity of salt affected land and learning to 'live with salt'. However, it is still recognised that on a property scale where local flow systems are operating, targeted remedial works may be cost effective.

Table 12. Status of management plans and implementation

Catchment	Plan	Implementation	Strategy
MURRAY BASIN			
Coorong and Districts	Local Action Plan	4th year of on-ground works	Recharge reduction
Upper South East	Dryland Salinity & Flood Management Plan	On-ground works in progress	Drainage, salt land agronomy, revegetation
Mallee	Local Action Plan	1st year of on-ground works	Recharge reduction
Goolwa to Wellington	Local Action Plan and Salinity Management Plan.	On-ground works commenced	Salt land agronomy, revegetation
EYRE PENINSULA			
Cummins – Wanilla	Catchment Plan in preparation	Major on-ground works continuing	Drainage, salt land agronomy, revegetation
Todd River	Salinity Management Plan	2nd year of major on-ground works	Salt land agronomy, revegetation
Driver River	Salinity Management Plan in preparation	On-ground works in planning stage	
Brooker	Salinity Management Plan	Demonstration sites	
Salt Creek	Salinity Management Plan in preparation	Demonstration sites	
KANGAROO IS			
Cygnet River	Catchment Plan. Salinity management plan in preparation	Demonstration sites	
Timber & Bugga Bugga Creeks	Catchment Plan and Salinity Management Plan.	2nd year of on-ground works	Salt land agronomy, revegetation
MT LOFTY RANGES			
Eastern Hills	Local Action Plan and Salinity Management Plan.	On-ground works in planning	

Each region or catchment should determine its management plan in line with hydrogeological data and cost:benefit analysis of the appropriate options. The implementation of these management plans will be largely the responsibility of local communities, and it is essential that these communities are ready to accept this responsibility This will require strong leadership from within and appropriate technical and financial support from without. Progress toward implementing management options is presented for each agricultural region in Table 12.

In this summary, a catchment plan includes water erosion control, biodiversity, acid soils and other natural resource issues with only generalisations about salinity management. However salinity management plans carried out by the PIRSA "Catchments back in balance" project are detailed and specific to salinity on a property scale, and include the development of a groundwater conceptual model for each catchment and running scenarios looking at the level of revegetation required to slow down or stop the spread of dryland salinity.

On-ground works programs include establishing perennials (pastures, trees, grasses, shrubs, fencing remnant vegetation) and improving agricultural production (liming acid soils, clay spreading, surface drainage, applying gypsum etc). Typically, these programs are supported by of the order of $100k per year per catchment. An exception is the $24M Upper South East Dryland Salinity and Flood Management Plan which is in the process of being implemented and incorporates a network of groundwater and surface water drains, the use of salt land agronomy, revegetation with perennial pastures and trees and coordinated management of wetlands.

The Coorong and Districts Local Action Plan and associated on ground works has become a national model whereby a local community has led implementation of significant on-ground works to increase rainfall utilisation and reduce salinity threats. Similar projects are emerging in other parts of the State.

Policy Initiatives

The South Australian Government formed the *State Salinity Committee* in January 2000 to bring a whole-of-government approach to the management of the growing salinity problem in SA. To this end, the Committee has overseen:

- the drafting of the *State Salinity Statement,* an overarching document which outlines the problems of salinity and defines the key principles for salinity management into the future. This document is supported by;
- the draft *South Australian River Murray Salinity Strategy* which defines salinity goals and management principles which will lead to a package of actions to reverse the trend of rising salinity in the River Murray, and
- the draft *State Dryland Salinity Strategy* which identifies various management options, key issues and priority actions.

In addition to outlining various management options to meet the challenge of dryland salinity as discussed earlier, the draft *State Dryland Salinity Strategy* also identified key points for implementation and made recommendations for actions.

Recommendations

After due consideration of the consultative inputs into the *State Dryland Salinity Strategy* and the technical findings of this Audit project, the following recommendations emerge:

- Investment must be made in providing adequate technical support to catchment groups to enable the formulation of specific and appropriate salinity management plans.
- Appropriate cost sharing arrangements and sources of investment must be identified for the implementation of on ground works in priority areas.

- Research and development is required into new farming and forestry systems which will reduce recharge, particularly in low rainfall areas such as the Mallee for salinity reduction in the River Murray.
- Agencies involved with monitoring the impacts and processes of dryland salinity must commit resources to maintaining and upgrading monitoring networks. The data collected must be made readily available to all stakeholders.
- The findings from this Audit should be revisited in five years and new projections of impacts and costs made if necessary.

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Listing of Appendices

Appendix 1 Methodologies

Appendix 2 Regional maps of dryland salinity extent in SA

Appendix 3 Monitoring Stations

Land capability mapping

Initial mapping of salinity from aerial photographs and ground truthing delineates current moderate to severe salt affected land only, as mildly affected land does not tend to show up on an aerial photograph. GIS mapping of the different catchments uses two ranking systems.

For land affected by patchy salt and salt patches:

- Not Affected;
- <2% affected;
- 2 – 10% affected;
- 10 - 50% affected; and
- >50 % affected.

For land affected uniformly by salinity:

- Low;
- Moderately Low (Raised subsoil salinity);
- Moderate (Raised surface soil salinity);
- Moderately High (Halophytes common);
- High (Halophytes only);
- Very High (highly tolerant plants); and
- Extreme (bare salt pan).

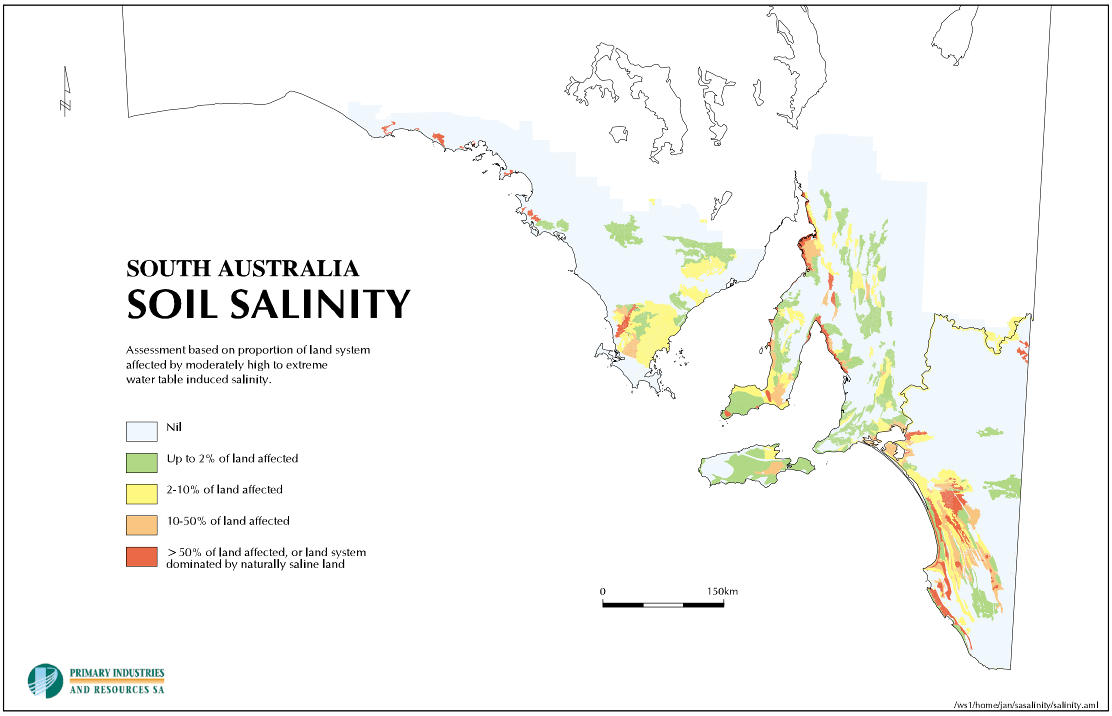


Figure 5. Land capability mapping of soil salinity in SA

This mapping is based on land systems and does not always map actual areas affected by dryland salinity. Because the purpose of the map is land capability, the cause of the soil salinity was not considered and consequently, tidal areas under marine influence and primary (pre-European salinity) were included as well as salinised areas caused by rising watertables.

Mapping of current extent

Mapping of the actual areal extent of dryland salinity in SA occurred at a local, catchment and regional scale using 1:40 000 aerial photographs. This involved mapping of individual property-scale seeps, scald areas and other indicators of salinity-affected land. This mapping was then transferred to 1:50 000 topographic or base maps and digitised for the creation of a GIS dataset.

Due to the comprehensive coverage of aerial photography, there is a moderate to high level of confidence in the estimates for extent of dryland salinity. Limitations are mainly related to the lack of detailed ground truthing, which requires significant resources and time. The complexity of dryland salinity also results in some reduction in confidence in the estimates of extent. Some of these complexities include:

- Overlap between primary (pre-clearing, natural) salinity and secondary (post clearing, human induced) salinity;
- Reflective linear features, in appropriate topographic locations, may be indicative of baseflow;
- Saline/sodic subsoils can be exposed but are not necessarily related to raised groundwater levels which defines dryland salinity; and
- Seasonal changes can result in rapid changes to the extent of dryland salinity.

Stream salinity

A three part process has been used to identify which water resources are at risk.

Review of Relevant Literature

A detailed overview of the water resources of South Australia was obtained from the most recent State Water Plan together with more detailed information on the operation of reservoirs in the Mount Lofty Ranges and pumping from the River Murray. Previous studies into identifying water resources at risk from dryland salinisation were also reviewed.

Interviews with Key Personnel

A series of interviews with key personnel in appropriate water supply and catchment management authorities were carried out in the various regions of the State thought to be under threat.

Historical Stream Salinity Trends

A list of water resources under threat from dryland salinisation was compiled on the basis of the literature review and interviews. Historical stream salinity (as EC) and flow data for key gauging stations in these areas (where available) was then extracted for statistical trend analysis.

Trends in stream salinity were determined using the semi-parametric methods. These provide both linear and non-linear trends in EC which are independent of flow and season (ie. the underlying EC trend due to changes in baseflow contribution). The statistical significance of the linear component of the trends is determined from the 95% confidence interval. It is not possible to derive the 95% confidence interval for the non-linear component, although the trend itself is useful in determining the locations in time when it changed (due to changes in the management of the catchment or the stream itself, or changes in climate).

The statistical methods use the Generalised Additive Model (GAM) approach. Additive regression terms are fitted to monthly averaged *logEC* (log µS cm^{-1}), the explanatory variables being *time*, *logflow* (log ML day^{-1}) and sinusoidal seasonal terms. This non-linear GAM model represents the response of *logEC* to *time* and *logflow* by arbitrary smooth curves using cubic splines with knots at each data point. The mathematical form of the regression is:

$$logEC = \alpha + S(time; df_t) + S(logflow; df_f) + \beta \sin(2\pi\, month/12) + \gamma \cos(2\pi\, month/12) + \varepsilon \quad (1)$$

where *logEC* is the natural logarithm of EC, *logflow* is the natural logarithm of flow, *time* is in years, *month* has values of 1 to 12, $S(t; df_t)$ is a smoothing spline of *logEC* versus *time* with df_t degrees of freedom, $S(logflow; df_f)$ is a smoothing spline of *logEC* versus *logflow* with df_f degrees of freedom; α, β, γ are linear regression coefficients and ε is the residual error. The terms df_t and df_f are smoothing parameters that determine the shape of the splines fitted to the data. It was assumed that values of 4 for df_t and 2 for df_f are adequate for data sets of the length used in this project. The term $S(x; m)$ is the sum of the linear (which is of the form a+b*x) and the non-linear (which has mean zero and no linear trend) components of the trend. By separating the linear and non-linear components of the spline function, Equation (1) is rewritten as:

$$logEC = \alpha + \eta time + C_{time} + \chi logflow + C_{logflow} + \beta \sin(2\pi\, month/12) + \gamma \cos(2\pi\, month/12) + \varepsilon \quad (2)$$

where η and χ are linear coefficients of *time* and *logflow* respectively, and C_{time} and $C_{logflow}$ are the non-linear components of $S(time;df_t)$ and $S(logflow;df_f)$ respectively. The linear coefficient of *time*, η, is used to calculate the percentage change in EC per annum using the formula:

$$\{100 * (e^{\eta} - 1)\} \quad (3)$$

The model fits are carried out using Ordinary Least Squares (referred to as the OLS approach) regression. If autocorrelation of the residuals of the OLS fits are found to be high (>0.2), then fits are carried out with first order autoregressive parameters (referred to as the TSM approach).

The significance of the trends at the 5% probability level was estimated as ±2 standard errors. Standard errors for stations with sufficient data to use the TSM approach are taken directly from the statistical output. However, if the number of missing months is too large (>20%), then the TSM approach fails and it is necessary to use the OLS approach with a multiplier applied to the standard errors. This multiplier is derived from likelihood theory and is adjusted both for the magnitude of the autocorrelation and for the amount of missing data :

$$\{1 + 2\,pAR\ /(1 - AR1)\}^{1/2} \quad (4)$$

where p is the proportion of available data and *AR1* is the first order autocorrelation coefficient. It should be noted that this multiplier is an approximation based on the assumptions that the missing values have occurred independently and at random.

Economic Analysis of Costs

This section describes how data sets were manipulated to determine the costs of dryland salinity in SA. The methods are described for determining losses in agricultural production, increased maintenance costs for roads and increased maintenance costs for buildings.

Losses in Agricultural Production

Losses in agricultural production were estimated by calculating the area of land affected by dryland salinity in hectares and multiplying this by the weighted mean gross margin. A lower, middle and upper estimate for areas affected were obtained based on the salinity risk map and were calculated in *Arcview*. For the interim estimate using the land capability mapping, the area calculation involved (i) calculating the area of the entire salinity hazard region and (ii) adjusting these estimates by the lower, middle or upper percentage of land likely to be affected. This gave three possible values for *area affected* in each salinity hazard region.

The weighted mean gross margin for all types of agricultural production across South Australia was obtained using the gross margin data and crop/pasture areas taken from the Integated Regional Database (IRDB) from ABS. This was achieved in the following stages:

- Obtaining a mean, minimum and maximum gross margin for each land-use type over the three rainfall regions.
- Determining the area assigned to production of each land-use type in the IRDB. These areas were then normalised to provide a percentage of the total area.
- Estimating a mean gross margin over all land-use types in each region, weighted by the percentage area used for their production. This had the affect of giving land-use types that were more widely produced a greater impact on the final regional gross margin. Mean, minimum and maximum regional gross margins were estimated. Pasture areas were used to develop the livestock gross margin estimates.

This process enabled derivation of a *dollars per hectare* figure which, given a salt affected area in hectares, can be used to determine the losses in production resulting from dryland salinity. From this process the lower, middle and upper weighted mean gross margins were calculated to be $37.12 per ha, $80.85 per ha, and $110.45 per ha.

Increased Costs of Maintaining Roads

By overlaying the road maps with the salinity risk regions, it was possible to determine the length of each road category (in kilometres) in each region. This was done using the *Intersect* command in *Arcview*. For the interim estimate, the length of roads in each hazard region was adjusted by the percentage area of salt affected land.
Maintenance costs of the roads indicating dollars per kilometre per year are indicated in a previous study as: (i) $2500 per km per year for main sealed roads, (ii) $1500 per km per year for minor sealed roads, and (iii) $800 per km per year for unsealed roads. These costs are the additional costs due to dryland salinity. As only data for sealed and unsealed roads were used in this study, it was assumed that all sealed roads incurred additional maintenance costs of $2000 per km per year.

Increased Costs of Maintaining Buildings

The number of buildings affected was approximated by the number of dwellings per statistical local area (SLA) as indicated in the IRDB. To determine whether a dwelling was affected, the SLA map (with number of dwellings per SLA attached as an attribute) was overlain with the salinity risk map to produce a set of sub regions. Given that this process changes the size of the original SLAs, it is necessary to make adjustments to the number of dwellings per SLA. This was done by using area proportion adjustments. For example, if an SLA was broken up into two sub-regions of equal area, then 50% of the dwellings were assigned to each sub region. If buildings tend to be located in elevated areas not prone to dryland salinity, then the result is an over estimate.
The result of the overlay procedure provided data on the number of dwellings impacted by each salinity category. The costs of dryland salinity to buildings applied in this study can then be determined by:

- Houses subject to minor or moderate impacts of high watertables require around $250 in annual maintenance.

- Houses subject to severe impacts of high water tables require one-off remedial works which average at $15 000 and are effective for 10 years. Assuming a 7% discount, this is equivalent to an average annual annuity of $2135 per household per annum.

For the interim estimate, the number of dwellings was reduced by the proportional area of salt affected land in each sub-region from the land capability mapping to provide a lower, middle and upper estimate of the number of buildings affected. These buildings were assigned '*no impact*', '*moderate impact*' or '*severe impact*' corresponding to the appropriate salinity classes. This approach led to a higher number of dwellings being classified as severely affected as opposed to moderately affected. This would be expected because where areas of salt hazards are most severe, they tend to also cover a larger area (thereby impacting on more buildings) within the soil landscape unit. Better data on the distribution of houses per impact zone is needed.

Economic Case Study

In carrying out an economic analysis and cost sharing assessment of six dryland salinity management options for the Lower Eyre Peninsula (LEP) in SA, several key components were necessary to build an economic model.

Relationship between recharge reduction and salt affected area

The relationship between recharge reduction and salt affected area is based on the following statements in the report by Stauffacher *et al.* (2000): "*under a 50% reduction in recharge, the area* [in the Wanilla Catchment] *increases by the year 2020 to 11.7%*" and "*a 90% reduction is required to allow the possibility of recovering some already saline areas*". Given that 8% of the catchment is currently affected, it is possible to develop a function which allows 'area affected in 2020' to be determined from 'recharge reduction'.
This function is shown in figure 5. It is a disjointed linear function separated at a 50% recharge reduction, which corresponds to an 11.7% area affected in 2020. If necessary, it may be acceptable to assume that the percentage recharge reduction equals the additional percentage area revegetated in recharge zones. However this assumption was not needed in this study. The recharge reduction was already given by Stauffacher *et al.* (2000).

Given that the current area of dryland salinity in the Wanilla Catchment is 8% (and is assumed to be the same in the LEP), it is possible to determine the area of salt affected areas in each year up to and including 2020. This is done by assuming the increase in salt area over the 20 year period is linear. Land-Use in each year will be constrained by the size of the salt affected area.

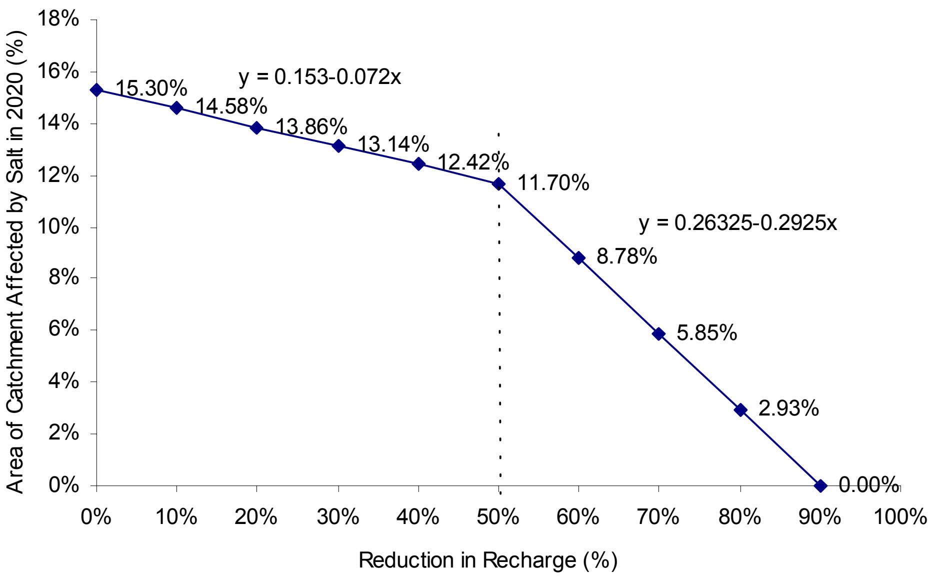


Figure 6. Assumed functional relationship between recharge reduction and the area of the Wanilla Catchment affected by salt in 2020

Gross Margins for Pastures and Crops

The gross margin used for pastures was based on livestock gross margins issued by PIRSA. Sheep are by far the most numerous livestock on the LEP. The gross margin booklets for the 400mm plus rainfall zone in SA indicate that (i) a stocking rate of seven sheep per hectare is attainable; (ii) with a gross price of $24 per sheep; and (iii) variable costs of production at $14 per sheep. This produces a gross margin of $70 per hectare which is considered to be the value of pastoral land uses.

The gross margin for crops was based on the 1999/2000 "Crop Harvest Report" issued by PIRSA. An average was taken of the values for wheat and barley, which provided a yield of 3.05 t/ha, gross returns of $164/t and variable costs of $178/ha. Using these values, the gross margin obtained for crops is $322/ha.

Gross Margin for Agroforestry

Several forms of agroforestry are potentially suited to the LEP region. These include a Eucalypt woodlot, Radiata pine forest, wide-spaced eucalypt agroforest, wide-spaced pine agroforest and Eucalypt firewood woodlot. Of these, the Eucalypt firewood woodlot provides returns within the shortest time period (around 10 years after planting), and hence were used to represent agroforesty in this study.

Values for timber yields and prices were derived from benefit cost analyses conducted for natural resource management projects in the Tod River Catchment which were based on an end product sold as firewood on-stump. They identify yield at maturity as 110 t/ha and revenue at $20/t. The establishment costs for a Eucalypt firewood woodlot are $880/ha, with a minimum period before return of 10 years.

Given these values, it was possible to obtain a gross margin for agroforestry by calculating an annual annuity over a 20 year growing and harvesting period. Additional maintenance costs over this period mostly related to landholder labour. As this is not usually costed in other gross margins, these costs were also set to zero in this study. Over the 20 year period, the establishment costs are only incurred once and harvesting is possible twice (at year 10 and year 20). This approach provides a gross margin for agroforestry of $68.87/ha/yr using the 8% discount rate adopted throughout the study.

Determining Yield Decline Near Salt Affected Areas

Much of the biophysical modelling work on dryland salinity produces results which suggest that land is 'all or nothing' affected by dryland salinity. In reality, there is likely to be a gradual shift in the severity of dryland salinity from an area where there is no yield loss, to an area where there is a high or complete yield loss. For the economic model used in this study, a decline in yield loss was assumed to occur in areas surrounding a salt patch. It was also assumed that an additional 10% of land surrounding the salt affected area would have a relative yield of 50% as shown in figure 6. The relative yield is used to adjust the crop yields or sheep stocking rates in the gross margins described above.

In the case of agroforestry, this meant that the gross margin would be negative. Assuming that an enterprise is abandoned when the gross margin falls below zero (this need not necessarily always be the case), a gross margin of zero was assigned to agroforestry occurring in partial yield areas surrounding salt patches. Pasture and crop gross margins do not fall below zero but are significantly reduced.

Costing the Impacts of Saline Water

The cost impacts of salt in domestic water supplies were only considered in the LEP basin. The Wanilla Catchment has overland waterflow which does not have a significant impact on drinking water supplies because most of the runoff enters the ocean. Several functions for costing the impacts of saline water supplies to urban households have been developed in a study aimed at costing the impacts of dryland salinity in the Murray Darling Basin. It was assumed that the increase in TDS over the 20 year period would be proportional to the increase in the salt affected area. For example, if the salt affected area grew by 5%, it was assumed that a TDS of 1000 mg/l in the year 2000 would be 1050 mg/l in the year 2020. Given this assumption, management scenarios which led to an increased salt area also led to increased costs from saline water supply.

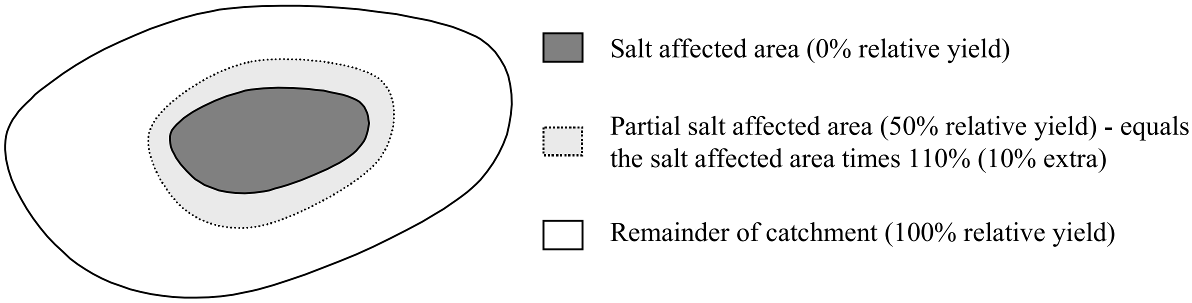


Figure 7. Method for modelling yield decline in areas surrounding a salt affected area

The number of households in the LEP basin was determined from ABS statistics for the Port Lincoln, Tumby Bay and the Lower Eyre Peninsula statistical regions. For each of these regions, the ABS holds values for the number of dwellings that are fully owned, rented or being purchased (1996 data was used). By summing the number of dwellings in each of these categories and then summing for the three statistical local areas, the number of households in the LEP basin was determined to be 6553. This enabled a total dollars per year figure to be estimated for each year over the twenty year period.

Road Maintenance Costs

The same methodologies as described in the previous section on economic analysis were utilised in this case study.

Segregating Landholder and Social Impacts

In order to facilitate cost sharing assessments, it is necessary to determine whether the costs and benefits accrue to landholders or society in accordance with the derived cost sharing framework. In the case of the Wanilla Catchment, the task was straight-forward because all tangible costs and benefits included in the BCA were assumed to accrue solely to landholders. This is because the only costs were land areas being lost from production, and the only benefits were land being prevented from becoming salinised so that it could be used for agricultural production. No infrastructure impacts were identified in the Wanilla Catchment.

In the LEP basin, infrastructure impacts on roads and saline water impacts were included in the BCA. These impacts were assumed to represent benefits to society (not landholders), with the result that in the LEP basin, two sets of NPV and BCR values were calculated, one for landholders and the other for society.

Choosing a Discount Rate

Despite many research efforts there is still no definitive answer or foolproof method for identifying an appropriate discount rate to be used in economic analysis. The discount rate has strong implications for sustainable development and if it is high, it can disadvantage future generations. As different people and social groups are likely to have different perspectives on what a discount rate should be, there is no single correct answer.

The discount rate used in this study is 8%. This is the same as that used in recent benefit cost analyses for natural resource management projects in the Tod River Catchment located within the LEP basin. Later in this case study, this discount rate is systematically varied to determine its impact on the final results.

Appendix 2 Regional maps of dryland salinity extent in SA

These maps of the agricultural regions of South Australia shows the actual affected areas by dryland salinity. It is not a risk map. these areas were delineated where possible by the most recently available aerial photography (and given some limitations in this aerial photography, professional judgement as well). An attempt was made to distinguish primary salinity (salinity occurring before European settlement) from secondary or human-induced salinity. Primary salinity has never been used for agricultural purposes and probably never will be. Lagoons and wetlands which have, or may become salinised have been delineated and excluded from areas of secondary salinity because again, they are not used for agricultural production. Areas under tidal influence along the coast were also excluded from the mapping coverage.

In the areas of the Murray Basin underlain by regional flow systems, areas at risk to dryland salinisation in the future were assessed on the basis of where the observed rising groundwater levels would rise within 1 – 2 m of the land surface and are displayed on the maps of the Upper Southeast and the Coastal Plain. These figures exclude areas of primary salinity. The extrapolated areas were derived assuming an approach to an equilibrium of salinised land and not an indefinite expansion.

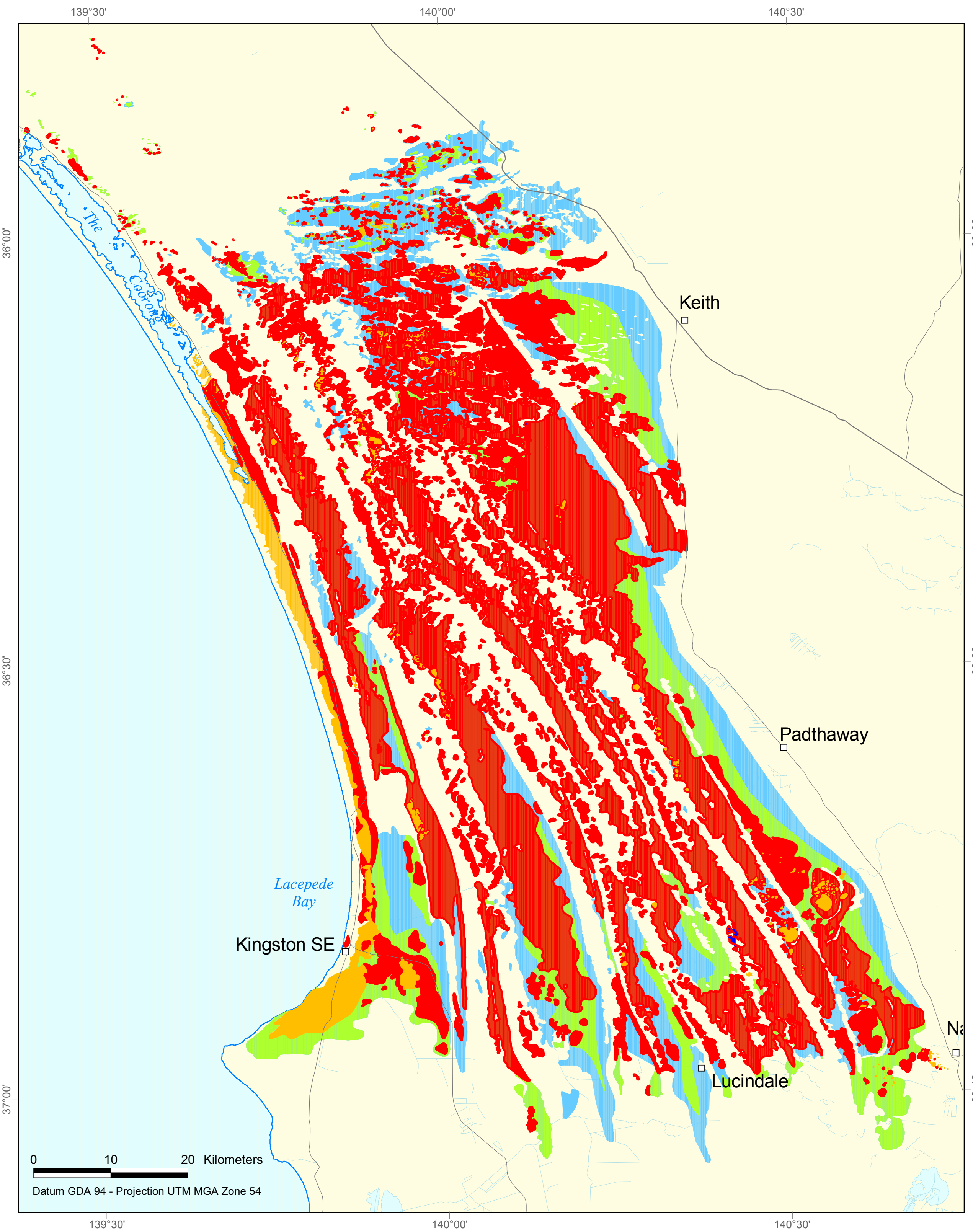
In other areas dominated by local or intermediate flow systems, a combination of anecdotal evidence and professional judgement has been used to determine areas at risk in the future. Because these areas at risk are quite small compared to the scale of the mapping coverage, no attempt was made to map them. Instead, estimates of the percentage increase from the current extent were made to determine the risk areas.

Due to the lack of readily available information, some of the large areas classified as secondary salinity in the Mid North and on Yorke Peninsula, may in fact be primary salinity.

The regional maps are presented in the following order.

Upper Southeast
Coastal Plain
Eyre Peninsula
Kangaroo Island
Mid North
Yorke Peninsula
Mt Lofty Ranges

DRYLAND SALINITY - UPPER SOUTH EAST



PRIMARY SALINITY

Areas thought to be pre-European salinity that have never been used for agricultural production

YEAR

2000: 22 500 ha

SECONDARY SALINITY

Areas that have been salinised by shallow rising watertables

YEAR

2000: 250 500 ha

2020: 324 000 ha

2050: 409 500 ha

LAKE/LAGOON

Natural areas that have, or may become salinised, but have never been used for agricultural production

YEAR

2000: 135 ha

GDA

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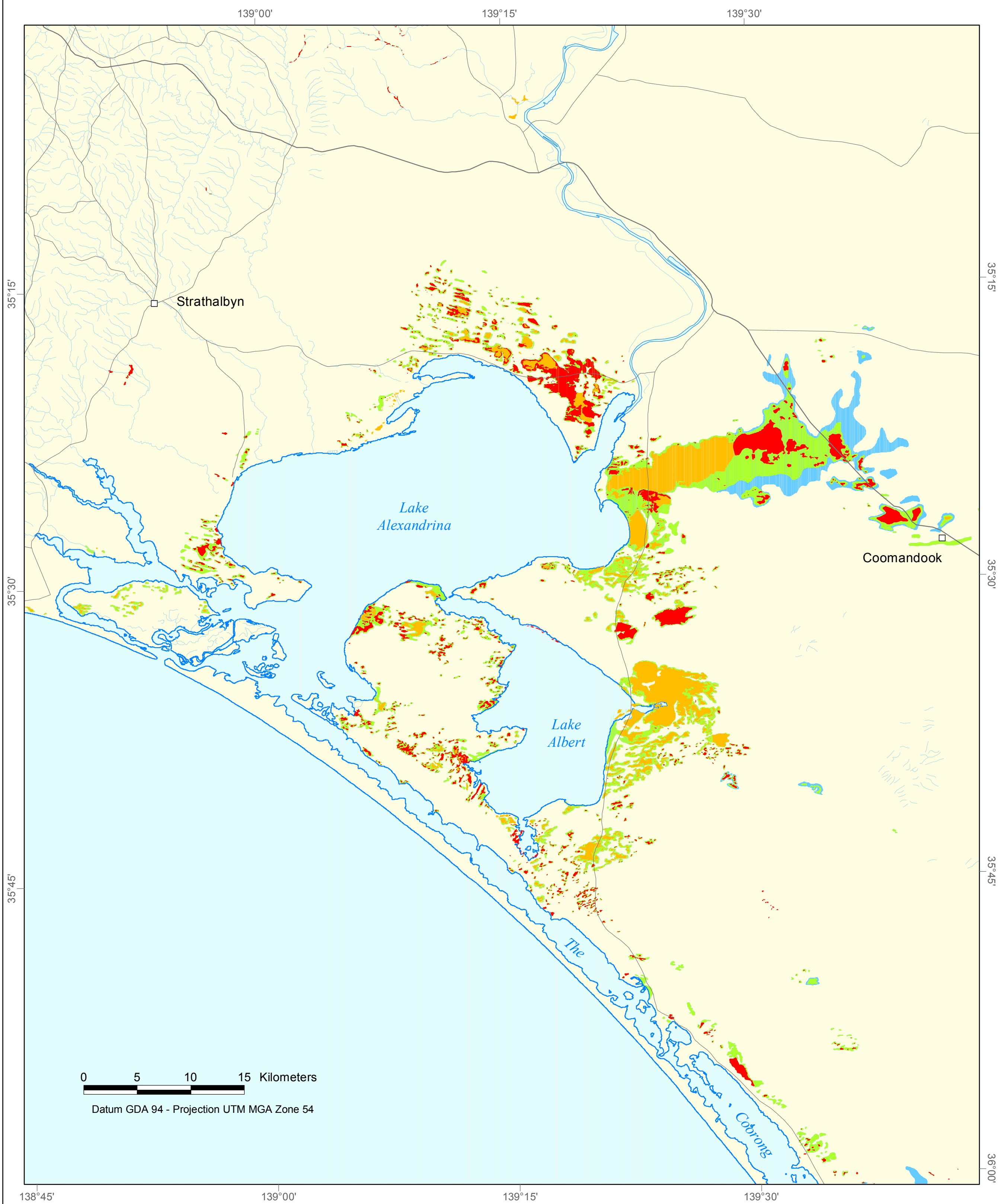
DRYLAND SALINITY - COASTAL PLAIN



PRIMARY SALINITY

Areas thought to be pre-European salinity that have never been used for agricultural production

YEAR
2000: 16 700 ha

SECONDARY SALINITY

Areas that have been salinised by shallow rising watertables

YEAR
2000: 19 800 ha
2020: 29 600 ha
2050: 34 000 ha

GDA

Government of South Australia

Department for Water Resources

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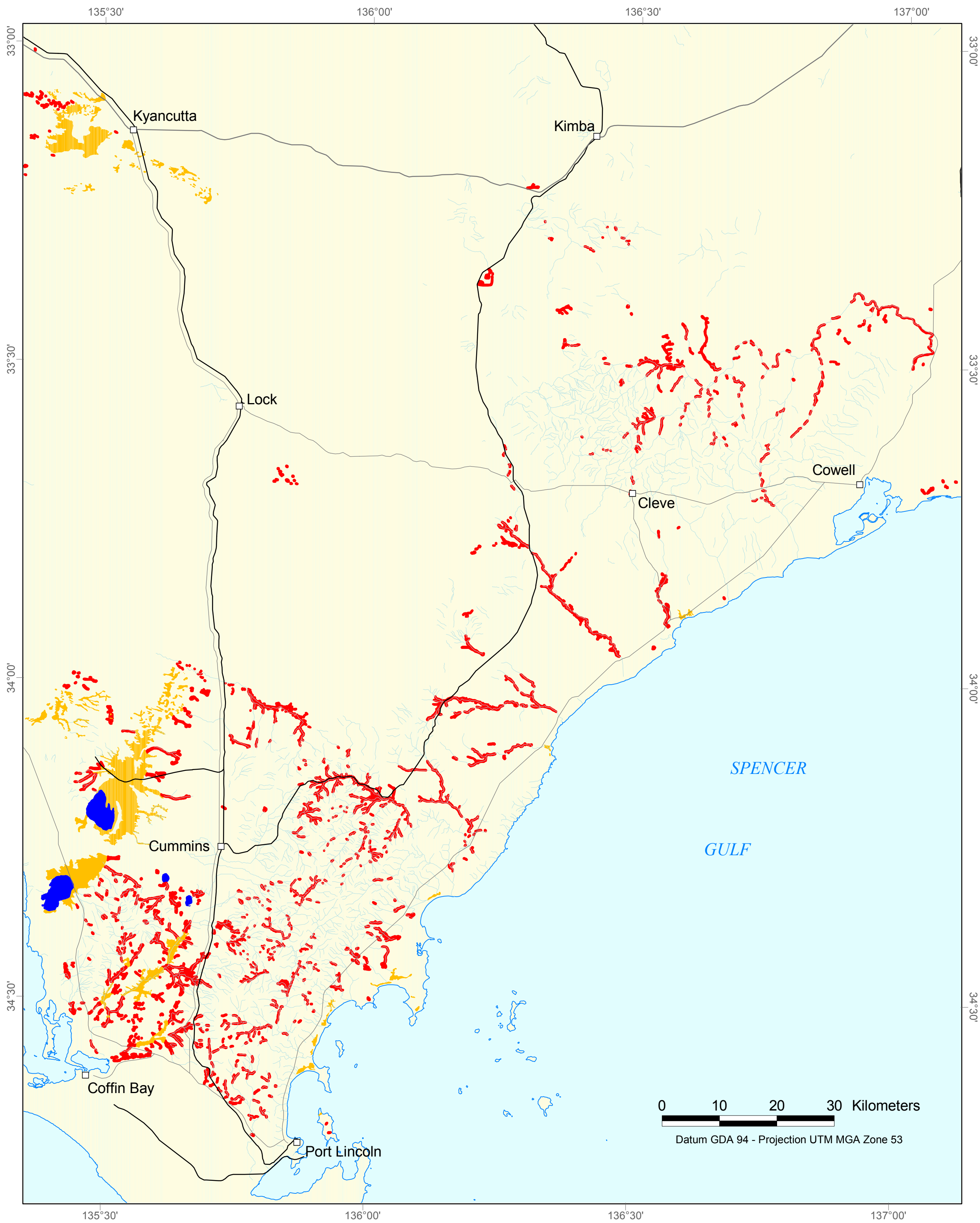
DRYLAND SALINITY - EYRE PENINSULA



PRIMARY SALINITY

Areas thought to be pre-European salinity that have never been used for agricultural production

YEAR

2000: 35 200 ha

SECONDARY SALINITY

Areas that have been salinised by shallow rising watertables

YEAR

2000: 20 400 ha
2020: 24 000 ha
2050: 27 000 ha

LAKE/LAGOON

Natural areas that have, or may become salinised, but have never been used for agricultural production

YEAR

2000: 4700 ha

GDA

Government of South Australia

Department for Water Resources

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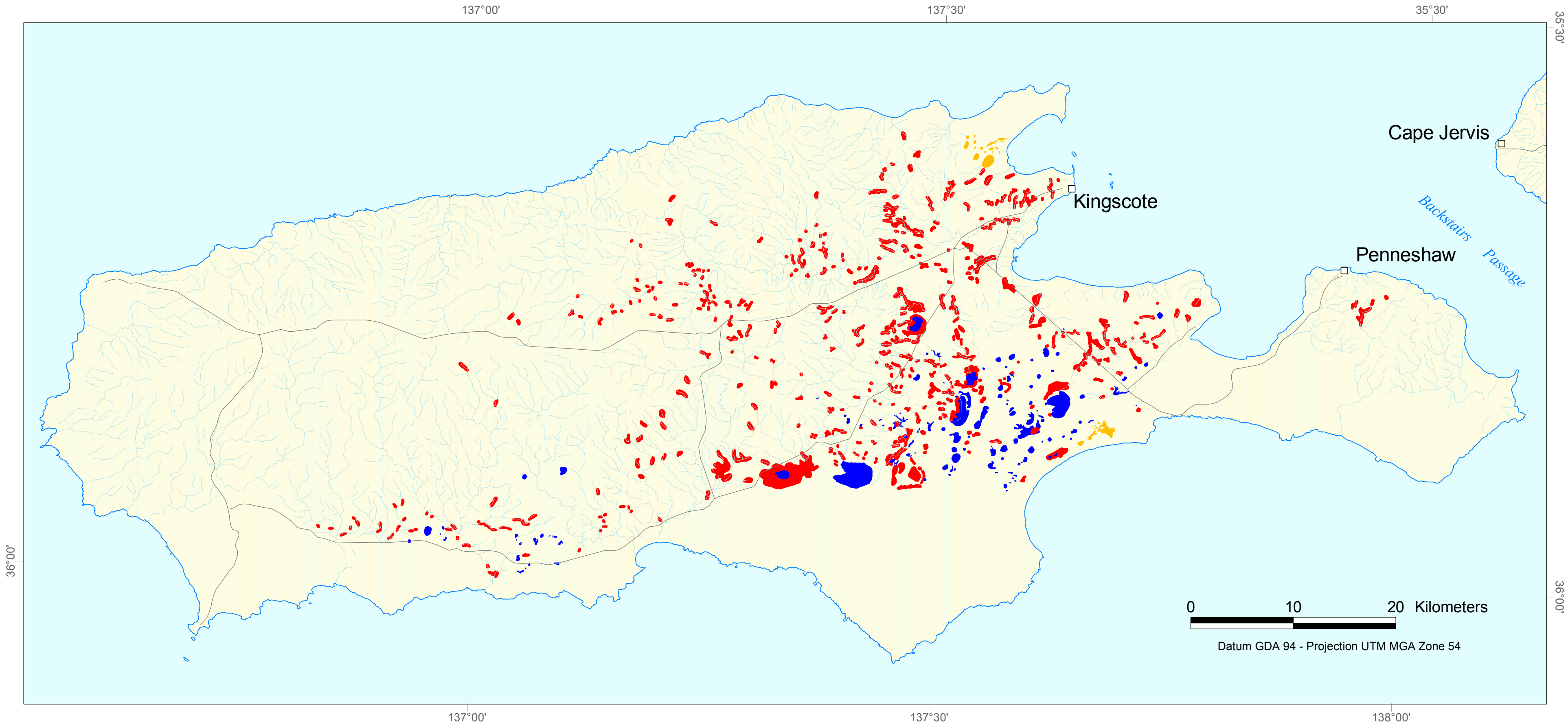
DRYLAND SALINITY - KANGAROO ISLAND



PRIMARY SALINITY
Areas thought to be pre-European salinity that have never been used for agricultural production

YEAR
2000: 500 ha

SECONDARY SALINITY
Areas that have been salinised by shallow rising watertables

YEAR
2000: 5600 ha
2020: 6500 ha
2050: 8000 ha

LAKE/LAGOON
Natural areas that have, or may become salinised, but have never been used for agricultural production

YEAR
2000: 3600 ha

GDA

Government of South Australia

Department for Water Resources

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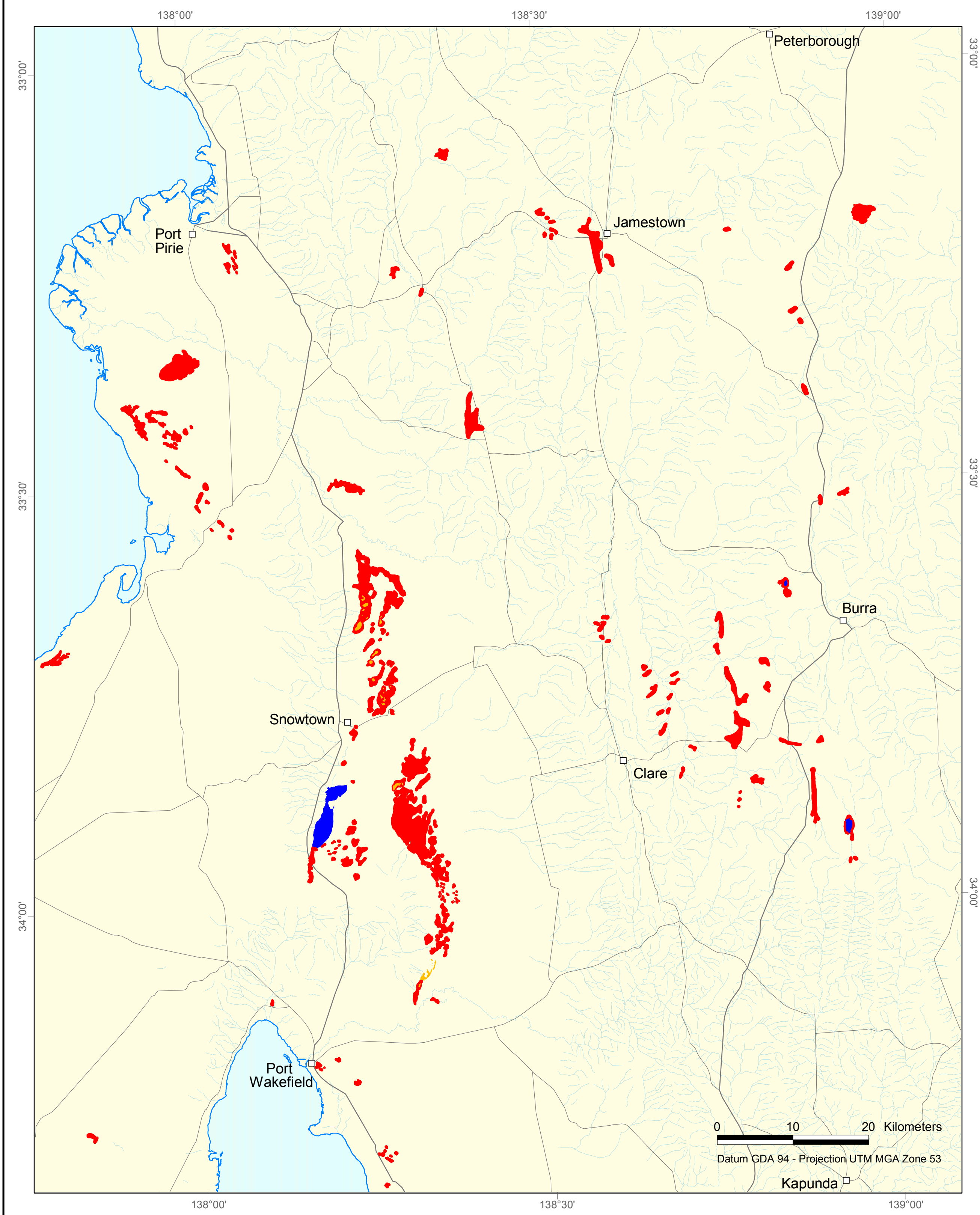
DRYLAND SALINITY - MID NORTH



PRIMARY SALINITY
Areas thought to be pre-European salinity that have never been used for agricultural production

YEAR
2000: 300 ha

SECONDARY SALINITY
Areas that have been salinised by shallow rising watertables

YEAR
2000: 14 800 ha
2020: 18 000 ha
2050: 21 000 ha

LAKE/LAGOON
Natural areas that have, or may become salinised, but have never been used for agricultural production

YEAR
2000: 1600 ha

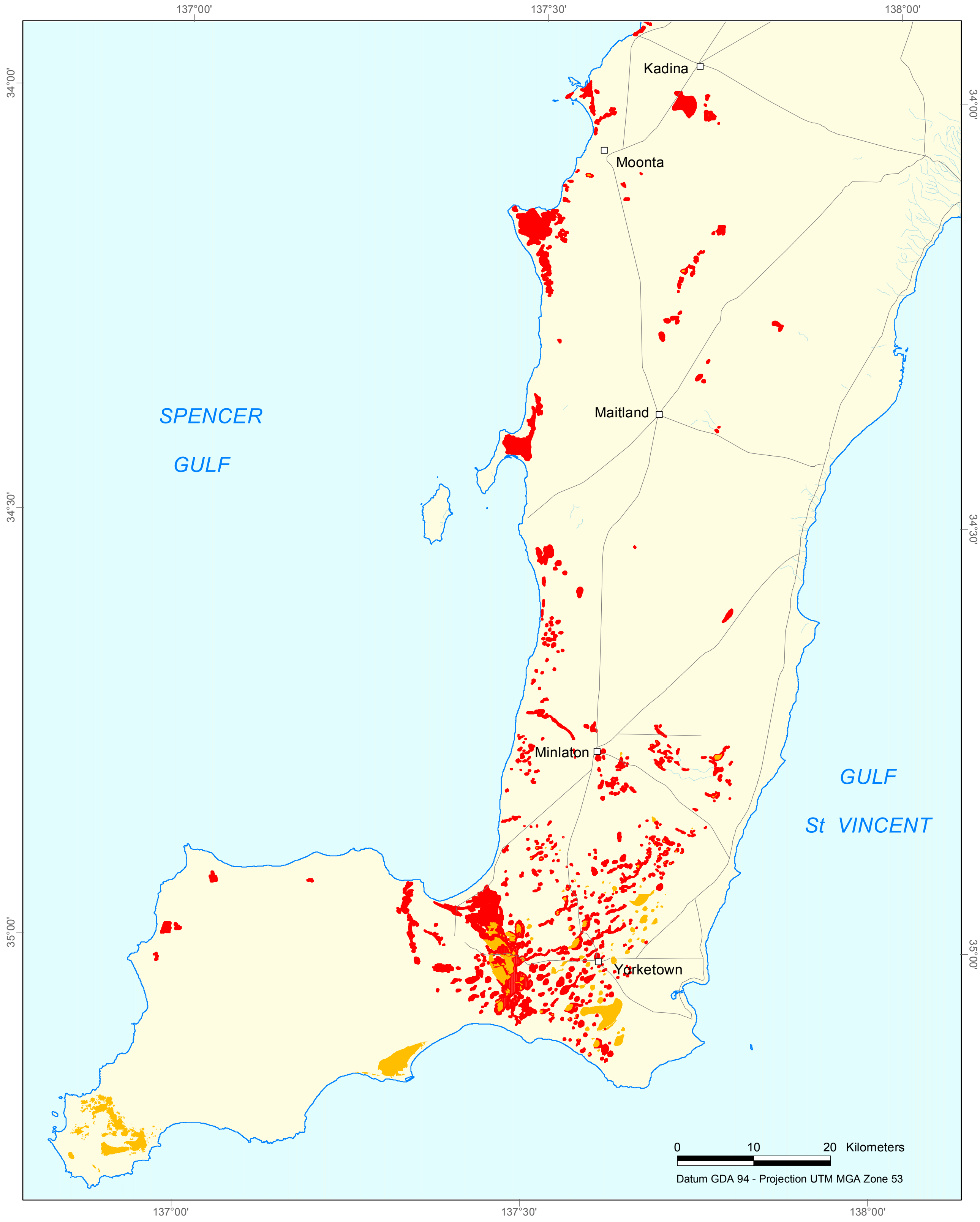
GDA

Government of South Australia

Department for Water Resources

PIRSA Publishing AV 200643_005

DRYLAND SALINITY - YORKE PENINSULA



PRIMARY SALINITY

Areas thought to be pre-European salinity that have never been used for agricultural production

YEAR

2000: 8000 ha

SECONDARY SALINITY

Areas that have been salinised by shallow rising watertables

YEAR

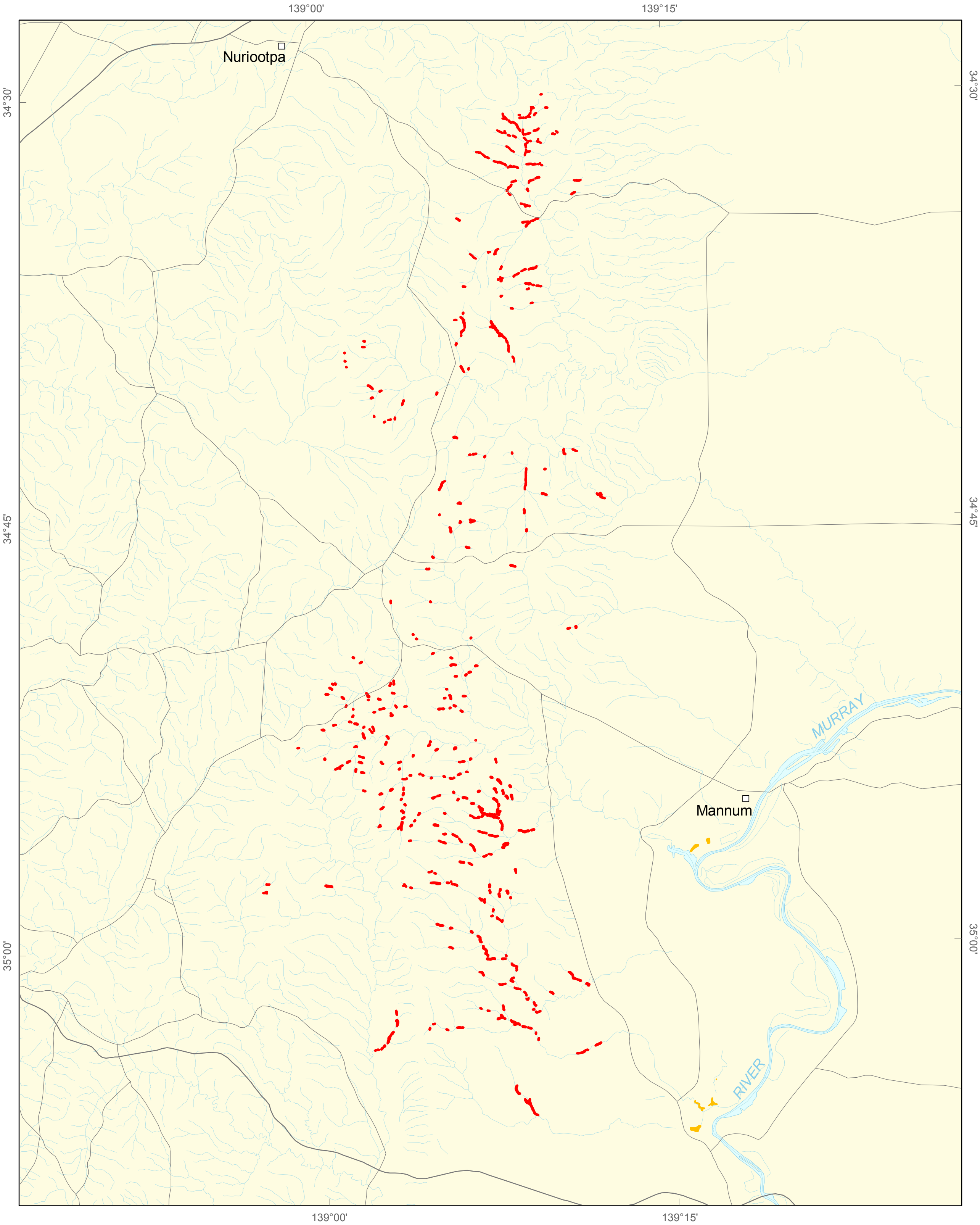
2000: 13 900 ha
2020: 17 500 ha
2050: 20 000 ha

Government of South Australia

Department for Water Resources

PIRSA Publishing AV 200643_007

DRYLAND SALINITY - EASTERN HILLS



PRIMARY SALINITY

Areas thought to be pre-European salinity that have never been used for agricultural production

YEAR

2000: 22 500 ha

SECONDARY SALINITY

Areas that have been salinised by shallow rising watertables

YEAR

2000: 1200 ha
2020: 1400 ha
2050: 1500 ha

0 5 10 Kilometers

Datum GDA 94 - Projection UTM MGA Zone 54

Government of South Australia

Department for Water Resources

PIRSA Publishing AV 200643_002

Appendix 3 Monitoring stations

Groundwater

Table 13. Groundwater observation networks monitoring dryland salinity

Region / Catchment	Number of Wells	Monitored by
MURRAY BASIN		
Coastal Plain	38	DWR (Contractor) 6 mthly (Mar, Sep)
Upper South East	300	DWR (Naracoorte) 6 mthly (Mar, Sep)
Mallee	30	DWR (Naracoorte) 6 mthly (Mar, Sep)
EYRE PENINSULA		
Wanilla	30	DWR (Crystal Brook) 6 mthly (Apr, Oct)
Cummins Basin	17	DWR (Crystal Brook) 6 mthly (Apr, Oct)
Darke Peak	13	DWR (Crystal Brook) 6 mthly (Apr, Oct)
YORKE PENINSULA		
Minlaton	15	DWR (Crystal Brook) 6 mthly (Apr, Oct)
KANGAROO ISLAND		
Narroonda	16	Discontinued
MID NORTH		
Jamestown	17	DWR (Crystal Brook) 6 mthly (May, Nov)
MT LOFTY RANGES		
Harrogate		CSIRO
Keyneton	21	PIRSA 2 mthly

Surface Water

The availability of stream monitoring data (flow and EC) throughout the State is summarised in Table 14.

Table 14. Availability of stream monitoring data in SA

Region / Catchment	Monitoring Data available
KANGAROO ISLAND	
Middle River	No data
MID NORTH	
Baroota, Bundaleer, Beetaloo	No data
Wakefield	1 grab sample station
Broughton	3 grab sample stations
EYRE PENINSULA	
Tod River	<6 years of continuously monitored data, 2 gauging stations only
MT LOFTY RANGES	
Angas Bremer	4 grab sample stations, 2 continuously monitored stations
Finniss	1 grab sample station
Marne	1 grab sample station
Myponga	1 grab sample station
Onkaparinga	5 grab sample stations, 3 continuously monitored stations
Torrens	4 grab sample stations, 1 continuously monitored station
North Para	5 grab sample stations, 6 continuously monitored stations
Wakefield	1 grab sample station
Broughton	3 grab sample stations