# Salinity Audit

## Upland catchments of the New South Wales Murray–Darling Basin

Department of **Environment & Climate Change** NSW

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Saline affected land, DECC

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# Summary

This report defines the current status and future trends in dryland salinity in upland areas of the Murray-Darling Basin in New South Wales. The effective management and remediation of dryland salinity is underpinned by a scientific understanding of the causes, locations and behaviour of salt mobilisation from landscapes. Knowledge of the spatial variability and extent of salt stores and the capacity to quantify water movement in landscapes are crucial to an understanding of the causes of dryland salinity.

This Salinity Audit reviews and updates the outcomes from previous Audits. Data, information and analyses that can be used to define the current status and future trends in dryland salinity were compiled. The results from this Audit take advantage of the advances in scientific understanding of salinity, data and technology improvements during the period since the first Audit was completed. In years since the original 1999 Salinity Audit, there has been a massive increase in the availability of time-series data, spatial data, analytical tools and computing capacity to apply these tools.

In general, previous estimates of the current status of salinity in New South Wales have been confirmed by this Audit. However, earlier Audits over-estimated the severity of future salinity impacts in 2020, 2050 and 2100. This should not be interpreted as indicating that there is no salinity problem. There is substantial evidence that salinity is contributing to poor water quality, decreasing agricultural productivity, dieback of native vegetation, increasing soil erosion and damage to roads, buildings and bridges.

Only some sub-catchments are now seen to have increasing salinity trends. Many sub-catchments appear to be in equilibrium and salinity management actions would be better focused towards reducing the cyclical variations in stream salinity due to climate variation. As a general rule, the variability in stream salinity as determined by rainfall volume, timing and distribution, catchment morphology and the location of salt stores within the landscape is much greater than the influence from longer-term rising or falling trends. Salinity management options would be better based on multiple criteria that reflect the inherently large seasonal, annual and decadal fluctuations in salinity.

The information contained in this report is valuable to support the identification of priority sub-catchments across the New South Wales Murray-Darling Basin. The additional information and analyses that have been compiled as part of this Audit will provide more confidence in catchment prioritisation. Sub-catchments can now be assessed using a wide range of indicators instead of one single indicator.

There are sub-catchments which have now been identified as priorities for improved monitoring and there are areas where saline outbreaks are causing problems, but from a management perspective, the challenge is not so much about managing for the advent of future problems, but about containing or reducing existing problems.

# 1 Introduction

Dryland salinity can occur if salts stored in the landscape are mobilised and redistributed within the catchment by surface runoff, subsurface lateral flows, recharge and groundwater discharge. The effective management and remediation of dryland salinity is underpinned by a scientific understanding of the causes, locations and behaviour of salt mobilisation from landscapes. Knowledge of the spatial variability and extent of salt stores and the capacity to quantify water movement in landscapes are crucial to an understanding of the causes of dryland salinity.

Awareness of dryland salinity within the Murray-Darling Basin has been increasing over the last 30-40 years. In 1989, the Murray-Darling Basin Commission Salinity and Drainage Strategy was initiated following an audit of river salinity for the period 1975 to 1985. The strategy consequently provided a range of measures for controlling rises in salinity in the Murray River in South Australia. The primary focus was on improving irrigation and river regulation practices and the application of engineering solutions, such as the construction of salt interception schemes. Salt contributions from dryland salinity catchments were assumed to have a relatively minor impact on rising river salinities in South Australia.

The Salinity and Drainage Strategy required a 10-year review to be undertaken in 1998. In the intervening period, a number of studies were published on salinity trends from dryland and upland catchments. Allison and Schonfeldt (1989) predicted an increase in stream salinity of approximately 80µS/cm at Morgan sourced from the dryland component of the riverine plain. Williamson *et al*. (1997) and Jolly *et al*. (1997) presented evidence for rising stream salinities in many dryland Murray-Darling Basin catchments. In the New South Wales land degradation survey of 1987–88 (Soil Conservation Service of NSW, 1989), dryland salinity was identified as a significant issue, principally because of its contribution to increased soil erosion in southern New South Wales.

The 1999 Salinity Audit was instigated in November 1997 to determine the magnitude of the threat posed by dryland salinity. As part of this Audit, New South Wales (Beale *et al.,* 2000) and Victoria (Sinclair Knight Merz, 1999) undertook investigations of stream salinity trends in their respective jurisdictions. These reports were subsequently synthesised by the Murray-Darling Basin Commission into the Murray-Darling Basin Salinity Audit (Murray-Darling Basin Ministerial Council, 1999). In New South Wales, instream salt loads were calculated for each of the major basins for the period 1975 to 1995. These were scaled up to predict salt loads for the years 2020, 2050 and 2100, based on estimates of groundwater rise and area affected by land salinisation.

Many issues with the methodology have previously been identified which suggest the original predictions of future salt loads were seriously overestimated. These were attributed to:

- inability to consider topographical effects because the analyses predated the availability of a suitable digital elevation model
- unreliability of groundwater trend estimates as a result of insufficient frequency in groundwater level monitoring
- the use of linear trends to represent groundwater rise processes
- lack of consideration of recharge processes
- lack of a physically-based representation for the transfer of groundwater salts to the stream via surface discharge pathways.

In 2001, the New South Wales Government established the New South Wales Salinity Strategy (Department of Land and Water Conservation, 2000). A key activity under this strategy was to provide better data and improve the scientific understanding of salinity processes in New South Wales, given the limitations of the 1999 Salinity Audit listed above. The Salinity Strategy provided the impetus to compile data sets and develop modelling tools to quantify a range of conceptual models for the mobilisation of salts within landscapes and from landscapes to streams. Many of the data sets, information sources and analytic tools presented in the report were developed under the New South Wales Salinity Strategy.

The aim of this report is to compile and consolidate available data, information and analyses that can be used to define the current status and future trends in dryland salinity in upland areas of the Murray-Darling Basin in New South Wales. This Salinity Audit update has a function to review, amend and update the outputs and outcomes from previous Audits. It takes advantage of the advances in scientific understanding of salinity, and of data and technology improvements during the period since the first Audit was completed. In the years since the original 1999 Salinity Audit, there has been a massive increase in the availability of time-series data, spatial data, and analytical tools, and computing capacity to apply these tools.

## 1.1 Scope of this report

Originally, the scope of this Salinity Audit was to undertake an update of reporting under the Murray-Darling Basin Agreement (Schedule C). In the past few years, there has been substantial effort in developing other reporting mechanisms at State and National levels. In 2003, the New South Wales Government introduced a number of major reforms for Natural Resource Management. The development and implementation of Natural Resource Management plans is now undertaken by 13 Catchment Management Authorities. State-wide targets and auditing is the responsibility of the Natural Resources Commission. Consequently, this report has been prepared to have relevance to a wider audience, including the Murray-Darling Basin Commission, the Natural Resources Commission, Catchment Management Authorities, National Salinity Indicators and State of the Environment reporting.

### 1.1.1 Natural Resources Commission salinity indicators

The Natural Resources Commission has established soil and land targets which include improvement in soil condition and an increase in areas which are being managed according to their capability. The soil and land monitoring system interprets threats to the soil's ability to provide ecosystem services or productivity as indicators. All indicators require monitoring and where they are evident, land management actions can be targeted towards management of the threat to land capability. Accordingly, soil and land salinity will be monitored through:

- periodic monitoring of the size and intensity of representative selected salt outbreaks
- monitoring of land management actions which influence salinity in recharge contributing areas associated with the monitored salt outbreaks
- measurement of soil salinity at soil monitoring sites.

In addition, monitoring activity in other themes, especially salinity in baseflows, depth to groundwater and groundwater salinity, will be added to the three soil and land salinity monitoring data sets to help evaluate and report on salinity in New South Wales.

### 1.1.2 Murray-Darling Basin Commission reporting

Under the terms of the Murray-Darling Basin Agreement (Schedule C), partner Governments are expected to update valley audits of salinity on a 5-year basis. These 5-yearly Audits should address:

- the current extent of the salinity problem in New South Wales
- the extent to which the situation has changed in the years since previous Audits
- the possible drivers of any changes

- evidence of patterns in the historical record that might provide some clue as to how the salinity situation might develop in the future.

This Salinity Audit update is the first of a planned program of Audit reviews to be undertaken in compliance with the protocols of the Murray-Darling Basin Commission (MDBC) Basin Salinity Management Strategy (MDBC 2005). Like the previous Audit (Murray-Darling Basin Ministerial Council 1999, Beale *et al.* 2000), the focus is on dryland salinity in the New South Wales Murray-Darling Basin.

### 1.1.3 National Salinity indicators

The National Natural Monitoring and Evaluation Framework has been developed by the Australian, State and Territory Governments to assess both the health of the nation's land, water and biological resources and the performance of Government programs, strategies and policies (particularly the National Action Plan for Salinity and Water Quality and Natural Heritage Trust programs). This framework defines 'matters for target' which can be reported using a range of indicators. Indicators include biophysical resource condition indicators as well as community and social indicators relevant to natural resource management programs and the adoption of sustainable management practices. For the Land Salinity 'matter for target' the following indicators have been proposed:

- depth to groundwater
- groundwater salinity
- baseflow salinity
- location, size and intensity of salt-affected areas.

## 1.2 Report structure

This report defines the current status and future trends in dryland salinity in upland areas of the Murray-Darling Basin in New South Wales. Chapter 2 provides a summary of the contextual data and information that can be used to characterise salinity processes across New South Wales. Chapter 3 contains interpreted data and information compiled from a range of spatial data sets, temporal data and analytical tools and mapping. This includes:

- compilation and analyses of stream flow and salinity data to provide information on stream flow, salt loads and salt export rates from all upland catchments
- statistical analyses of stream Electrical Conductivity (EC) trends
- statistical analyses of groundwater level trends
- mapping and modelling of salt outbreaks
- modelling of potential land salinisation.

The current status of salinity across the upland areas of the Murray-Darling Basin in New South Wales is described in Chapter 4. This information is compiled for three salinity indicators: groundwater level, stream EC and land area salinised. Information on the current status of salinity in New South Wales is further refined in Chapter 5, which presents results on a sub-catchment basis and explores the spatial variability in salinity processes using contextual data from Chapter 2.

Future trends in salinity in New South Wales are presented in Chapter 6. These trends were determined using biophysical modelling and will be compared to statistical stream salinity trends.

# 2 Contextual data

The interpretation of results presented in this report must be made with an understanding of the spatial variability in salinity processes across New South Wales. This chapter provides a summary of the contextual data and information that can be used to characterise the variability of climate, soils, topography, geology, groundwater systems and land use across upland catchments of the New South Wales Murray-Darling Basin. This information is presented as a series of maps for the study area. Tabular summaries for each major valley are also provided.

## 2.1 Study area and information sources

The geographical extent of the synthesis of available data and analyses in this report is shown in Figure 1. The study area comprises 114 upland sub-catchments in the New South Wales Murray-Darling Basin. For the stream EC and groundwater trend analyses presented in this report, some additional areas have also been included.

**Figure 1:** Geographical extent of sub-catchments for the Salinity Audit

Data presented in this chapter (sections 2.2 to 2.10 inclusive) were compiled from a wide range of temporal and spatial data sets. A brief description of each data set, its scale and source are summarised in Table 1. Contextual data and information presented in this chapter are also tabulated on a sub-catchment basis (defined by gauging station) for each valley in Appendix A.

For each of these data sources, consistent mapping techniques were used across the whole study area at the designated scale or resolution. Some spatial data sets, especially soils and groundwater flow systems, are available at finer scales and resolutions, but these are not consistent across the whole study area and have not been used for this Audit. However, the more detailed data would be preferable for catchment and local scale planning.

**Table 1:** Sources of spatial and time series data used as contextual information

| Data | Description | Scale/resolution | Source |
|---|---|---|---|
| Rainfall | ANUCLIM[1] Average annual rainfall surfaces | 2.5 km raster | Hutchinson (2004) |
| Winter surplus | Calculated from average monthly rainfall and average monthly evaporation surfaces | 2.5 km raster | Derived |
| Land use | DNR erosion land use mapping reclassified into cropping, pasture, trees and other categories | 1: 100 000 | (ANZLIC ANZNS0359000148) |
| Soils | Bicentennial soil map | 1: 1 500 000 | New South Wales Department of Environment and Climate Change |
| Landforms | Derived from the 25 m digital elevation model and the FLAG topographic analysis model | 25 m raster | Dowling (2000)<br>ANZLIC for DEM<br>Summerell (2004) |
| Geology | Major geological units | 1: 250 000 | |
| Groundwater flow systems | CSIRO MDB groundwater flow systems mapping | 1:250 000 | Murray-Darling Basin Commission |
| Stream monitoring network | New South Wales Department of Water and Energy stream gauging stations | Points | New South Wales Department of Water and Energy |
| Groundwater monitoring network | Monitoring bores maintained by the New South Wales Department of Water and Energy | Points | New South Wales Department of Water and Energy |
| Stream flow | Time series data of stream flow collected at gauging stations across New South Wales | Not applicable | HYDSYS and IQQM stream flow data |
| Salt loads | Derived from time series of stream flow and stream EC data collected at gauging stations across New South Wales | Not applicable | Triton, HYDSYS and IQQM salt loads data |
| Depth to watertable | Interpolated depth to watertable map compiled as part of Department of Natural Resources groundwater availability mapping | | New South Wales Department of Water and Energy |

1. ANUCLIM is a software package that enables the user to obtain estimates of monthly mean climate variables, bioclimatic parameters and indices relating to crop growth.

## 2.2 Climate data

Climate is the major driver for water movement through landscapes. Different climatic regimes affect the relative volumes and pathways of water movement from landscapes to streams. In New South Wales, priority salinity areas occur across three different climatic zones ranging from sub-tropical in northern New South Wales, to temperate (uniform rainfall in central New South Wales ) and temperate (winter dominated rainfall) in southern New South Wales (Table 2). These different climatic mechanisms result in vastly different hydrological and salt mobilisation processes across the State. Therefore, conceptual models of salt mobilisation are also highly variable across upland sub-catchments of the New South Wales Murray-Darling Basin.

A summary of climatic zones across Australia is provided in Table 2. Salinity expressions have been identified across wide areas of Victoria, South Australia and south-west Western Australia. These areas all fall within a temperate climatic zone dominated by winter rainfall. Salinity expressions in Queensland generally fall within a sub-tropical climatic zone with a dominant summer rainfall pattern. In New South Wales, the climate drivers for salt mobilisation are more complex with salinity occurring across different climatic zones. This also illustrates the potential for the highly variable nature of salt mobilisation processes in New South Wales. While a narrow range of conceptual models for salt mobilisation may be appropriate in other areas of Australia, this is not the case in New South Wales, where both the nature of salinity expressions and the processes driving those expressions are highly variable.

**Table 2:** Climate zones for priority salinity areas across Australia

| Location | Climate zone | Rainfall dominance |
|---|---|---|
| Queensland | Sub-tropical | Summer |
| New South Wales | Sub-tropical<br>Temperate<br>Temperate | Summer<br>Uniform winter/summer<br>Winter |
| Victoria | Temperate | Winter |
| Tasmania | Temperate | Winter |
| South Australia | Temperate | Winter |
| Western Australia | Temperate | Winter |

Average annual rainfall for the study area is presented in Figure 2. The majority of the area has an average annual rainfall in the 600–800 mm range. Highest rainfall occurs in the eastern and southern parts of the study area. Rainfall decreases to the west with western areas having average annual rainfalls ranging from 400 to 600 mm.

The seasonality of rainfall across upland areas of the New South Wales Murray-Darling Basin is shown in Figure 3. This map shows the winter surplus of rainfall where winter surplus was calculated from winter rain minus winter evaporation. Winter surplus indicates those areas where rainfall exceeds evaporative demand during winter, resulting in excessive storage of water in the soil and in landscapes during winter months. This can result in saturated soils, shallow perched watertables and surface discharge of shallow groundwater. This surplus water has the potential to mobilise salts from the soil and regolith.

Higher winter rainfall surplus occurs in the southern temperate zone. In the northern sub-tropics there is a winter rainfall deficit, with winter evaporation exceeding winter rainfall. The switch from winter deficit to winter surplus occurs in the mid-Macquarie area. This is consistent with the boundary between the sub-tropical and temperate climate zones in New South Wales.

Figure 2: Average annual rainfall

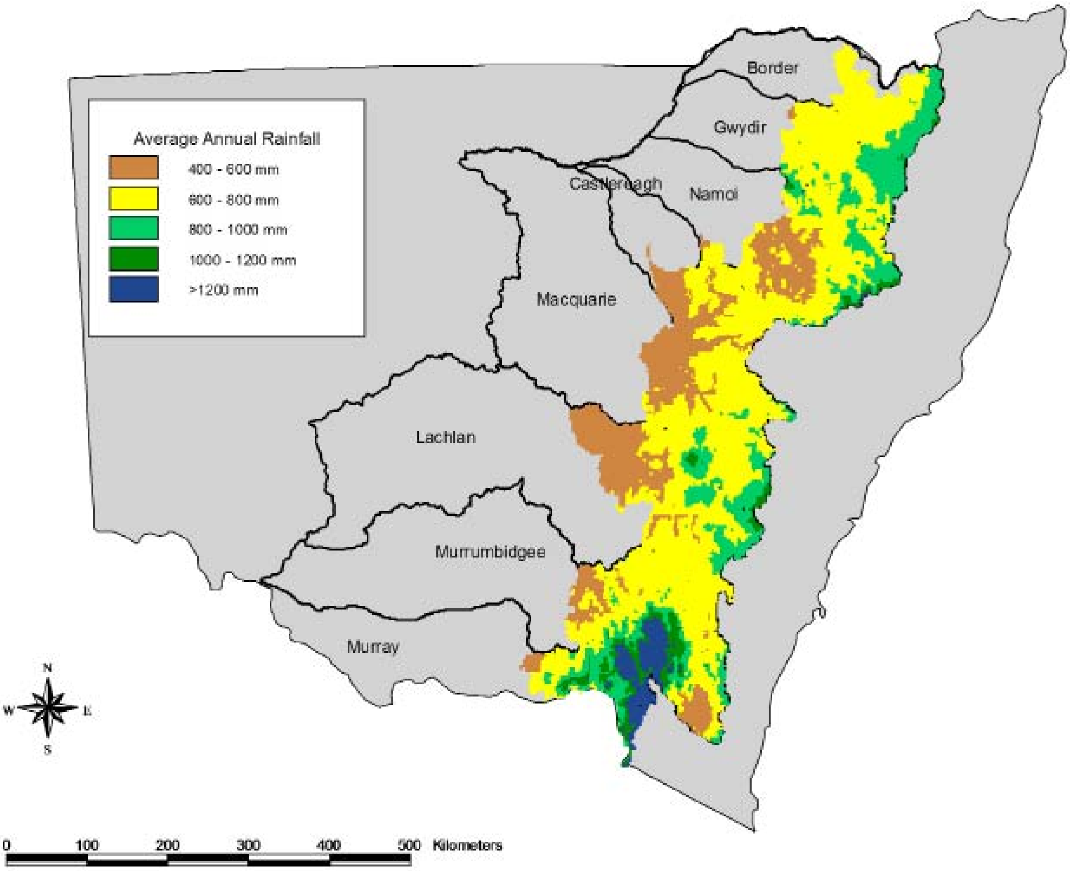
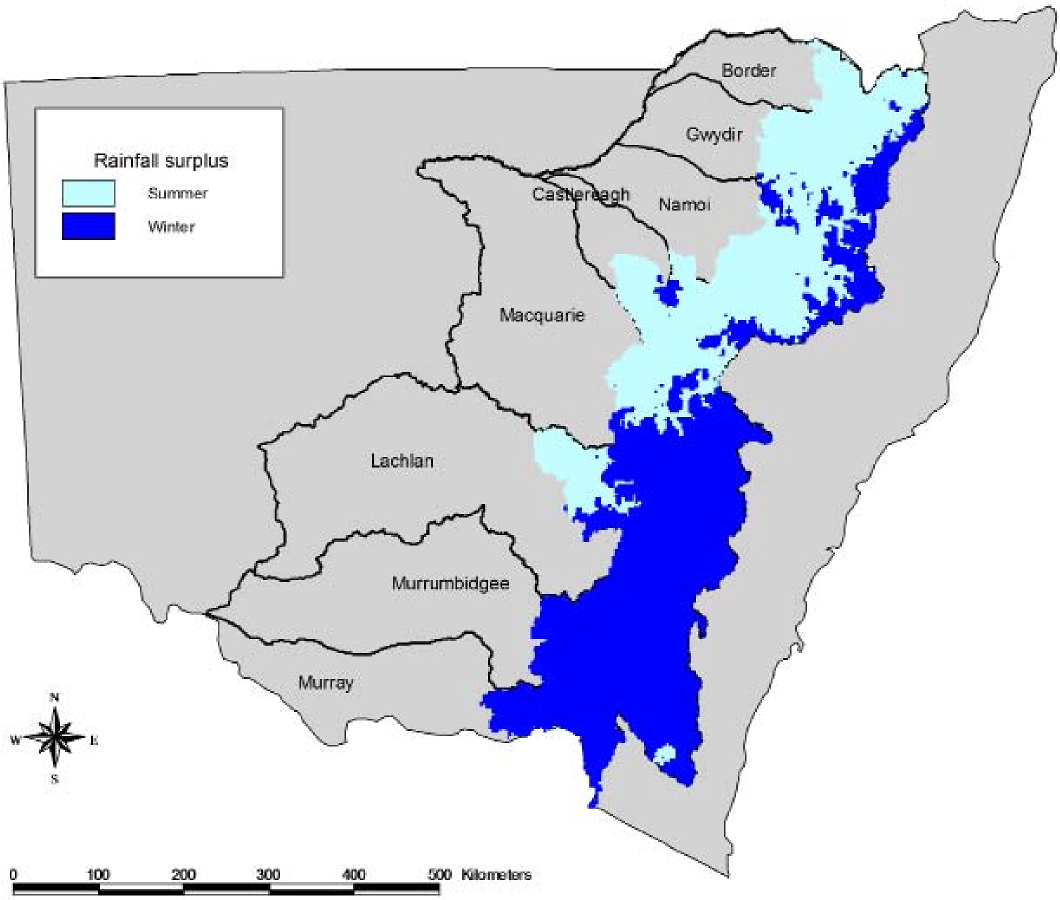


Figure 3: Surplus of rainfall during winter months



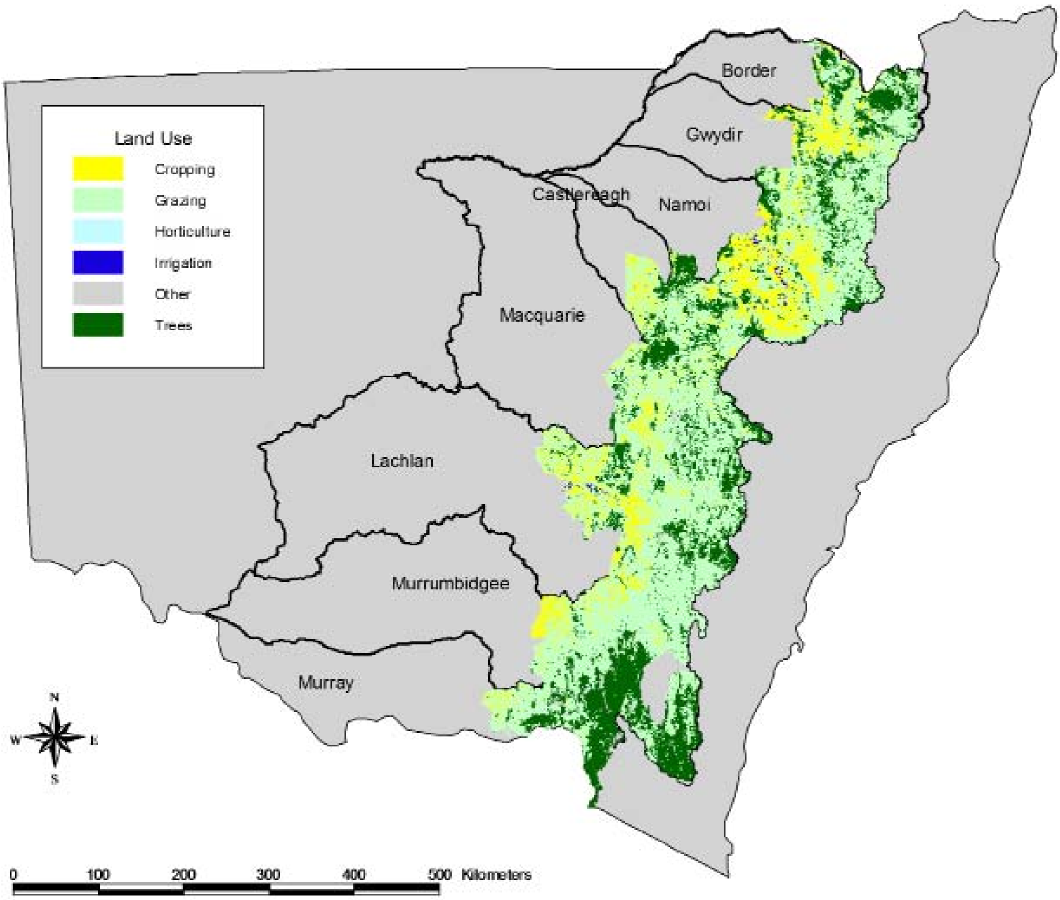
## 2.3 Land use

Major land uses for the study area are shown in Figure 4. More detailed land use categories have been amalgamated into the major land uses of trees, pasture, cropping and other land uses. A summary of land use across the study area has been compiled and is presented in Table 3. Pasture is the major land use, comprising almost 61% of the study area. Approximately 24% of the study area is treed and 13% of the study area is cropped. Many intervention strategies for land use change for salinity benefits target cropping areas and these statistics provide an overall summary of the potential area for these strategies.

**Table 3:** Summary of land uses across the study area

| Land use | Area ('000 ha) | Area (%) |
|---|---|---|
| Pasture | 8 587 | 60.9 |
| Trees | 3 448 | 24.4 |
| Cropping | 1 834 | 13.0 |
| Other | 238 | 1.7 |

**Figure 4:** Land uses of the upland catchments



## 2.4 Soil types

Major soil types that occur across the upland areas of the New South Wales Murray-Darling Basin are shown in Figure 5 and a tabular summary is presented in Table 4. Each of these soils types has unique hydrological properties and salt stores. The spatial variability of these factors are part of the interpreted data and modelling analyses that are described in Chapter 3 of this report.

**Figure 5:** Major soil types of the upland catchments

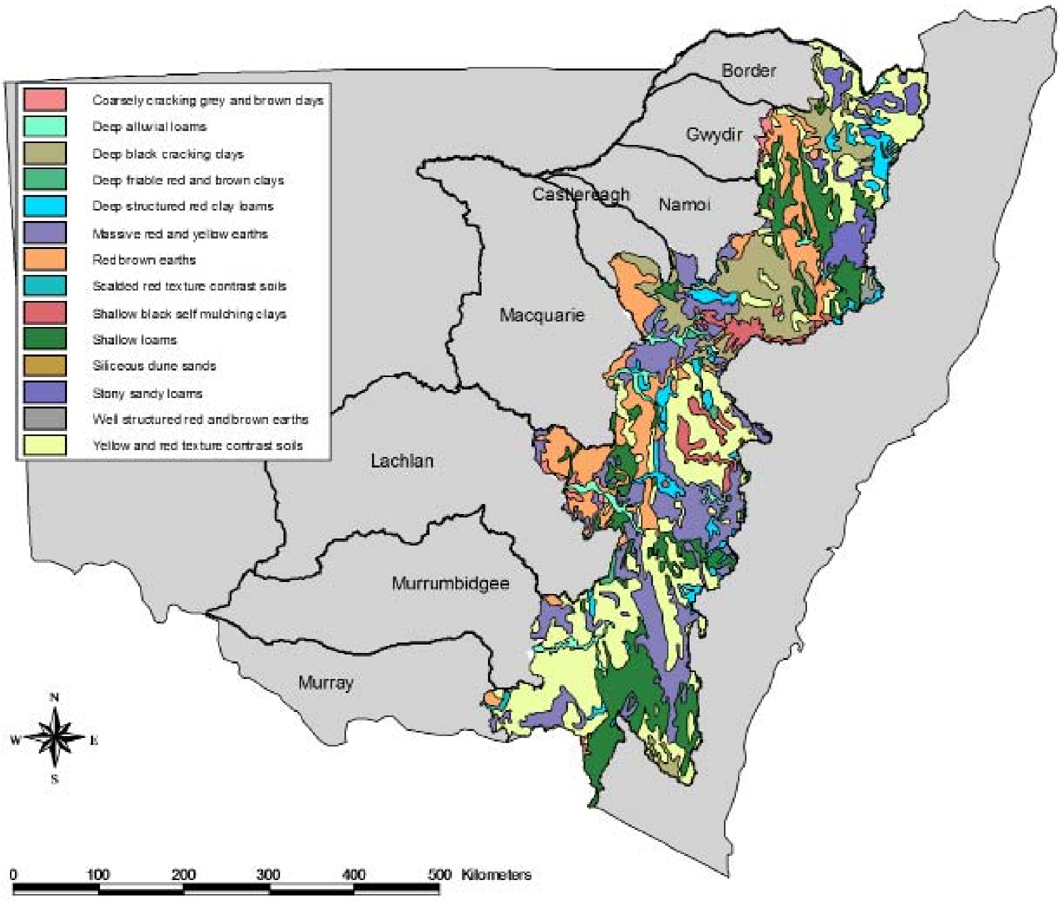


**Table 4:** Summary of major soil types across the study area

| Soil type | Area ('000 ha) | Area (%) |
|---|---|---|
| Yellow and red texture contrast soils | 3 784 | 26.3 |
| Massive red and yellow earths | 2 576 | 17.9 |
| Shallow loams | 2 139 | 14.9 |
| Red brown earths | 1 881 | 13.1 |
| Deep black cracking clays | 1 619 | 11.3 |
| Deep structured red clay loams | 705 | 4.9 |
| Stony sandy loams | 550 | 3.8 |
| Shallow black self-mulching clay | 489 | 3.4 |
| Deep alluvial loams | 427 | 3.0 |
| Coarsely cracking grey and brown clays | 90 | 0.6 |
| Well structured red and brown earths | 51 | 0.4 |
| Deep friable red and brown clays | 63 | 0.4 |

## 2.5 Landforms

The identification of landform elements was based on topographical analyses using the FLAG wetness index from Dowling (2000) and a 25 m resolution Digital Elevation Model. The method of determining landforms was based on Summerell (2004) and Summerell *et al* (2005). This work demonstrated how the distribution of the Cumulative Distribution Function of the Fuzzy Landscape Analysis GIS (FLAG) wetness index (UPNESS) provides a reliable descriptor of landform dominance within a catchment. The shape of the Cumulative Distribution Function of UPNESS indicated whether a catchment is dominated by steeper or flatter landforms.

Results from the topographical analysis using the FLAG model are shown is Figure 6 and are summarised in Table 5. Landforms have been identified as crests of hills, upper slopes, mid slopes and lower slopes. The landform index provides a consistent data set for comparing the proportions of landforms across upland areas of the New South Wales Murray-Darling Basin. Approximately 76% of the study area has mid-slope and upper-slope landforms that highlight the upland characteristics of the study area.

**Figure 6:** Land forms of the upland catchments

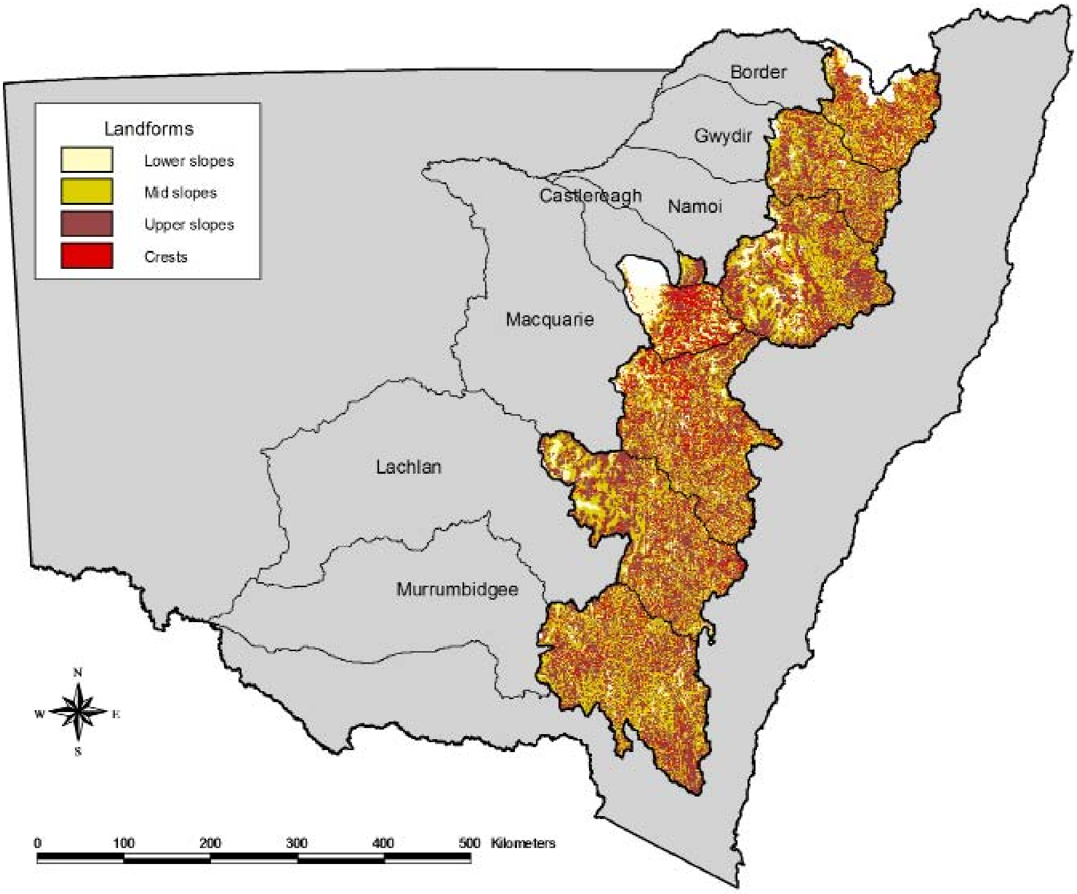
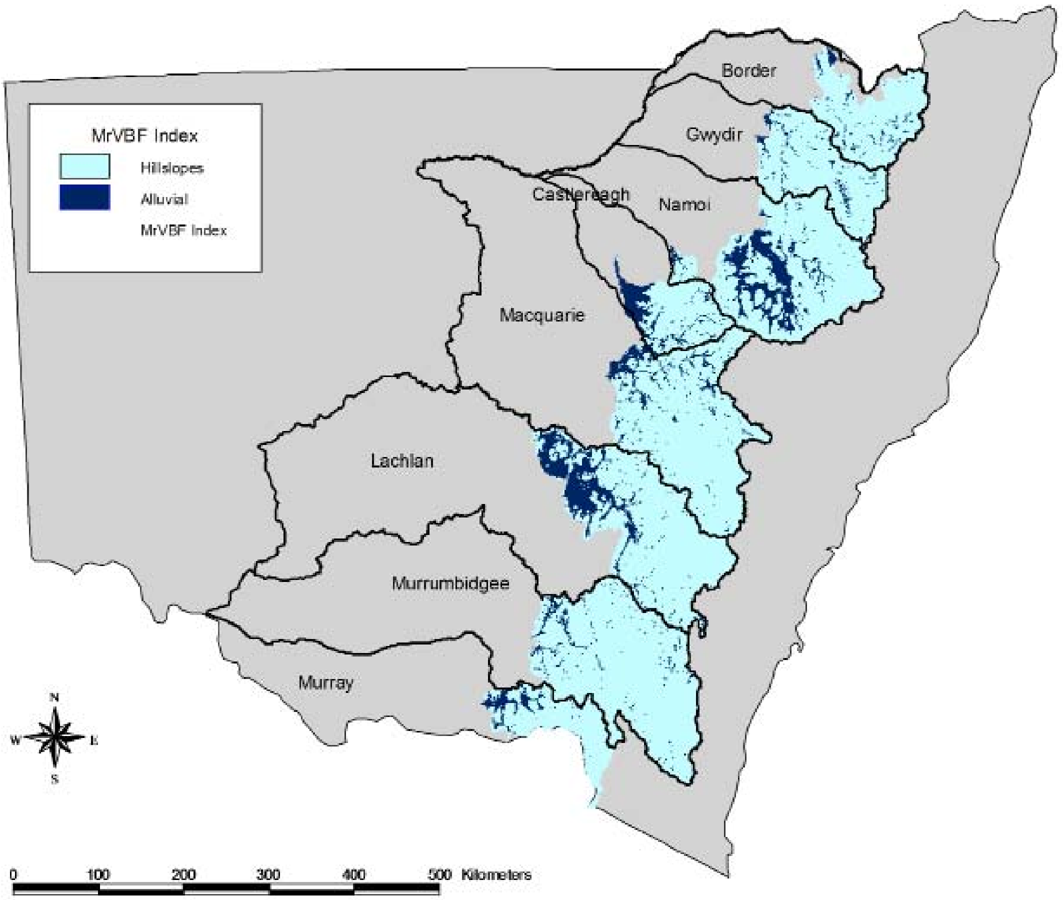


**Table 5:** Summary of land forms across the study area

| Landform element | Area ('000 ha) | Area (%) |
|---|---|---|
| Upper slopes | 5 814 | 40.4 |
| Mid slopes | 5 176 | 36.0 |
| Crests | 2 019 | 14.0 |
| Lower slopes | 1 363 | 9.5 |

Further topographical analyses were also undertaken using the MrVBF model (Gallant and Dowling 2003). MrVBF is a terrain analysis program that delineates uniformly flatter areas of catchments and produces a single topographic index which increases in value for flatter areas. It identifies and delineates both major alluvial areas and the smaller alluvial areas occurring in upland areas of many sub-catchments. Output from MrVBF that delineates alluvial areas occurring across upland areas of the New South Wales Murray-Darling Basin is shown in Figure 7.

**Figure 7:** Alluvial land forms of the upland catchments



## 2.6 Geology

The underlying geology influences both the behaviour of groundwater flow and the potential sources of salt. Geology when combined with topography is used to define groundwater flow systems (Section 2.7). A map of major geological units occurring in upland areas of the New South Wales Murray-Darling Basin is presented in Figure 8 and an area summary is shown in Table 6.

**Figure 8:** Major geological units of the upland catchments

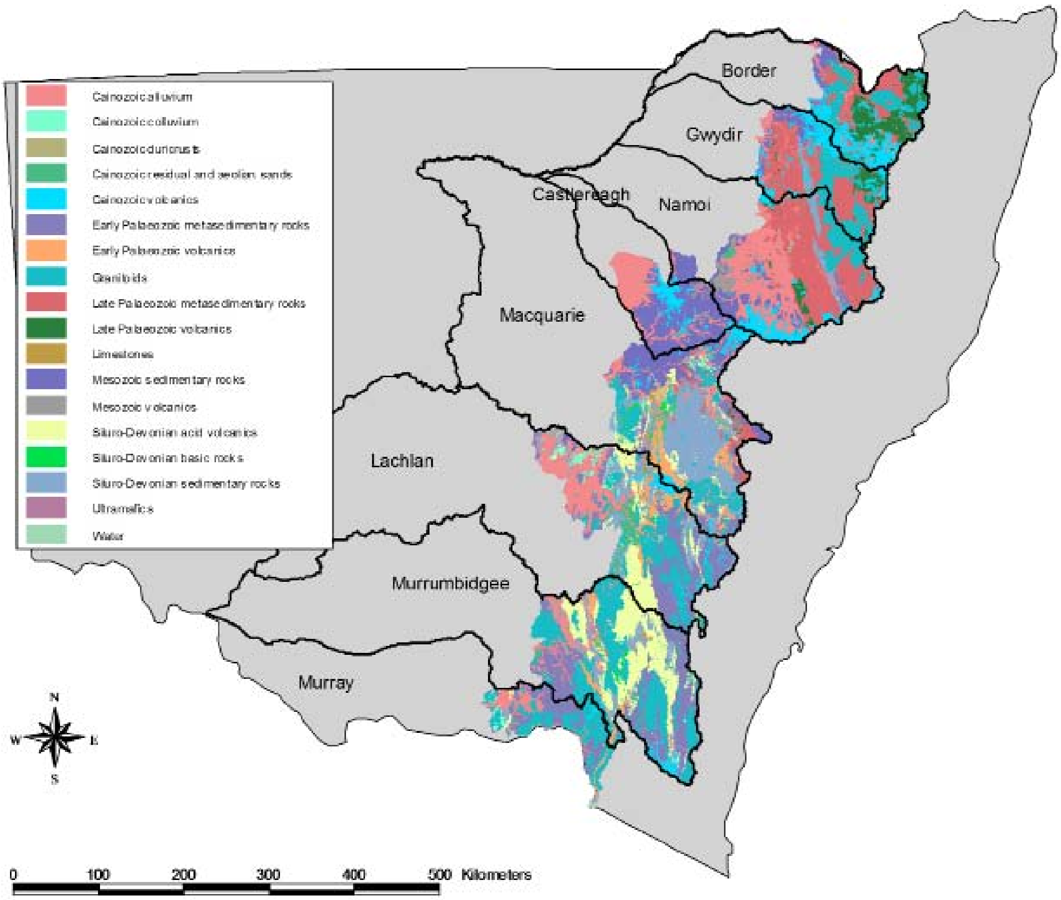


**Table 6:** Summary of geology across the study area

| Geological unit | Area ('000 ha) | Area (%) |
|---|---|---|
| Granitoids | 2 313 | 16.0 |
| Cainozoic alluvium | 2 010 | 13.9 |
| Mesozoic sedimentary rocks | 1 863 | 12.9 |
| Late Palaeozoic metasedimentary rocks | 1 652 | 11.4 |
| Siluro-Devonian sedimentary rocks | 1 470 | 10.2 |
| Early Palaeozoic metasedimentary rocks | 1 349 | 9.4 |
| Cainozoic volcanics | 1 244 | 8.6 |
| Siluro-Devonian acid volcanics | 1 075 | 7.5 |
| Late Palaeozoic volcanics | 409 | 2.8 |
| Early Palaeozoic volcanics | 385 | 2.7 |
| Cainozoic residual and aeolian sands | 199 | 1.4 |
| Cainozoic colluvium | 138 | 1.0 |
| Mesozoic volcanics | 128 | 0.9 |
| Siluro-Devonian basic rocks | 80 | 0.6 |
| Limestones | 62 | 0.4 |
| Water | 27 | 0.2 |
| Ultramafics | 22 | 0.2 |
| Cainozoic duricrusts | <1 | 0.0 |

## 2.7 Groundwater flow systems

The groundwater flow system (GFS) framework was originally published by Coram *et al*. (2001) as part of the National Land and Water Resources Audit. It delineates appropriate spatial units for differentiating between areas on the basis of salinity behaviour. The classification system emphasises the role of geology and landscape position in determining groundwater flows and salinity processes. However, collection points for stream flow and salinity data are based on surface catchments, which may not align with sub-surface groundwater flows. The significance of groundwater contributions to stream salinity must be inferred from the stream salinity record, which is complicated in most sub-catchments with multiple groundwater flow systems.

Groundwater flow systems are defined by various physical attributes that influence how the GFS might respond to different forms of management intervention. The size of an aquifer has a significant influence on its responsiveness to changes to its recharge regime. Three broad classes of GFS have been defined, based on the scale of aquifer:

- *local* — small-scale, relatively shallow aquifers, with lengths not exceeding about 5 km. Local GFSs tend to occur in upland catchments where there is substantial relief providing the hydraulic gradient driving groundwater flow. In fractured rock areas, discrete flow cells can occupy each hillslope, recharge is highly episodic and occurs on the hillslopes, and discharge is primarily via low order streams.
- *intermediate* — medium-scale aquifer systems occurring in terrain that has insufficient relief to interrupt groundwater flow. Aquifer lengths can be up to 20–30 kilometres. In fractured rock areas, recharge primarily occurs in the headwaters of sub-catchments, where the fractured rock is exposed, with discharge occurring down-catchment, where the hydraulic gradients reduce with decreasing elevation and slope.
- *regional* — large scale aquifers, which often span hundreds of kilometres. In the Murray-Darling Basin, they occupy the basinal (or alluvial) sediments that dominate the vast Riverine Plains areas west of the slopes and tablelands. Owing to their large size and low hydraulic gradients, they respond relatively slowly to changes in recharge regime. Depending on the system, recharge can occur where the beds are exposed at the surface or from overlying aquifers. Recharge areas are often small, relative to the size of the whole groundwater system.

Equilibrium response times in local groundwater flow systems tend to be relatively rapid, owing to their smaller size and storage potential, and steeper topographic gradients. In intermediate and regional groundwater flow systems, the increases in aquifer length and volume and lower overall gradients contribute to less responsive systems, hence longer response times. The responsiveness is also related to the area affected by a change in recharge regime relative to the total area of the aquifer.

Groundwater flow systems for upland catchments of the New South Wales Murray-Darling Basin are shown in Figure 9 and are summarised in Table 7. Local flow systems dominate the entire study area. The dominant GFSs across the study area are flow systems occurring in fractured rock aquifers. Local flow systems in upland alluvium and colluvial fans occur across most of the study area.

**Figure 9:** Groundwater flow systems of the upland catchments

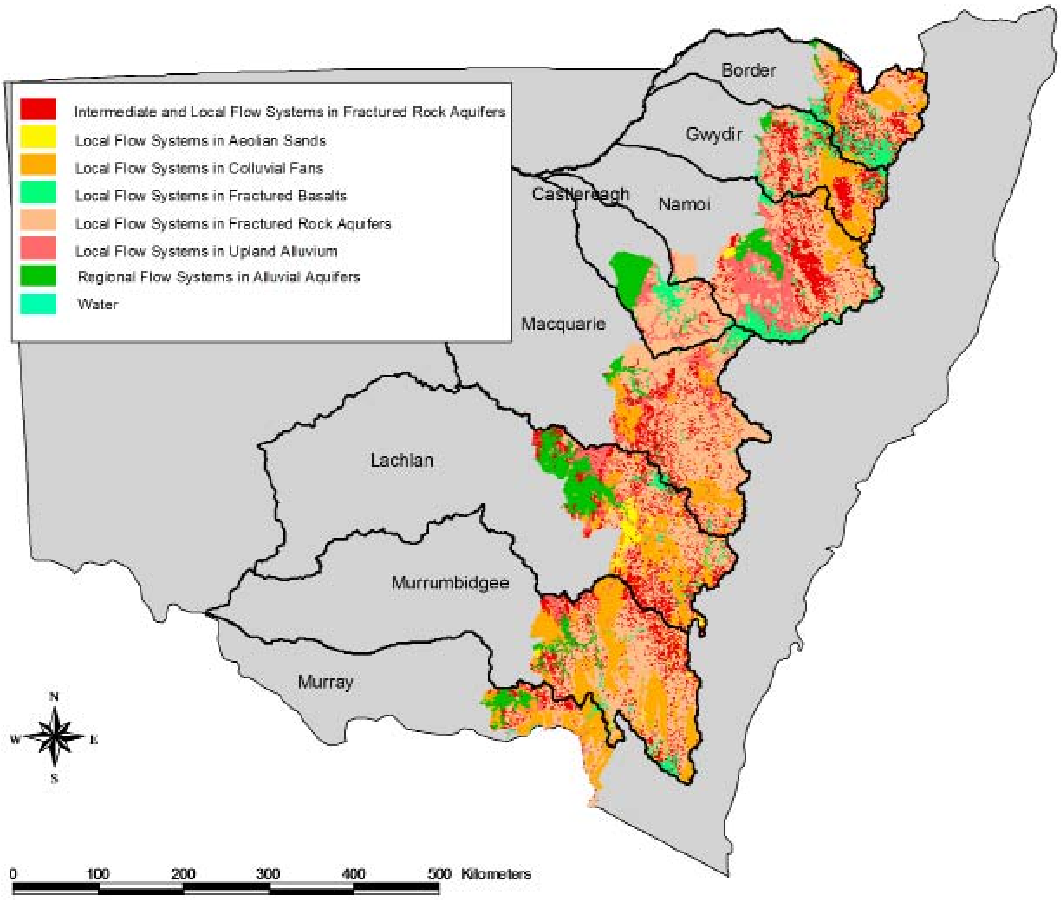


**Table 7:** Summary of groundwater flow systems across the study area

| Groundwater flow system | Area ('000 ha) | Area (%) |
|---|---|---|
| Local flow systems in fractured rock aquifers | 6 380 | 46.8 |
| Local flow systems in upland alluvium | 1 294 | 17.4 |
| Local flow systems in colluvial fans | 2 303 | 16.7 |
| Intermediate and local flow systems in fractured rock aquifers | 2 270 | 15.8 |
| Local flow systems in fractured basalts | 1 069 | 7.9 |
| Regional flow systems in alluvial aquifers | 822 | 5.7 |
| Local flow systems in aeolian sands | 196 | 1.6 |
| Water | 25 | 0.4 |

## 2.8 Groundwater monitoring network

No systematic surveys or analyses of registered bore data were conducted in New South Wales prior to the early 1980s. In the late 1980s and early 1990s, numerous groundwater reconnaissance surveys were undertaken (Gates and Williams 1988; Salas and Garland 1989; Williams 1990; Williams and Saunders 1990; Woolley 1991; Bish and Gates 1991; Hamilton 1992; Bish 1993; Lytton *et al*. 1994). Most of these surveys did not make distinctions between bores based on the geology in which they were drilled. The influence of climatic factors on bore water level responses was not taken into consideration in these early investigations. The reconnaissance surveys provided a new impetus to establish new bore monitoring programs, as well as a basis for undertaking more detailed studies of the possible development of salinity.

A map showing the location of groundwater monitoring bores in New South Wales is shown in Figure 10, with a catchment summary provided in Table 8. The focus for groundwater monitoring in New South Wales has been irrigation areas. In upland areas there are only isolated areas with adequate groundwater monitoring networks for salinity assessments.

**Figure 10:** Monitoring bores in the New South Wales Murray-Darling Basin (Ife and Skelt 2004)

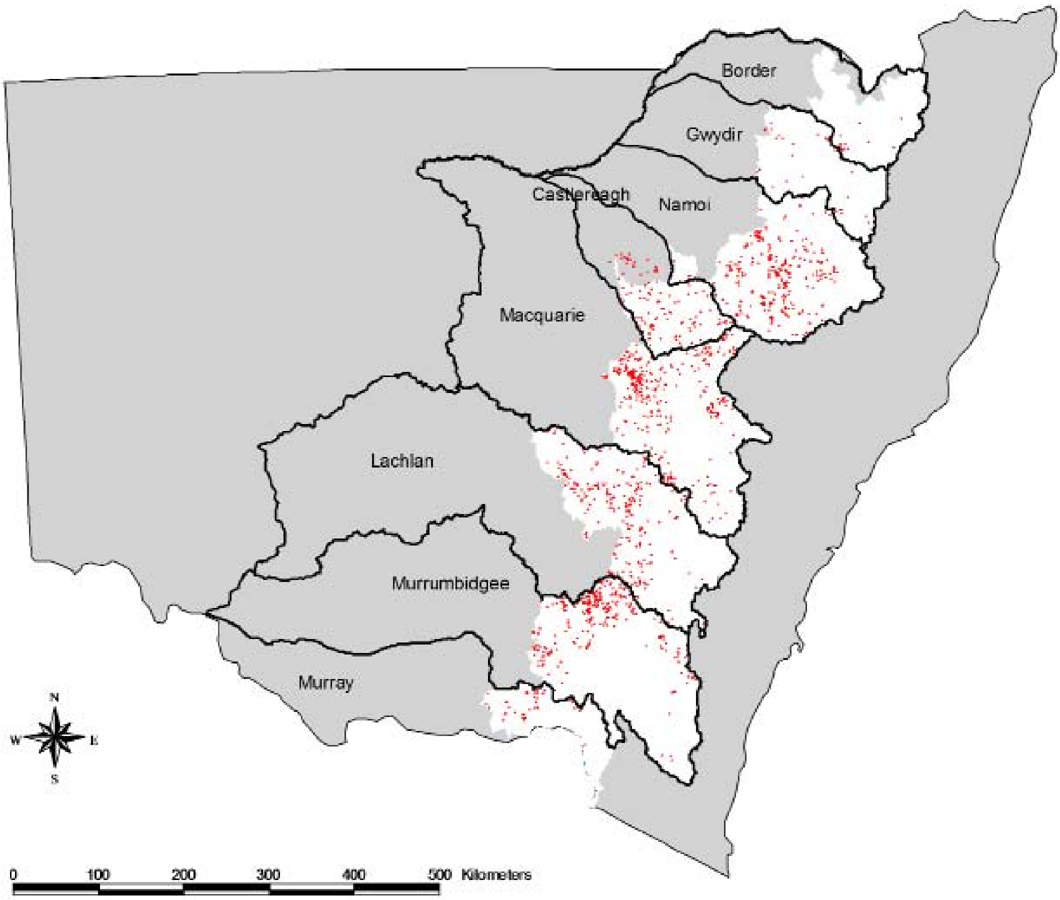


**Table 8:** Summary of groundwater bores in New South Wales (Ife and Skelt, 2004)

| Catchment | Subsystem | Number of bores | Number of hydrographs | Number of salinity graphs |
|---|---|---|---|---|
| Border Rivers | Barwon Highlands | 0 | 0 | 0 |
| | Great Artesian Basin | 120 | 17 | 0 |
| | Gunnedah Subsystem | 8 | 4 | 0 |
| | Narrabri Subsystem | 28 | 4 | 0 |
| Gwydir | Barwon Highlands | 5 | 5 | 0 |
| | Great Artesian Basin | 22 | 7 | 0 |
| | Gunnedah Subsystem | 59 | 9 | 0 |
| | Narrabri Subsystem | 55 | 10 | 0 |
| Namoi | Barwon Highlands | 8 | 8 | 0 |
| | Great Artesian Basin | 15 | 5 | 0 |
| | Gunnedah Subsystem | 93 | 34 | 0 |
| | Narrabri Subsystem | 94 | 54 | 0 |
| Central West | Central West Highlands | 22 | 22 | 0 |
| | Great Artesian Basin | 19 | 2 | 0 |
| | Gunnedah Subsystem | 42 | 6 | 0 |
| | Narrabri Subsystem | 49 | 21 | 0 |
| Lachlan | Central West Highlands | 13 | 9 | 0 |
| | Renmark Subsystem | 36 | 21 | 0 |
| | Calivil Subsystem | 124 | 26 | 0 |
| | Lachlan Subsystem | 110 | 9 | 0 |
| | Shepparton Subsystem | 10 | 6 | 0 |
| | Cowra Subsystem | 121 | 39 | 0 |
| Murrumbidgee | Murrumbidgee Highlands | 13 | 13 | 0 |
| | Renmark Subsystem | 58 | 26 | 0 |
| | Calivil Subsystem | 88 | 34 | 0 |
| | Lachlan Subsystem | 63 | 18 | 0 |
| | Shepparton Subsystem | 13 | 13 | 0 |
| | Cowra Subsystem | 73 | 29 | 0 |

## 2.9 Stream flow and saltloads

The New South Wales Government maintains a network of approximately 450 stream gauging stations across the New South Wales Murray-Darling Basin. Of these, 262 are located in upland areas (Figure 11). Each gauging station provides a record of stage height and stream flow, while a subset of these 262 stations provide data on stream salinity. Of these 262 gauging stations, 89 have been used to define major sub-catchments across the study area. Average annual runoff depths (mm) and average annual exports (t km$^{-2}$) have been compiled using data from 1975 to 2000, which is the Murray-Darling Basin Commission's Benchmark period for reporting on salinity targets. These data sets are presented in Figures 12 and 13 for flow and salt loads respectively. These maps do not report stream flow data for the Murray catchment because this area is not in the part of the State reporting to the Murray-Darling Basin Commission. Modelling of stream flows and salinities for the Murray catchment is undertaken separately within the Murray-Darling Basin Commission.

**Figure 11:** Stream gauging stations in the New South Wales Murray-Darling Basin

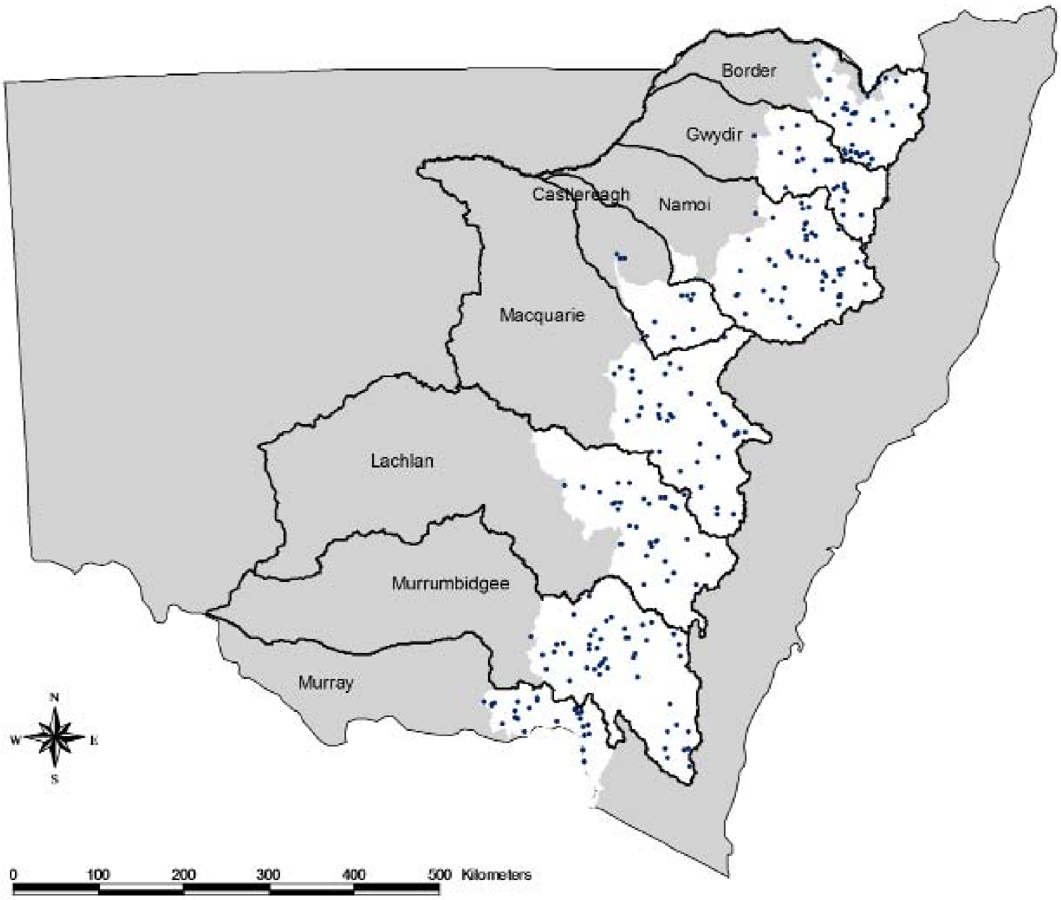


**Figure 12:** Average annual stream flow (mm) for the study area

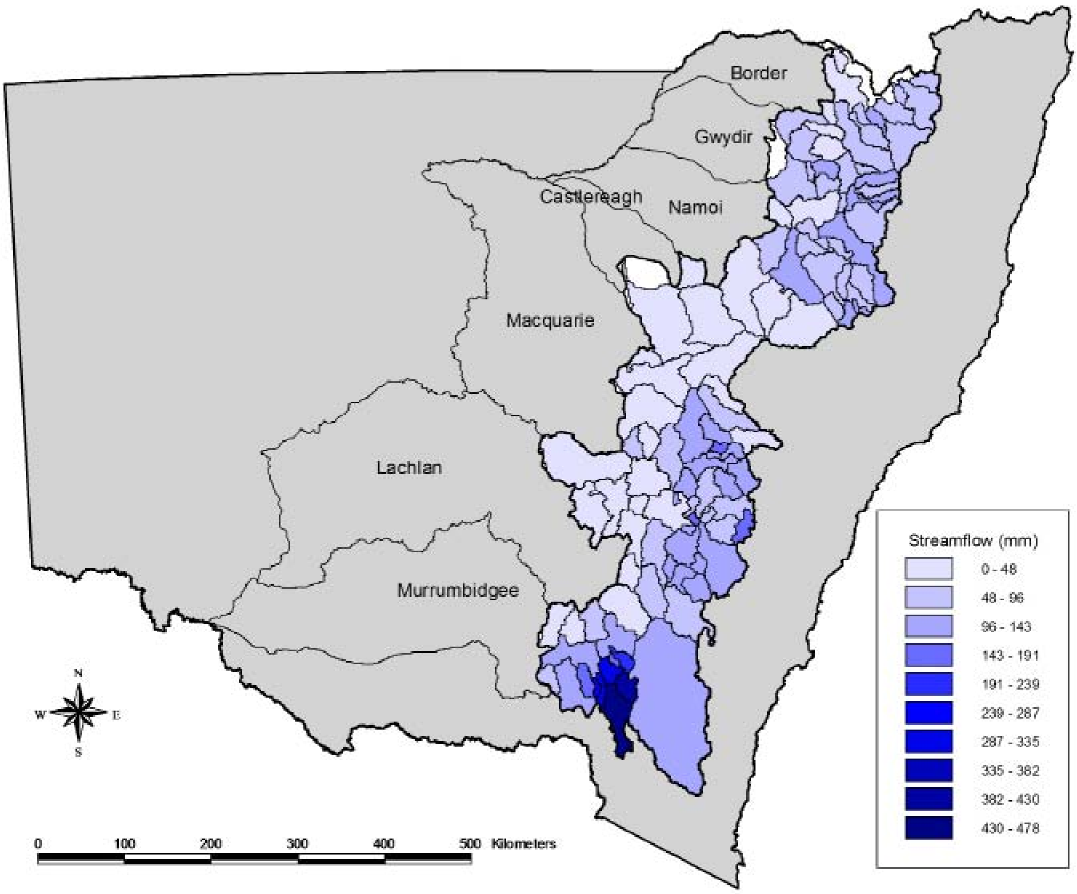
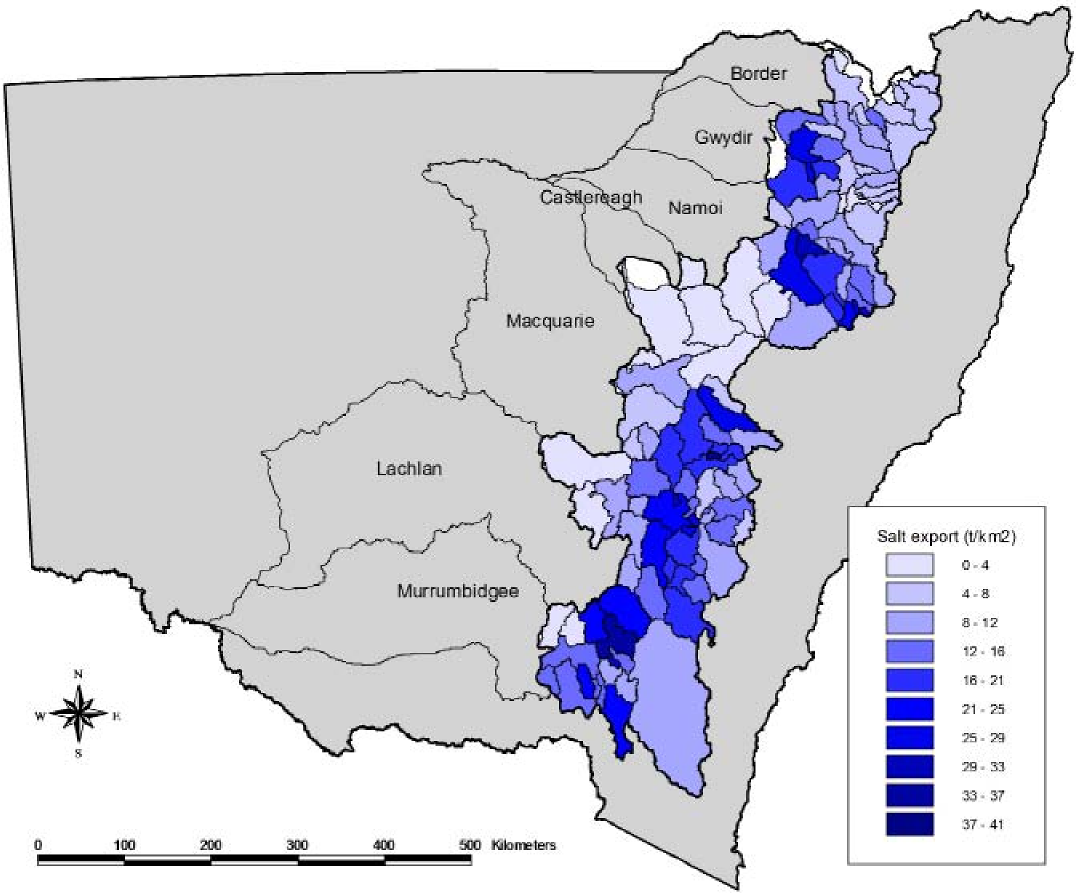


**Figure 13:** Average annual salt export (t km$^{-2}$) for the study area



## 2.10 Depth to watertable

Key areas of New South Wales have been mapped to identify locations where the risk of contamination of ground water is greatest. These maps can be used as a guide for the location of future developments to minimise their impacts on the groundwater resources within specific catchments. The groundwater vulnerability maps assess the susceptibility of the underlying groundwater resource to contamination from surface activities. Almost all groundwater resources are vulnerable to some degree; however, some are more vulnerable to contamination than others. Groundwater vulnerability maps display the relative vulnerability of a groundwater resource within a catchment.

The production of groundwater vulnerability maps required assessment of depth to watertable, recharge, aquifer conditions, overlying soil conditions, and topography. Maps showing depth to watertable are useful contextual information to support this audit of salinity from upland catchments. The depth to watertable map for upland areas of the New South Wales Murray-Darling Basin is shown in Figure 14 and summarised in Table 9.

**Figure 14:** Depth to watertable of the upland catchments

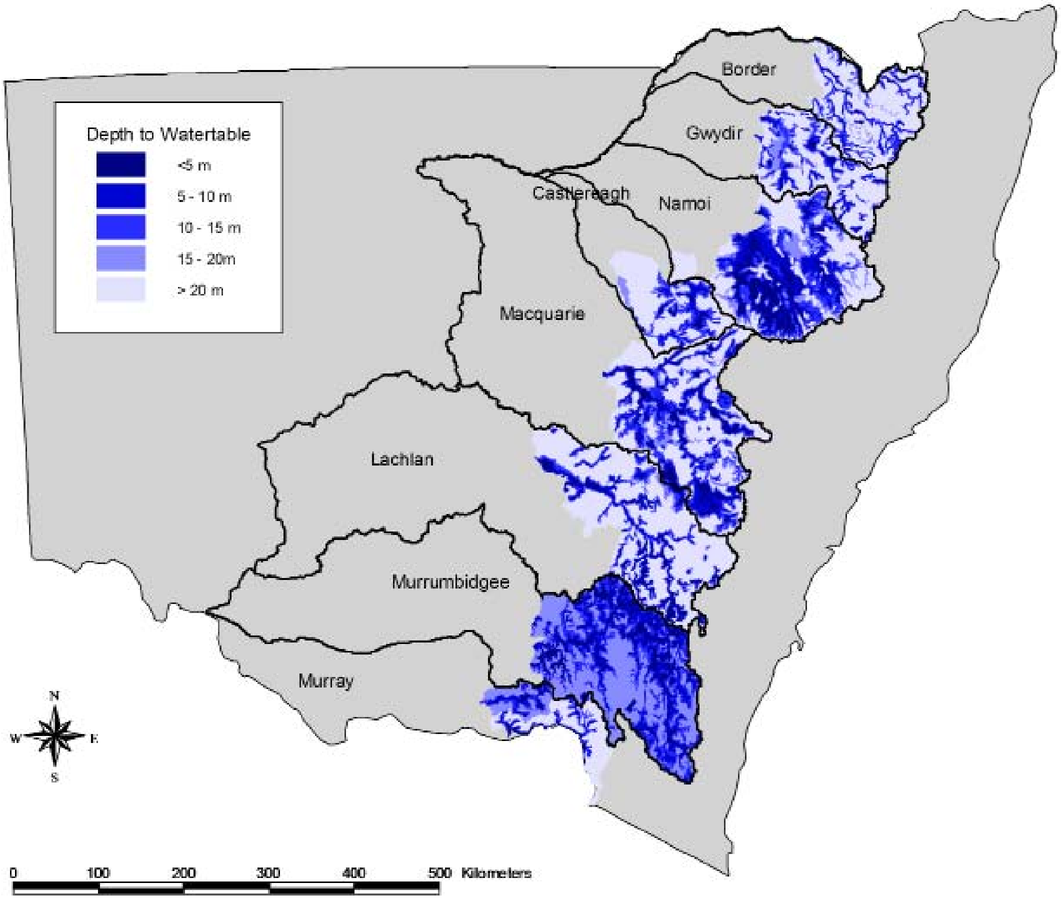


**Table 9:** Summary depth to watertable across the study area

| Depth to watertable | Area ('000 ha) | Area (%) |
|---|---|---|
| <5 m | 1 164 | 8.1 |
| 5–10 m | 2 086 | 14.5 |
| 10–15 m | 2 245 | 15.6 |
| 15–20 m | 2 820 | 19.6 |
| >20 m | 6 059 | 42.2 |

## 2.11 Salt stores

Total salt store for the upland catchments of the New South Wales Murray-Darling Basin is shown in Figure 15. The salt store consists of three components: salt stored in the soil, salt stored in the regolith and salt stored in the ground water.

Soil salt store was derived by combining soil profile electrical conductivity data contained within the New South Wales Soil and Land Information System (SALIS) and an amalgamated coverage of the best available digital soil mapping for New South Wales. All test results of electrical conductivity were converted to weight of salt by weight of soil using lookup tables of soil bulk density. The soil salt store information was then ranked in a 1 to 5 rating.

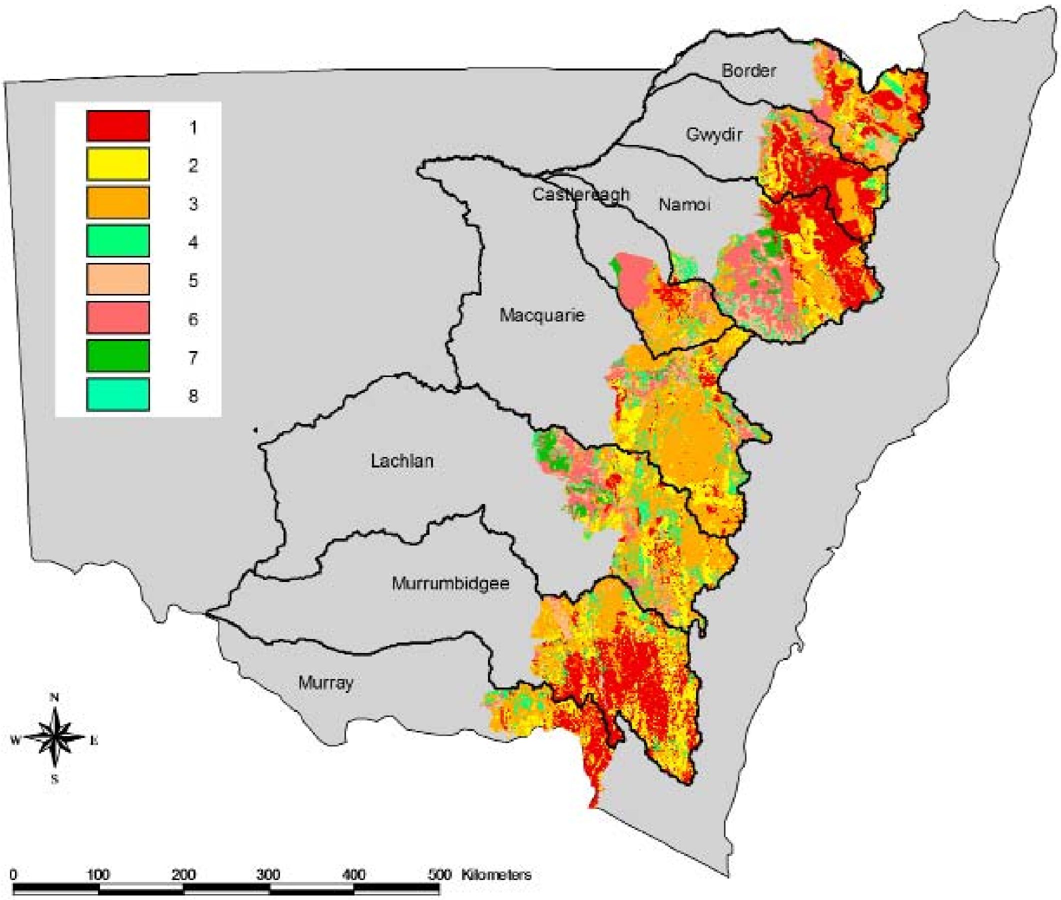
Regolith salt store is the amount of salt stored below the soil but above the watertable. The regolith can store substantial amounts of salt with significant impacts, if mobilised. There are very few data available to provide quantitative estimates of the salt mass stored in the regolith. Regolith salt store information was largely derived using qualitative methods and expert opinion from spatial data compiled as part of the Groundwater Vulnerability Mapping program. Regolith salt store information was then ranked in a 1 to 5 rating.

Groundwater salt store was derived from an empirical model that assessed the volume of ground water in upper parts of the saturated zone, and multiplied it by the salt concentration of the shallowest ground water at any particular site. Aquifer thickness was set so that the salt store mass was only representative of the upper parts of the saturated zone that have a potential to interact with surface and sub-surface lateral flows of water and mobilise salts.

Data were classified into an equal interval spread to produce a 1 to 5 ranking (low to high).

The total salt store map presented in Figure 15 is an additive model of the three component salt stores. These combined rankings were then grouped into eight classes based on the natural breaks in the distribution rather than equal intervals.

**Figure 15:** Total salt stores map of upland catchments



# 3 Analyses and interpreted data

This chapter presents a range of interpreted data sources that can be used, at varying levels for the assessment of the current status of salinity and future trends in salinity. In the data analyses that underpin this Audit, available data were examined for spatial extents, trends, inter-relationships between different information sources and spatial/temporal patterns.

Separate project activities investigated current extents of salt outbreaks, land salinisation trends, stream salinity trends, and groundwater levels, salt mobilisation processes and trends, and end-of-valley contributions of water and salt from individual sub-catchments. More detailed information for these analyses can be found in:

1. Summerell, G., Miller, M., Beale, G., Emery, K., Lucas, S., Scown, J. and Spiers, P. (2009). *Current and predicted minimum and maximum extents of land salinisation for the NSW upland portion of the Murray Darling Basin*. NSW Department of Environment and Climate Change, Sydney.
2. Harvey, F., Koen, T., Miller, M. and McGeoch, S. (2009). *Stream EC trends for inland New South Wales 2006*. NSW Department of Environment and Climate Change, Sydney.
3. Rancic, A., Salas, G., Kathuria, A., Johnston, W., Smithson, A. and Beale, G. (2009). *Climatic influence on shallow fractured- rock groundwater systems in the Murray-Darling Basin, NSW*. NSW Department of Environment and Climate Change, Sydney.
4. Littleboy, M. (2006). Application of 2CSalt in New South Wales. 10th Murray-Darling Basin Commission Groundwater Workshop, 18–20 September 2006, Canberra.
5. Berhane, D. (in prep). 'Simulation of the impacts of recharge (climate) variability on the shallow groundwater system seepage face dynamics for selected small catchments in NSW'. NSW Department of Water and Energy.

Summerell *et al.* (2009) mapped land area salinised from temporal series of air photos at seven sites to investigate land salinisation trends over time. When combined with topographical analyses, modelling techniques were developed to spatial generalise potential land salinisation across the New South Wales Murray-Darling Basin. Harvey *et al.* (2009) and Rancic *et al.* (2009) focus on determining patterns of stream EC and groundwater behaviour over the period for which data are available. Littleboy (2006) presented results from the preliminary application of the 2CSalt model across 113 sub-catchments in upland areas of the New South Wales portion of the Murray-Darling Basin.

Individually, each of these studies focuses on one aspect of salinity behaviour and the manifestation of salinity in landscapes or streams. In Chapters 4 and 5 of this report, a picture of current levels and future trends in salinity is developed by integrating the various information sources presented in the above reports. Information presented in this chapter is also tabulated on a sub-catchment basis (defined by gauging station) for each valley in Appendix B.

## 3.1 Salt outbreak mapping

Land salinisation is one manifestation of salinity. The development or expansion of saline areas poses a threat to soil condition, agricultural production, and terrestrial biodiversity. There is a need to understand the controls on land salinisation and to determine whether salt-affected landscapes can be managed reduce the development and expansion of salt outbreak areas. The salt-affected areas are parts of the landscape where soils and vegetation are degraded by the discharge of saline ground water or are affected by erosion mobilising salt stored in the soil. Different methods can be used to identify and monitor salt affected areas. These include electromagnetic surveys, aerial photographs, satellite imagery and soil surveys.

Previous studies in New South Wales have mapped salt affected areas. Wagner (1986) undertook the first large scale attempt to look at changes in salt affected areas over time (1941–43 to 1986) using historical aerial photography at approximately 10-year intervals. The study included 92 saline sites within the southern tablelands of New South Wales. Wagner (1986) reported that individual sites showed fluctuations in their extent over the years and concluded that the study sites were still degrading or at least showing no improvement. Overall there appeared to be a significant increase in scalding in the late 1950s to early 1960s. Through the 1960s to 1970s most sites continued to degrade. In the early 1980s half the sites continued to degrade, one quarter remained stable and the final quarter began to regenerate.

Dominis (1999) studied the causes for the fluctuation of the size of salt scalds around Baldry in the Macquarie Catchment using aerial photography from 1958 to1999. Seven interrelated factors— climate, geology, geomorphology, soils, vegetation, land use, and measures for remediation— were investigated to see which of these variables influence the greatest changes in scald size. Dominis (1999) concluded that the factors such as geology, geomorphology and soils dampened to different degrees the impacts of changes in climate, land use and measures of remediation, making the change not always consistent with the patterns in climate. However, the average trend was attributable to climate. Area of bare patches at the Baldry site generally increased in size from 1958 through to 1996. After 1996 the growth of the bare patches (scalds) appeared to have stabilised.

Plowman (1999) studied the changes in scald behaviour in the Spring Creek catchment on the South Western Slopes of New South Wales. Different scald responses were observed where the saline areas appeared to oscillate in size from 1953 to1994. Greater extents of salt-affected areas occurred in 1953, 1963, 1973 and 1989 and the low salt-affected areas occurred in 1970 and 1983. The increasing and decreasing trends observed were considered a short-term phenomenon, related to immediate environmental processes occurring in the landscape, of which climate appeared to be the main driver.

As part of the New South Wales Salinity Strategy, a program of salt outbreak mapping was undertaken using aerial photographs taken in about 2000. Saline outbreaks were mapped using the following levels of classification:

- dryland salinity outbreak affected by low to moderate levels of sheet erosion
- dryland salinity outbreak affected by severe to extreme rates of rill and sheet erosion
- early phase of dryland salinity outbreak indicated by presence of salt-tolerant plant species
- early phase of salinity caused by irrigation practices with salt-tolerant plant species present
- extreme gully erosion: salt discharges within gully floor or from banks of gully
- minor gully erosion: salt discharges within gully floor or from banks of gully
- moderate gully erosion: salt discharges within gully floor or from banks of gully
- salinity caused by irrigation practices and with low to moderate levels of sheet erosion
- salinity caused by irrigation practices and with severe levels of sheet/rill erosion
- wind erosion with salting.

The mapped areas of saline outbreaks are presented in Figure 16 and are summarised in Table 10. The total area of current saline outbreaks for the upland portion of the New South Wales Murray-Darling Basin is approximately 62000 ha. Areas of salt outbreaks are higher for southern areas and lower for northern valleys.

**Figure 16:** Current salt outbreak areas across the upland catchments

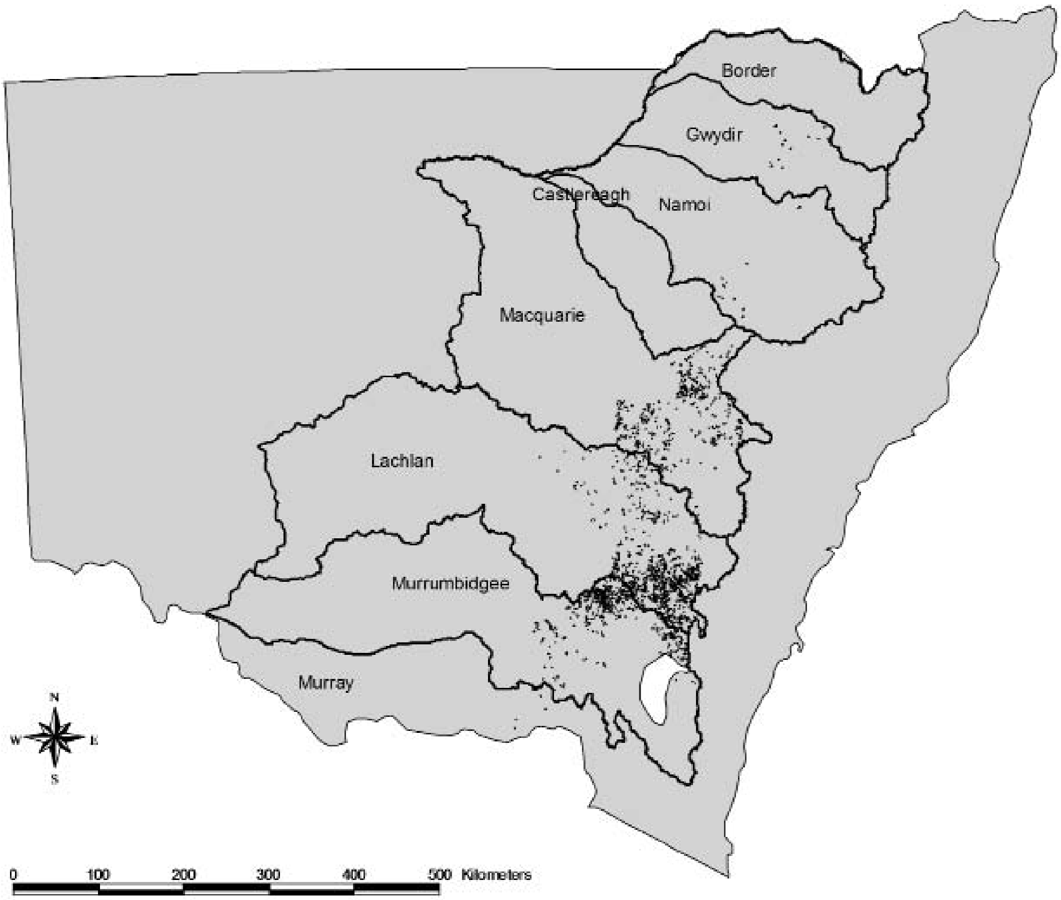


**Table 10:** Summary of saline outbreaks for each valley

| Valley | Salt outbreaks (ha) |
|---|---|
| Border Rivers | 158 |
| Gwydir | 1 575 |
| Namoi | 1 326 |
| Lachlan | 22 153 |
| Macquarie | 18 559 |
| Murrumbidgee | 18 222 |
| Murray | 379 |

## 3.2 Modelling extents of salt outbreaks

An increase in land salinisation has impacts on salinity management at a local scale and is also related to the variability in sub-catchment contributions to stream salinity. Summerell *et al.* (2005) examined patterns of salt outbreak expansion and contraction at seven sites across the New South Wales Murray-Darling Basin and developed a methodology for determining expansion limits based on topographical analyses. This type of analysis provides information that can be used to make inferences between local scale salinity and end-of-catchment stream EC trends.

The locations of the seven sites used to quantify the temporal variability in saline outbreaks are shown in Figure 17. The seven sites are located in the central and southern part of the State in valleys with high spatial extents of current salinity (Table 10) and one site is located in the northern part of the State. A summary of the major characteristics of each site is provided in Table 11.

Begalia is located within the Lachlan Fold Belt and is a sub-catchment of the Yass River. It covers an area of about 230 ha with elevation ranging from 620 to 730 m. The geology is dominated by volcanics and the mean annual rainfall for nearby Yass and Blackburn is 639 and 737 mm respectively. Sheep and cattle grazing are the dominant land uses. This catchment was also studied by Wagner (1986) for changes over time in the expressions of land salinisation.

Williams Creek is a small sub-catchment of the Yass River covering an area of about 200 ha. It is located between Gundaroo and Murrumbateman. The catchment geology is of Ordovician age consisting of siliceous slates which traverse the area from north to south. Elevations range from 400 to 640 m and the mean annual rainfall is approximately 640 mm. Sheep and cattle grazing are the dominant land uses. This catchment was also studied by Wagner (1986) for changes over time in the expressions of land salinisation.

Wattle retreat is adjacent to the regional divide between the Lachlan and Murrumbidgee Rivers and covers an area of 540 ha. The mean annual rainfall is approximately 596 mm. The catchment consists of undulating hilly country with a flat valley bottom. Elevations range from 340 to 400 m. Sheep and dryland cereal crops are the dominant land uses (Lawson 1994). The geology is dominated by igneous feldspar-quartz porphyry.

The Cowra and Applewood sites are small sub-catchments (200–280 ha) of the Waugoola catchment (37000 ha), located in the mid to upper Lachlan catchment. The primary geology is highly fractured volcanics with a minor component of meta sediments. Rainfall is approximately 650 mm. Land use is mixed farming of wheat, sheep, cattle and some viticulture.

Mumbil is a small sub-catchment of the Macquarie River and is located 23 km southeast of Wellington. The catchment is dominated by undulating terrain of moderate relief. Elevations range from 400-500 m Australian Height Datum (Anderson, 1992). The geology is dominated by volcanics and the mean annual rainfall is approximately 600 mm. Cattle, sheep and dryland cereal crops are the dominant land uses.

Box Hill catchment is located in the upper portion of the Gwydir catchment. The area is a sub-catchment of Mount Russel catchment draining west in the Myalls Creek system of the Gwydir River Valley. The catchment covers an area of about 640 ha and is approximately 4 km long and 1.5 to 2 km wide (Lawson, 1990). Elevation varies from 660 m at the outlet to 680 m on the eastern side. The geology is Tertiary basalt, which in turn is underlain by Permian granite and exposed at the lower end of the catchment. The mean annual rainfall at Inverell is 809 mm, with about 25% of the annual rainfall falling during the summer months of December and January (Lytton *et al.* 1994). Land use is mainly cattle grazing. Salinity expression at this site is controlled by structural controls caused by a change in geology near the lower slopes. A saline area is present in the western part of the Box Hill catchment in the flatter zone above the outlet.

Overall, the contributing area of each site is small, with the Box Hill site having the largest contributing area of 640 ha (6.4 km$^2$). Most sites are contained in small sub-catchments with drainage areas in the range of 200 to 300 ha. Typical distances to the catchment divide are 1–1.5 km up to a maximum of approximately 3 km at the Wattle Retreat and Box Hill sites. Average annual rainfall is generally within the 600–700 mm range. The geologies of the sites are mostly Silurian-Devonian metasediments and intrusive volcanics, with the exception of Box Hill, where the geology is Cainozoic basalt. Upland alluvium has also been mapped at many of the sites.

**Figure 17:** Location of the seven sites used for temporal analysis of land salinisation

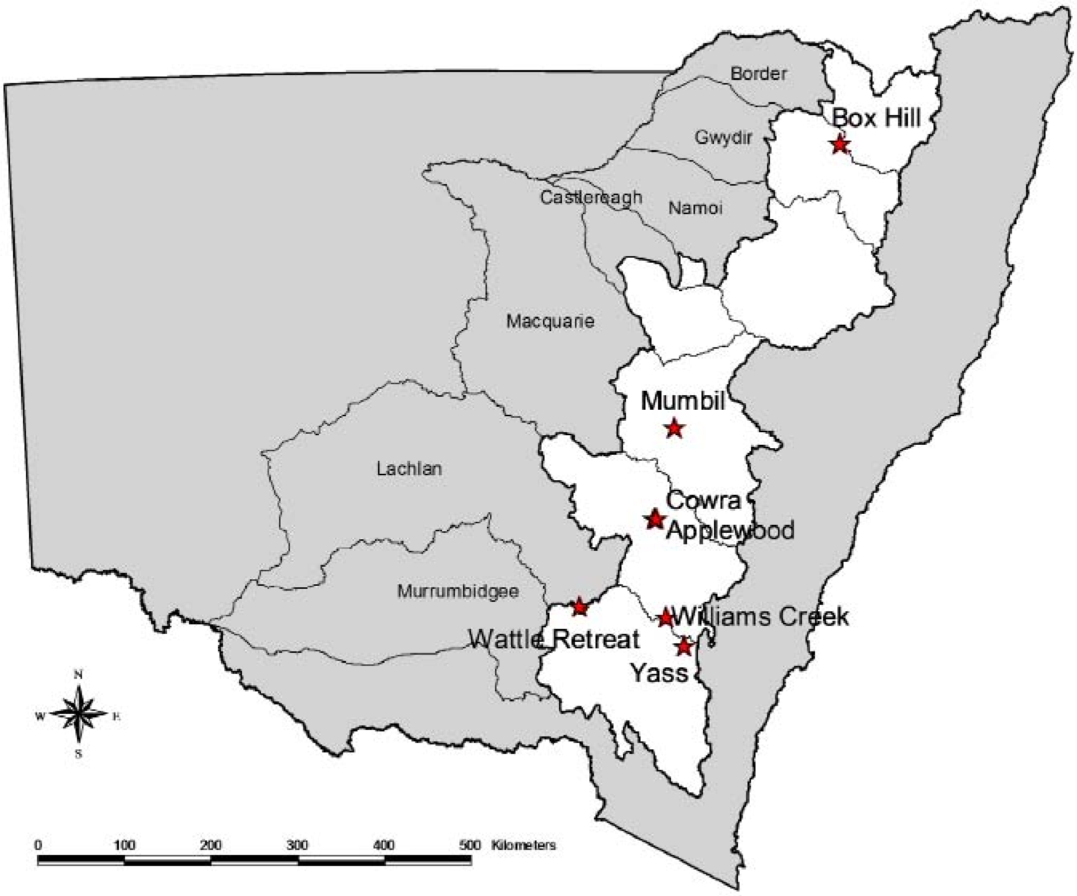


**Table 11:** Site characteristics of the seven sites

| Site | Area (ha) | Basin | Mean annual rainfall (mm) | Geology |
|---|---|---|---|---|
| Begalia | 230 | Murrumbidgee | 690 | Metasediments |
| Williams Creek | 200 | Lachlan | 640 | Metasediments (Silurian volcanics) |
| Wattle Retreat | 540 | Lachlan | 600 | Metasediments (Devonian volcanics) |
| Cowra | 250 | Lachlan | 700 | Metasediments (Silurian-Devonian) |
| Applewood | 250 | Lachlan | 700 | Metasediments (Silurian-Devonian) |
| Mumbil | – | Macquarie | 600 | Metasediments (Silurian-Devonian) |
| Box Hill | 640 | Gwydir | 740 | Basalt |

The analysis of land salinisation trends and extents in Summerell *et al.* (2009) contained three parts. The first part was an analysis of temporal patterns in extent of land salinisation at seven sites using historical aerial photographs. The second part was the development of a methodology to correlate the minimum and maximum extents of land salinisation at each site using indices from topographical analyses. The third part was to apply this methodology to spatially generalise the minimum and maximum extents of land salinisation across all upland areas of the New South Wales Murray-Darling Basin.

For each site, the extent of land salinisation was mapped from geo-rectified aerial photographs taken at different times since 1944. Salt outbreak areas were identified from aerial photos using evidence of scalding and/or tonal variations in colour, which reflect vegetation and moisture differences. The methodology for aerial photograph interpretations was identical to the methods used for the salt outbreak mapping presented in Figure 16.

The number of points in time for which aerial photography was available at a site varied between four and eight. Area of salt outbreak was calculated using GIS software at each point in time to generate a time-series of land salinisation extent. The availability of aerial photography varied across all sites so it was not possible to have identical dates across all sites.

The extents of mapped salt outbreaks over time for each site are shown in Figures 18 to 24. Differences in temporal trends are evident between the southern sites and the central and northern sites. For the central and northern sites (Applewood, Cowra, Mumbil and Box Hill), the area of salt outbreak increased between the 1960s and the late 1990s, before stabilising or decreasing. The southern sites, Wattle Retreat and Williams Creek, exhibited a tendency to fluctuate considerably in extent, while at Begalia, the area of salt outbreak fluctuated but over a narrow range. In absolute terms, the changes at the Begalia, Applewood and Cowra sites were small.

**Figure 18:** Temporal trends in land salinisation at Begalia (Summerell *et al.* 2009)

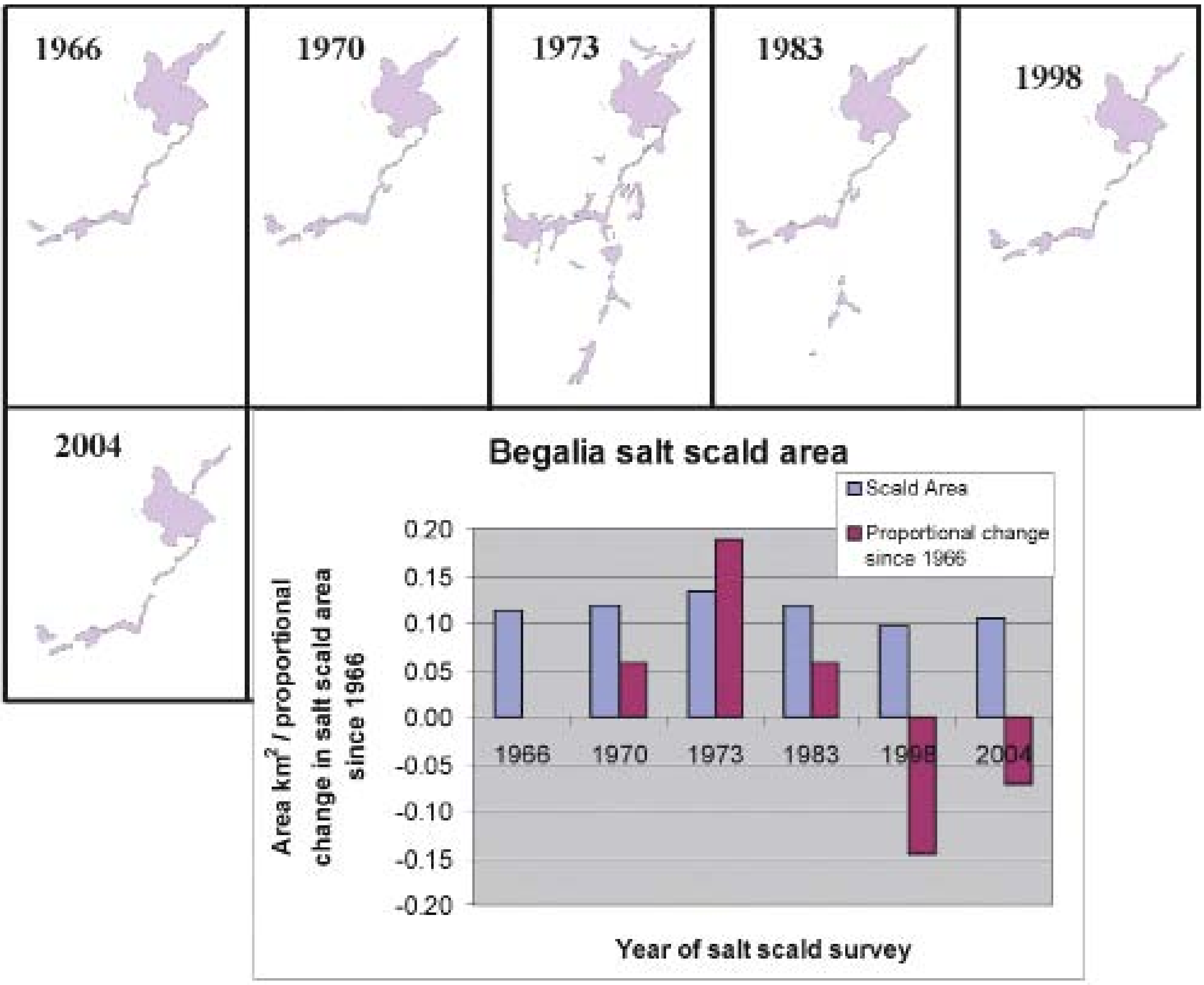
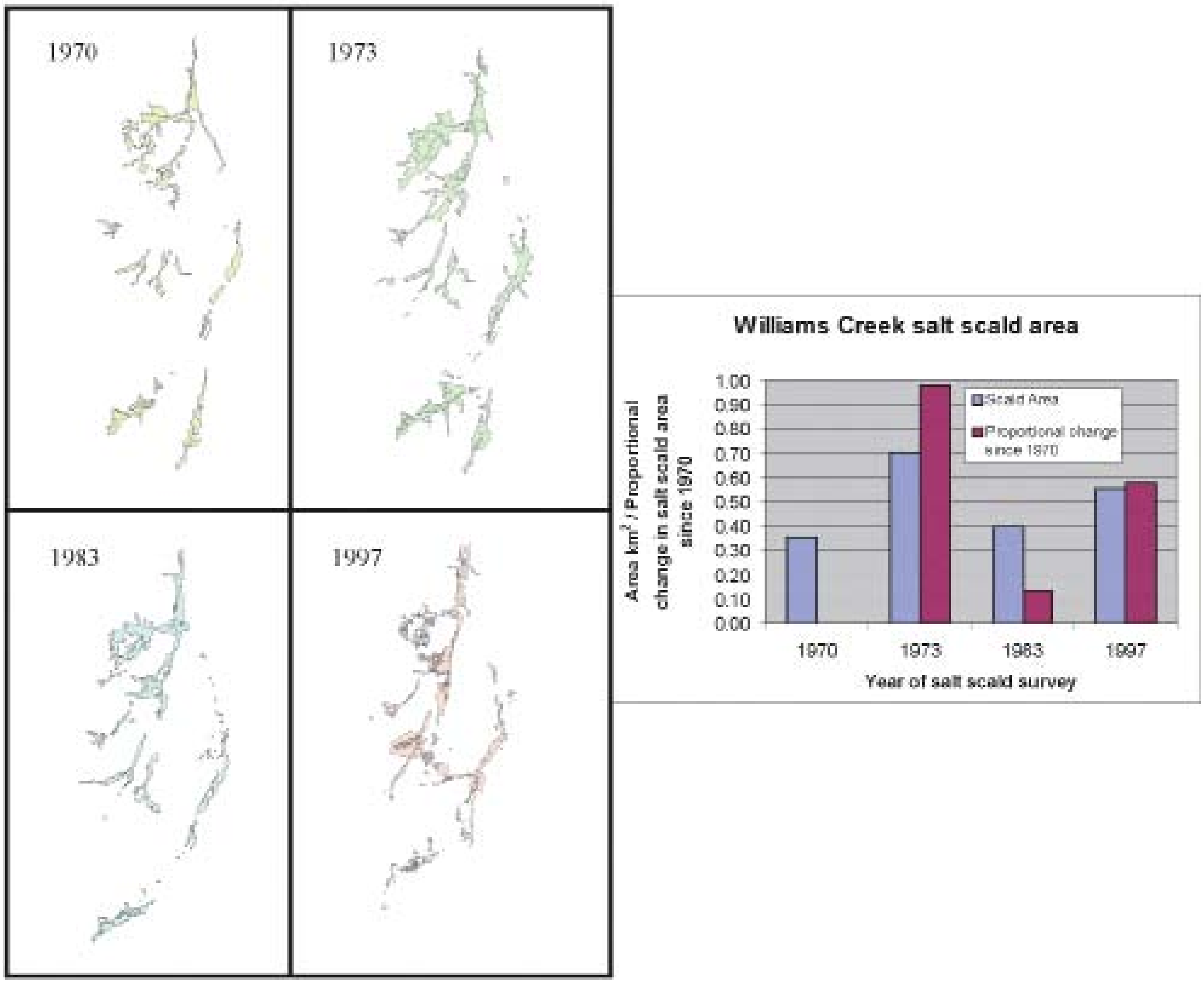


**Figure 19:** Temporal trends in land salinisation at Williams Creek (Summerell *et al.* 2009)

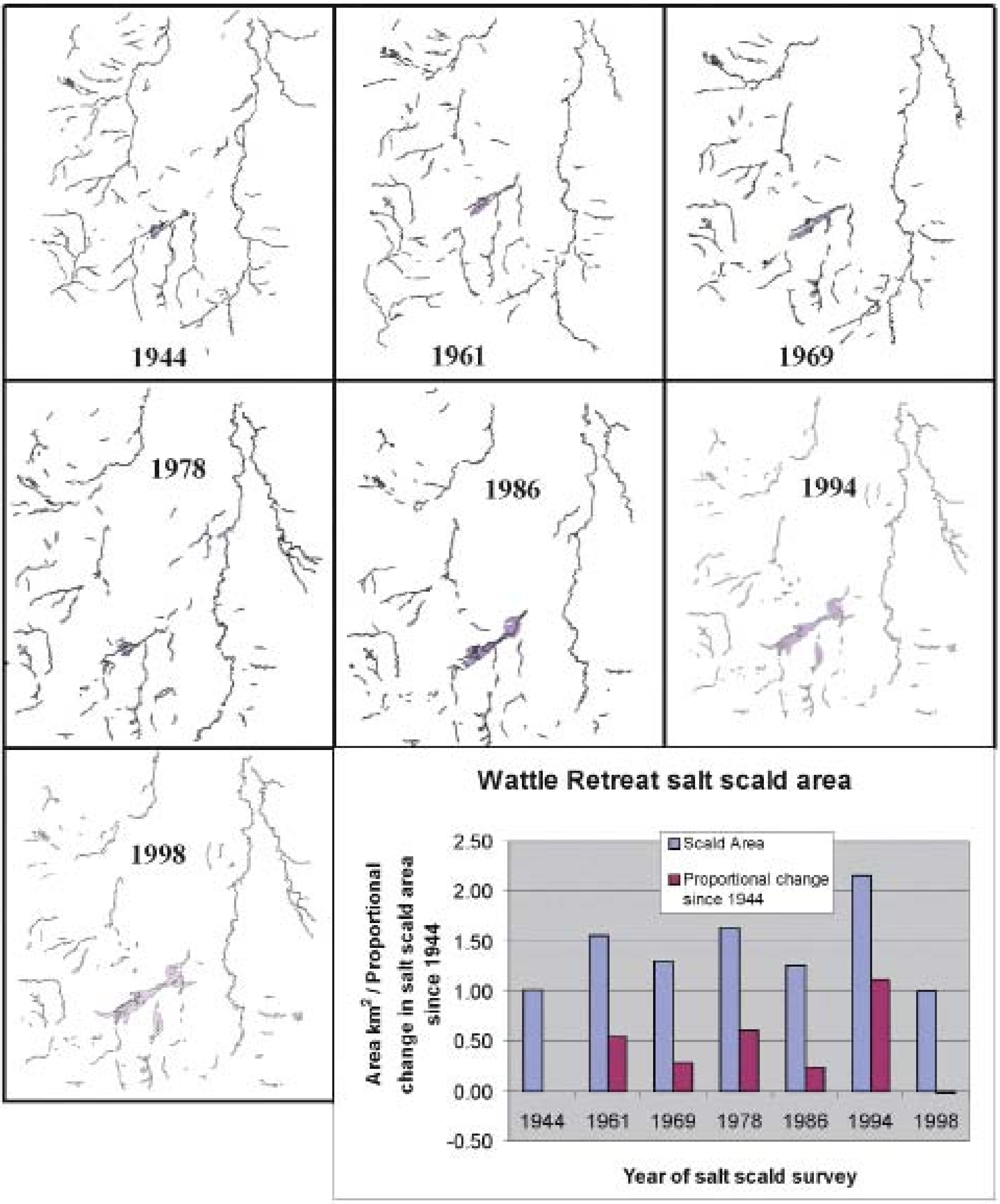


Summerell *et al.* (2009) developed a framework for predicting land salinisation potential based on catchment topography. Salt outbreak areas often develop in low-lying areas, at break-of-slopes or where geophysical constraints force ground water to the surface. In catchments dominated by hill slopes with little alluvial fill, saline outbreaks will fluctuate in size over a narrow range. In catchments with large alluvial areas, saline outbreaks have the potential to expand and contract over larger areas.

The methodologies to limit potential salt outbreak expansion were based on constraints and thresholds derived from topographic analyses. These types of topographic analyses were not possible for earlier Salinity Audits because of computational complexity and the limited availability of Digital Elevation data at suitable resolutions. The analyses described in Summerell *et al.* (2009) are the first attempt to undertake such techniques across the New South Wales Murray-Darling Basin. They provide a basis for future research and application of topographical analyses to improve the prediction of the spatial extents in land salinisation.

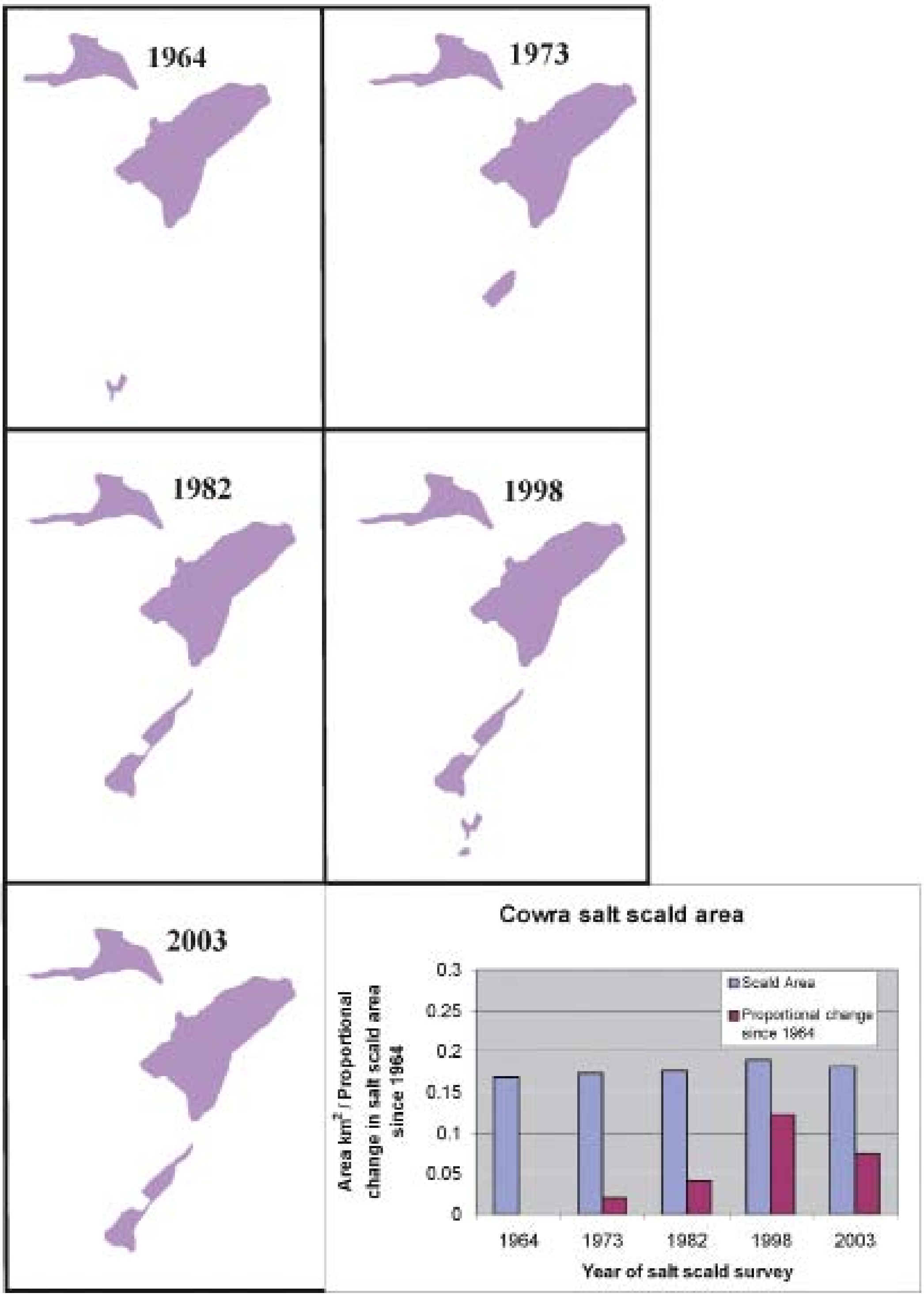
Summerell used the FLAG (Fuzzy Landscape Analysis GIS) UPNESS index to classify catchments by landform dominance (cf. Figure 6). The UPNESS index is derived from digital elevation data and is the accumulation of upslope area at any given point. Unlike contributing area, the UPNESS index can cross topographic boundaries, provided the adjacent uphill areas in the next catchment are monotonically higher. The distribution of the cumulative distribution function (cdf) of UPNESS provides a descriptor of landform dominance within a catchment. The UPNESS value at the inflection point of each catchment's cdf was used to classify the catchment into one of three classes: steep (0 to 0.00016), even (0.000161 to <0.001) or flat (≥0.001) landform features.

**Figure 20:** Temporal trends in land salinisation at Wattle Retreat (Summerell *et al.* 2009)



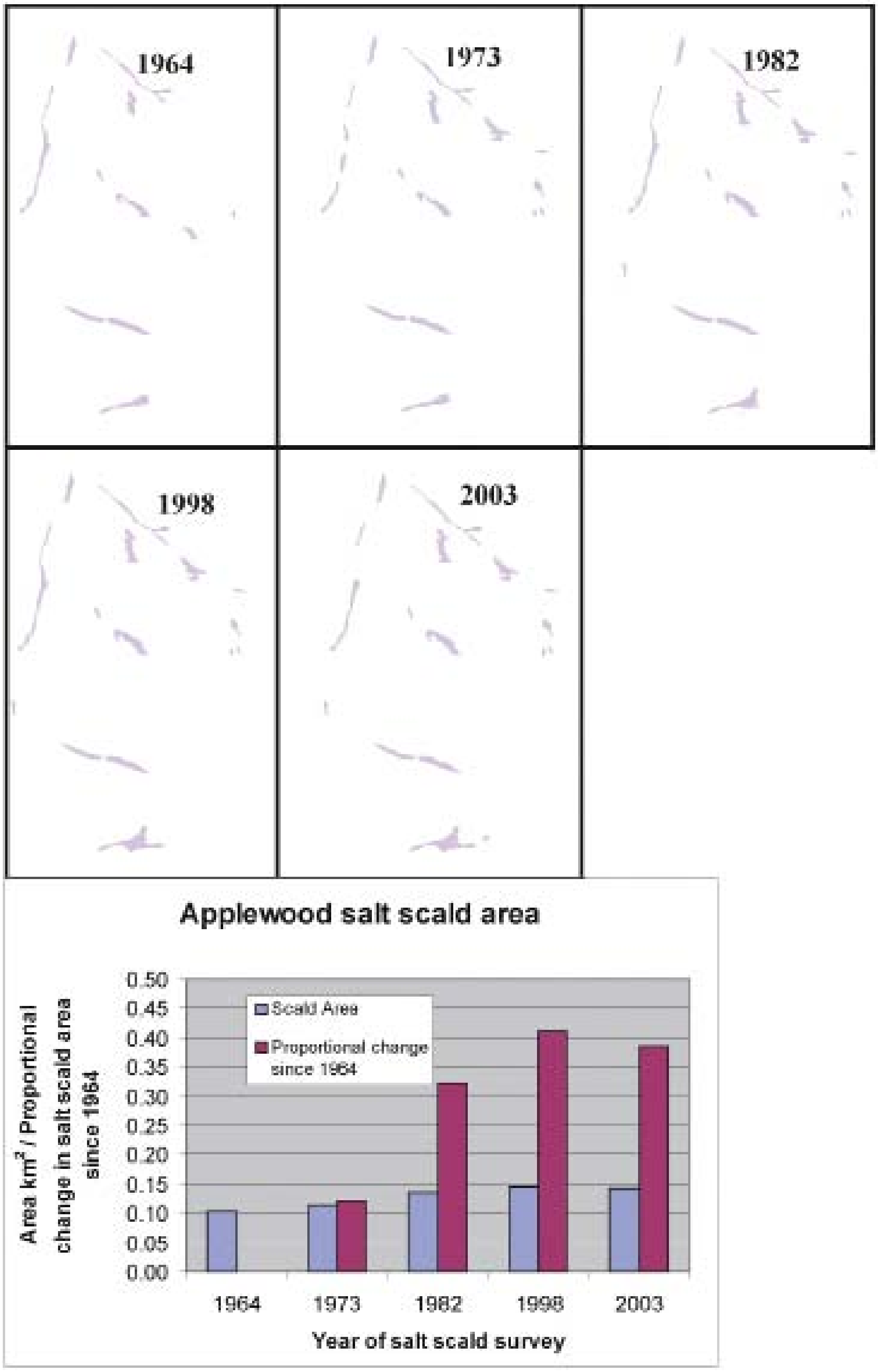
Potential expansion distances were determined by taking multiple measurements from the margins of the minimum extent area to the edge of the maximum extent area for each of the seven sites. Potential expansion distances for each site were then combined with each of the three landform dominance classes. For *steep* landforms, salt outbreak areas were assumed to expand and contract over a radial distance of 150 m. For *even* landforms, it was assumed that salt outbreak areas will expand and contract over a radial distance of 250 m. For *flat* landforms a maximum radial distance of 575 m was determined.

**Figure 21:** Temporal trends in land salinisation at Cowra (Summerell *et al.* 2009)



Current expansion rates were calculated based on the relativities between the 2000 mapping (Figure 16) and the potential minimum and maximum extents. For each site, current land salinisation was expressed as a percentage of potential. This provided a set of scaling factors when coupled to topographic analyses, and enabled the spatial extrapolation of current salt outbreak mapping to their minimum and maximum extents. The minimum and maximum extents of land salinisation were determined by combining 2000 salt outbreak mapping, the 25 m resolution FLAG wetness index, and land form dominance, with current expansion rates. The approach does assume that all areas with similar landforms close to one of the seven study areas are at a similar stage in their 'saline extent cycle'.

**Figure 22:** Temporal trends in land salinisation at Applewood (Summerell *et al.* 2009)



In summary, for the seven sites, the methodology:

- used air photos to determine maximum and minimum extents
- calculated maximum expansion distance from minimum and maximum extents
- correlated the maximum expansion distance to landform dominance of the catchment
- used the proportion of the maximum expansion distance from the existing scald expression to buffer existing salt scalds to set the analysis window for terrain analysis using FLAG wetness
- expanded or contracted the existing salt scalds within the FLAG wetness analysis window based on an area percentage change from the field site observations.

**Figure 23:** Temporal trends in land salinisation at Mumbil (Summerell *et al.* 2009)

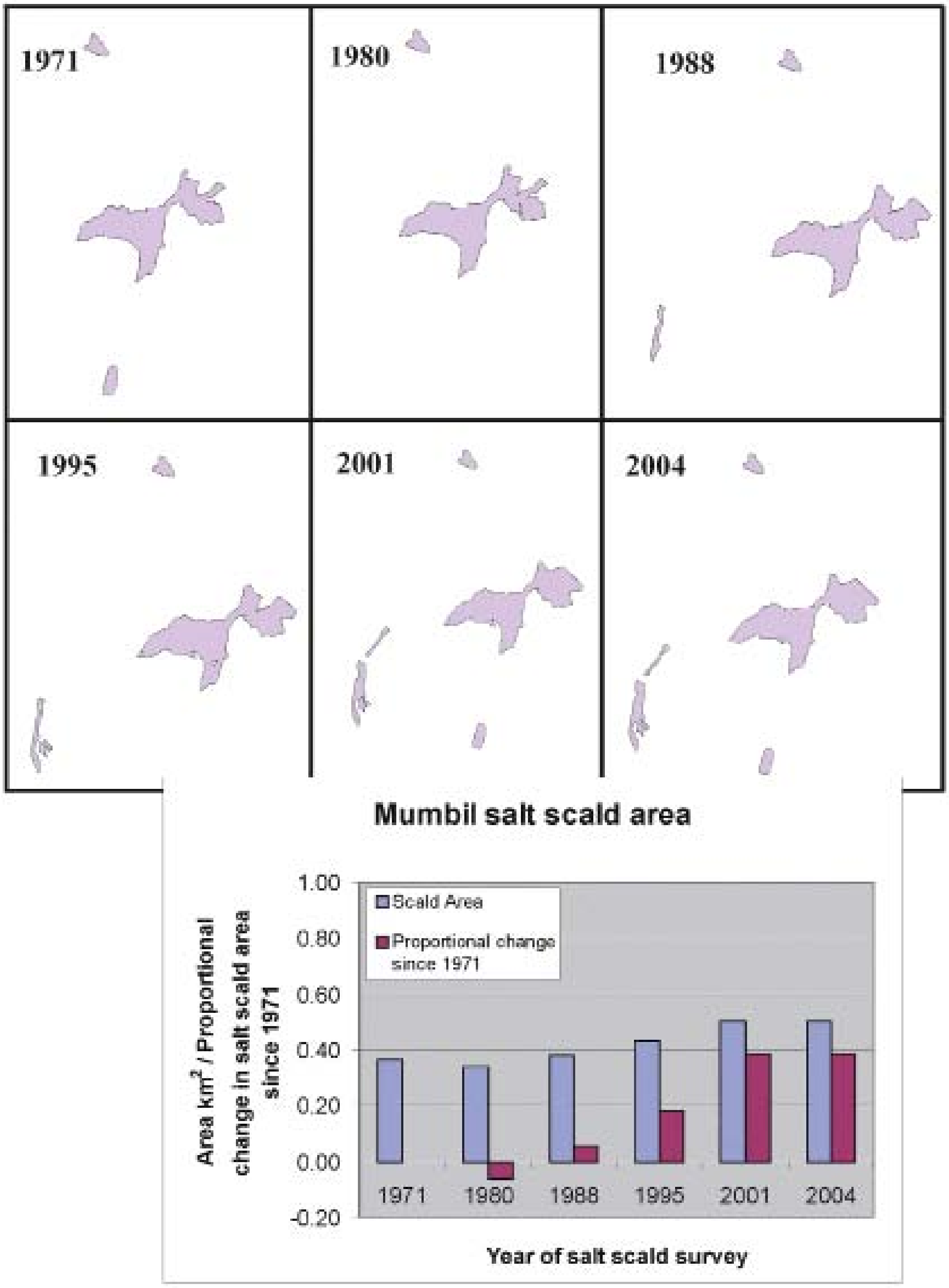
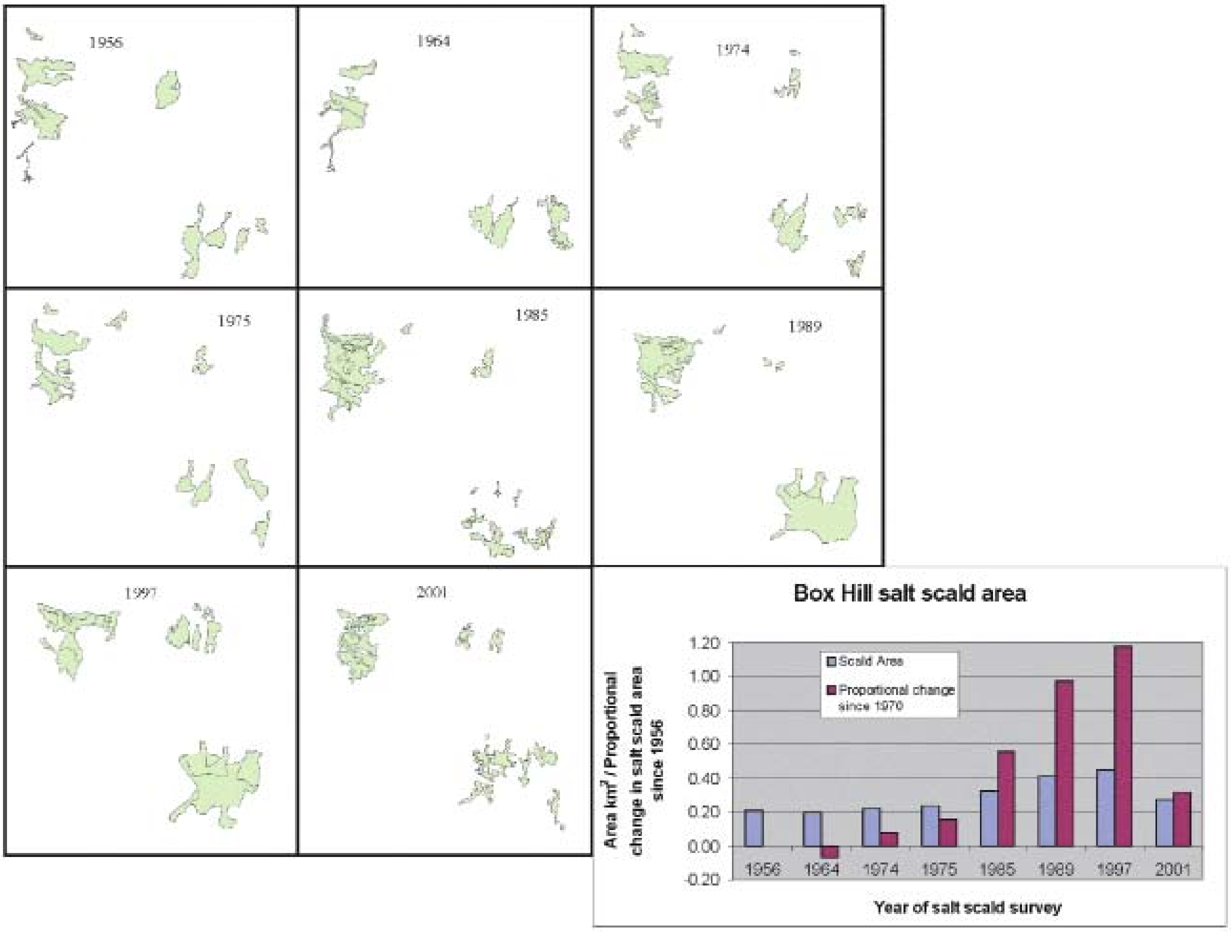


**Figure 24:** Temporal trends in land salinisation at Box Hill (Summerell *et al.* 2009)



To extrapolate across all sub-catchments in the study area, the methodology:

- determined the appropriate buffer distance for all catchments based on landform dominance
- applied buffers to 2000 salt scalds accordingly
- applied the analysis window to FLAG wetness
- expanded or contracted all 2000 salt scald outbreaks within the analysis window and applied the trends observed from the field site observations of catchments within the general area. The aim is to represent through terrain analysis the scald expansions and contractions in about the right place and at about the right size, following the trends from observations.

The estimated minimum and maximum extents in land salinisation are presented in Figures 25 and 26 and summarised in Table 12.

**Figure 25:** Predicted minimum extent of saline outbreaks

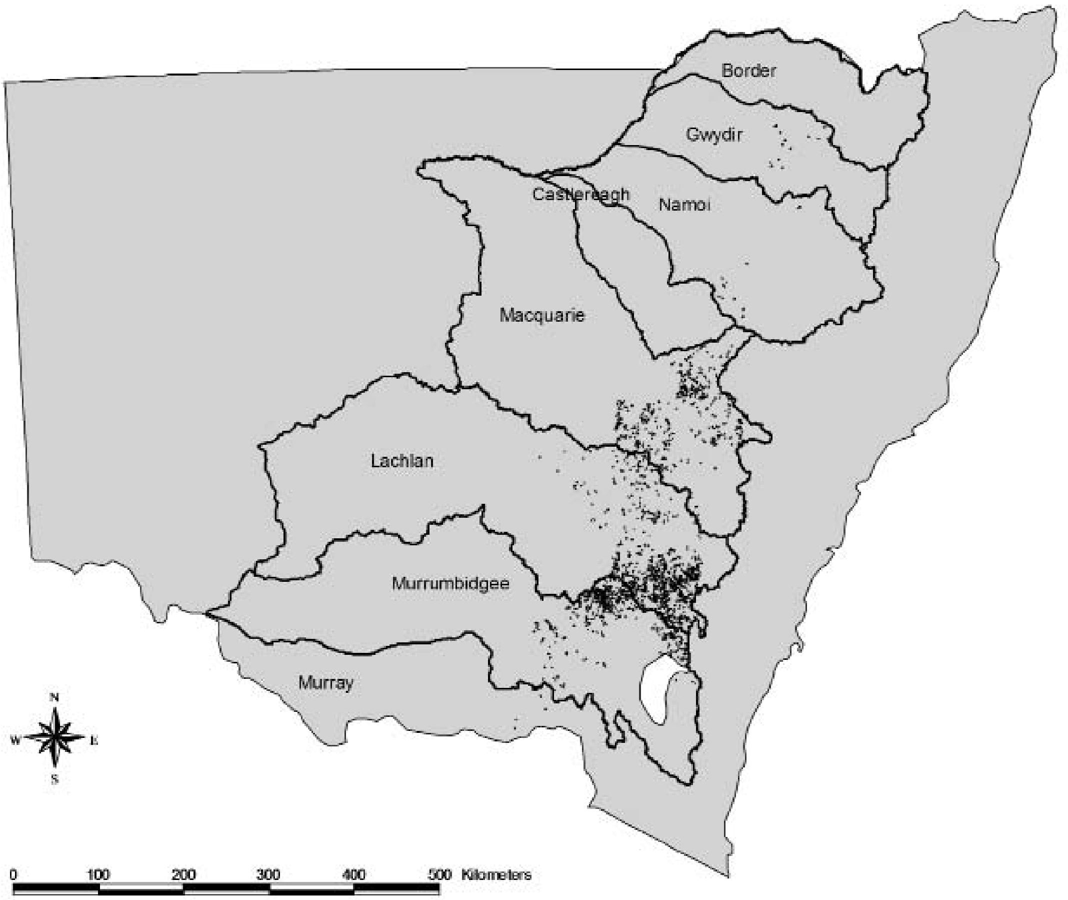


**Figure 26:** Predicted maximum extent of saline outbreaks

**Table 12:** Summary of current and predicted minimum and maximum land salinisation extents for each valley

| | 2000 | Minimum | Maximum |
|---|---|---|---|
| Border Rivers | 158 | 15 | 158 |
| Gwydir | 1 575 | 824 | 1 575 |
| Namoi | 1 326 | 471 | 1 326 |
| Lachlan | 22 153 | 1 326 | 22 689 |
| Macquarie | 18 559 | 10 434 | 18 559 |
| Murrumbidgee | 18 222 | 15 996 | 22 179 |
| Murray | 379 | 379 | 611 |

The results suggest that the current level of land salinisation in the northern and central valleys is close to the maximum observed extent and it is unknown if scalds will continue to expand. For the southern Lachlan and the Murrumbidgee valleys, small increases in land salinisation are possible based on previous historical observations. However, dramatic changes are not expected as scalds are currently smaller then maximum observed extents.

The relatively small changes observed at some sites suggest that the indicators used to map salt outbreak areas do not vary significantly with rainfall. Sites characterised by scalds and saline gullies are expected to show less variation through time. These erosion features represent more permanent features of the landscape. Where mapping is based on indicators of wetness, a more variable salt outbreak response is expected.

Since this analysis was the first attempt to predict spatial extents of land salinisation, the results should be viewed with some caution for the following reasons.

- The methodology only considers salt outbreaks that have currently been mapped and does not allow for the initiation of new saline sites in other areas.
- Only seven sites were used to measure expansion rates of salt scalds. While additional sites would be beneficial to represent a wider range of landforms, topographies, soil types, groundwater flow systems and climatic regimes, it must be recognised that mapping of saline sites from aerial photographs is extremely resource intensive.
- An unfortunate reality is that the timing of historical aerial photography across the State varies substantially. It is impossible to obtain consistent time series of aerial photographs across the whole of New South Wales. Any impacts of using photographs with different dates across sites would be very difficult to quantify. However, aerial photos are also our only method of capturing historical information.
- There can be significant mapping uncertainties, particularly where subtle colour variations are used to delineate the outbreak zone. To minimise this problem, only areas identified as bare soil were used for scald area calculations.
- There is potential for significant digitising error, especially for earlier photography taken at higher altitudes.
- It is difficult to consider the representativeness of the rainfall pattern during the analysis period compared to the longer rainfall record, or whether the observed extents at each site are truly representative of the potential maximum salt outbreak extents for the site. The maximum extent from the sample of measurements at each site is assumed to represent the 'true' maximum, and is adopted as the upper limit for that site.
- Determination of the three buffer zone categories was limited to observations from only seven sites.
- The analyses assume that the expansion potential of salt outbreak sites is limited by topography. Other factors such as geological constrictions are not included, owing to the paucity of appropriate data describing geological structures.

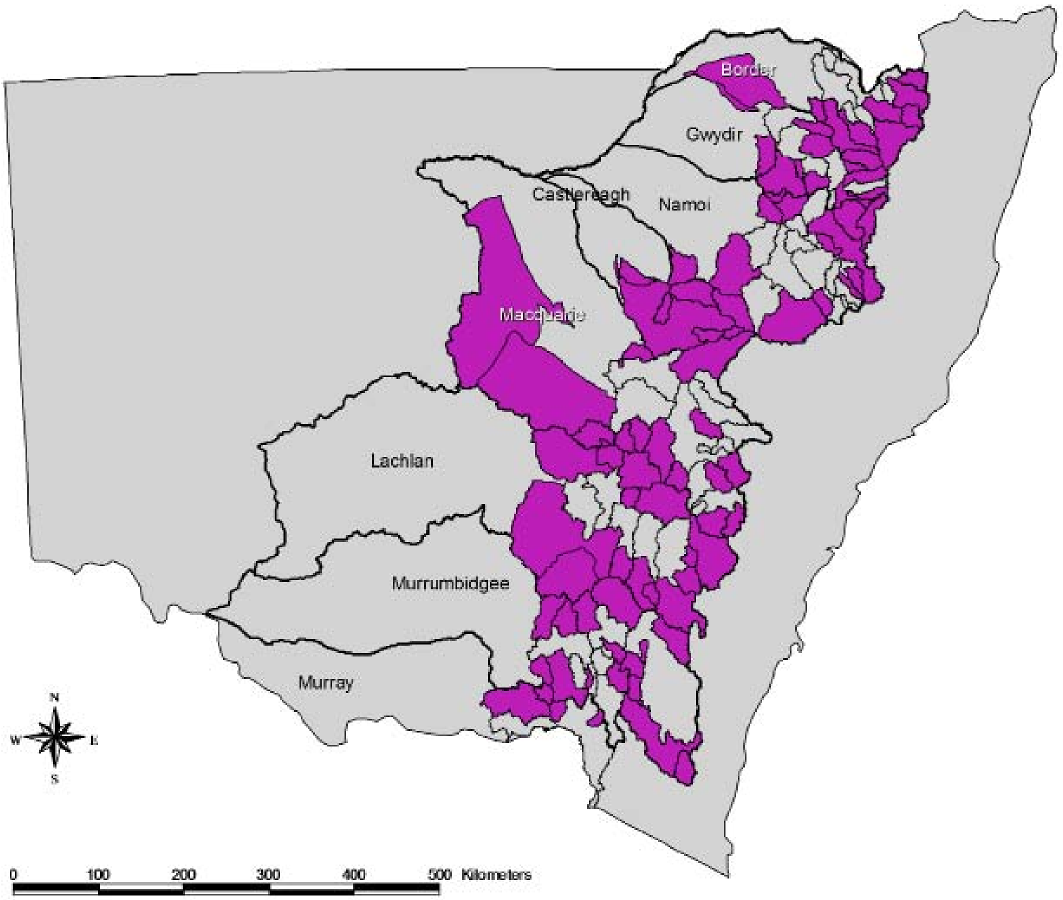
## 3.3 Stream EC trends

This section summarises the stream EC trend study undertaken by Harvey *et al*. (2009), who analysed stream EC data from 90 unregulated and two regulated streams across inland New South Wales (Figure 27). While the catchments cover a range of catchment conditions, most are in upland areas. A limited number of lowland catchments were included, but these are relatively data-poor and more difficult to interpret. Analyses generally apply to the period 1965 to 2005, although there is often a significant gap in the stream EC data between 1992 and 1998 when EC measurements ceased at many gauging stations. Since 1998, the number of locations sampled has increased significantly; these new locations have been included in the trend analyses.

In New South Wales, stream EC has been collected within the Department of Natural Resources and its predecessors. Harvey *et al.* (2009) reviewed data quality and identified potential systematic errors in the data set. Obviously, data collection practices were not completely consistent because data collection procedures and measurement technologies have evolved throughout the period of collection.

Stream EC data used for trend analyses were manually collected samples. Data from the limited number of gauging stations with continually measured stream EC were not used because data had not undergone a rigorous quality assurance process. Data sets used for trend analyses varied in length, with a maximum of 40 years. Between the late 1960s and the early 1990s, measurements usually occurred at 6 to 12 week intervals, with occasional additional measurements during high flow periods. Harvey *et al.* (2009) reported some evidence to suggest stream EC data collected between 1969 and 1975 could be underestimates because of measurement issues. In the past, these underestimates may have contributed to an over-estimation of rising trends.

**Figure 27:** Catchments analysed for EC trends



A preliminary investigation of stream EC data was undertaken to determine whether EC samples were representative across the entire range of flows for each stream. For many catchments, EC samples spanned the range of time-weighted flow conditions. However, there were a number of streams where samples were not representative of the flow-weighted range. For these catchments, the trend analyses are only representative of base flow or low flow conditions. These occur most of the time, and hence may provide good coverage of water quality through time. However, the absence of EC samples from high flow means that these data sets are less useful for estimating salt loads. Figure 28 shows the percentage (located at the high end of the flow range) of the total flow that is not represented by the EC sample. The EC data for the northern catchments tend to be less representative of the range of flow conditions than for the southern catchments.

**Figure 28:** Percentage of total flow not represented by EC samples

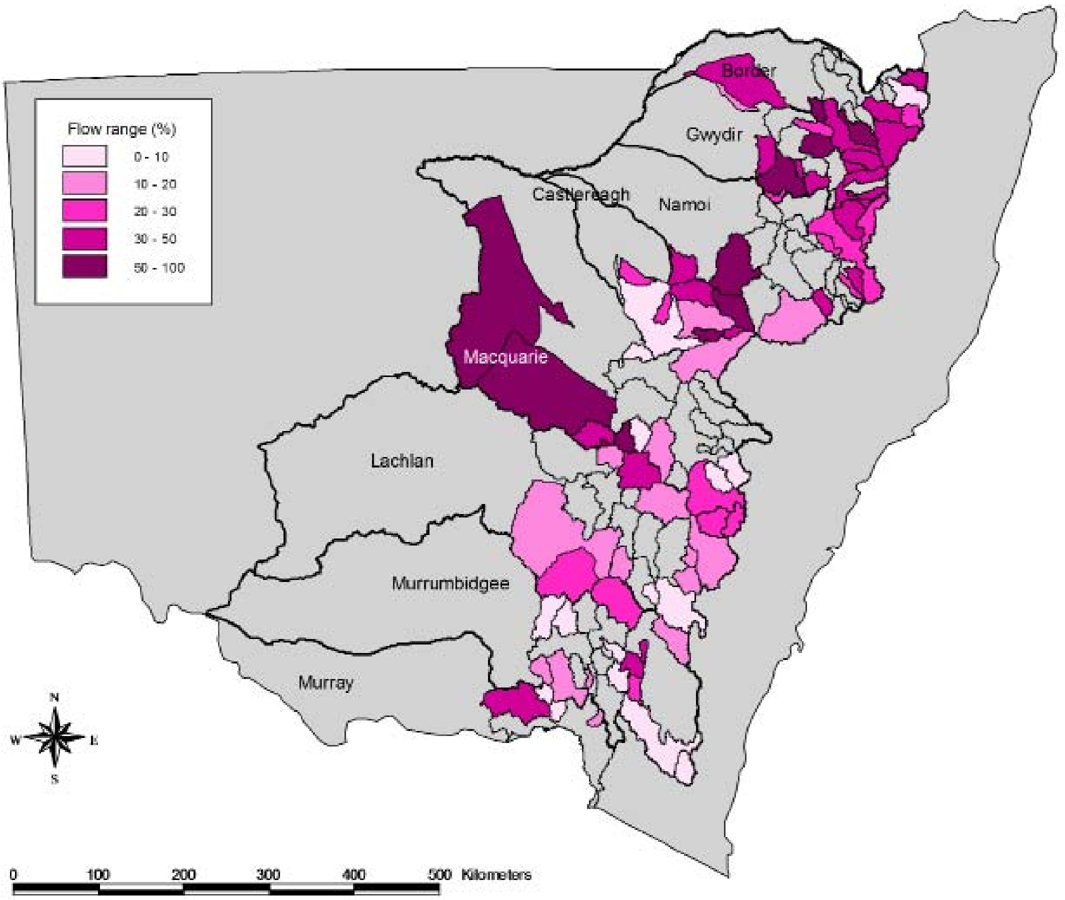
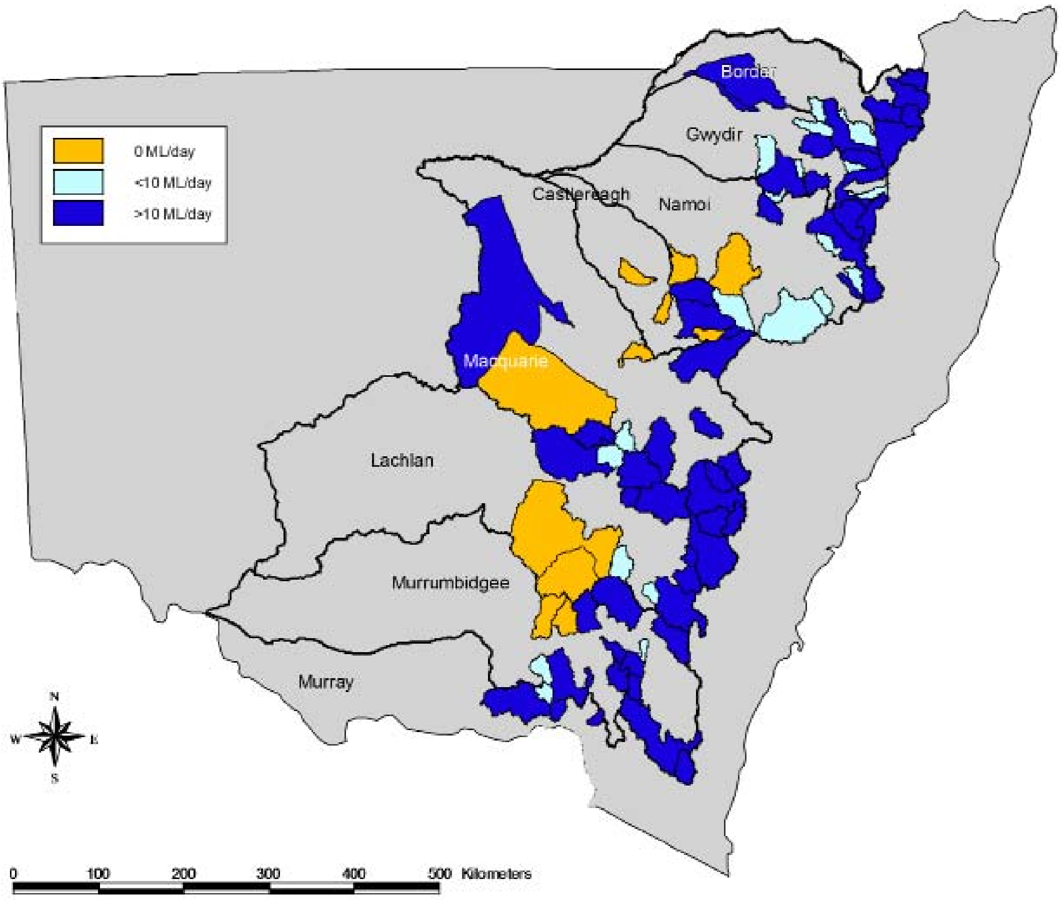


Figure 29 shows that median flow for some catchments is either small or zero. This suggests that ephemeral catchments may be contributing negligible stream salt load in average or dry conditions. Their EC contribution during such conditions might be insignificant on a Basin scale. However, there is no evidence available as to whether ephemeral behaviour is also associated with an increased rate of saline accumulation. Any increased accumulation would not become evident in the stream system until the advent of wetter conditions.

Data from each catchment were statistically analysed to determine trends in stream EC that are independent of season of observation and flow rate. Harvey *et al.* (2009) used the trend detection methods of Morton and Cunningham (Morton, 1997a, 1997b, 2002; Cunningham and Morton, 1983; Morton and Cunningham, 1985). Morton (2002) reviewed statistical methods for the detection and estimation of trends in water quality and concluded that Generalised Additive Models (GAMs) were the preferred statistical method where the data exhibit non-linear behaviour and autocorrelation is present. However, while GAMs are useful for describing a given set of data, trends detected in the analyses cannot be extrapolated into the future unless the trend curvature is statistically non-significant. At best, they provide an indication of the short-term trajectory of stream EC trends.

**Figure 29:** Median flows for study catchments.



Harvey *et al.* (2009) adopted a semi-parametric GAM, which involves fitting smooth curves to the data series with regression terms represented parametrically. The GAMs used by Harvey *et al.* (2009) aim to relate stream EC behaviour to the combined effects of instantaneous flow, seasonality and time.

All trend analyses were based on natural logarithms of the stream EC and flow data. The log-transformation stabilises variance and reduces the skewness, thus making the error distribution more symmetrical. The relationship between $log_eEC$ and $log_eFlow$ was found to be approximately linear in most catchments, which simplified the adjustment of EC for flow.

The regression model accounts for both linear and non-linear EC behaviour. The linear coefficient of the time term describes the linear trend in EC per year over the period of observation. If the trend is markedly non-linear, the linear trend component will not give an adequate summary of the trend and the non-linear component assumes greater significance.

Harvey *et al.* (2009) investigated the relative significance of flow, seasonality and time on stream EC by analysing each data set with progressively more sophisticated models. The three most significant models were:

- Model 3, which examined the relationship between EC and flow, with a seasonality component
- Model 5, which examined the relationship between flow-adjusted EC and time
- Model 7, which examined the relationship between EC, flow, seasonality and time.

There was considerable variability in how each of these models fitted the EC data for each catchment, as can be seen from the coefficients of determination ($r^2$) in Table 13. A number of trend indicators were also produced by Harvey *et al.* (2009), but only two are discussed here:

- statistical linearity (in $\log_e$ space), which quantifies trends in EC and their statistical significance
- cyclicity, which quantifies the extent of the non-linearity of Model 7. The principal indicator adopted was the *Percentage of Cycle,* which measures the real-scale difference between calculated EC at its peak and trough, as a percentage of their mean EC.

A summary of the results from the statistical analyses and an assessment of catchment characteristics are presented for all the study catchments in Table 13. A high coefficient of determination for Model 3 indicates that flow and/or seasonality have a significant influence on stream EC. Catchments in which the salinity behaviour is well explained by flow are found throughout the State, with a greater proportion in the Castlereagh catchment, and along the Great Divide of southern New South Wales (Figure 30). However, the salinity behaviour in other catchments is not well explained by flow. The spatial distribution of these catchments across the State shows no obvious patterns. Seasonality appears to exert an influence on EC in the far northern catchments, although it was rarely statistically significant.

Model 5 was used to determine whether the flow-adjusted EC data exhibited any non-linear time trends. In most of the study catchments, salinity behaviour is not well explained by non-linear time (Figure 30). For many catchments the $r^2$ was small, indicating comparatively little dependence on time (Figure 30). However, in the south (Murrumbidgee and Lachlan basins), a limited number of streams show salinity responses that are influenced by time ($r^2 \geq 0.3$):

- 410025 — Jugiong Ck @ Jugiong
- 410047 — Tarcutta Ck @ Old Borambola
- 410048 — Kyeamba Ck @ Ladysmith
- 410103 — Houligans Ck @ Downside
- 412099 — Manna Ck Nr Lake Cowal
- 412103 — Bland Ck @ Mongarell

Model 7 provided the best fit to the EC data, as evidenced by the coefficients of determination in Table 13. However, relying on $r^2$ values alone can be misleading as the sole indicator of stream EC behaviour. Harvey *et al.* (2009) defined an $r^2$ of 0.65 or greater as a successful model fit. Twenty-five catchments fall within this category, with a further eight catchments classified as marginal ($0.6 \leq r^2 < 0.65$). Figure 30 shows the spatial pattern of catchments, classified by the performance of Model 7. This model was a better descriptor of EC behaviour in the south than in the north, and for most northern catchments offered little improvement in performance over Model 3.

In 14 of the catchments, stream EC behaviour is not well explained by flow, time or seasonal factors. In another 30 catchments, these factors only partially describe the observed salinity behaviours. The failure of the different models to describe EC behaviour suggests processes other than the ones represented in the models.

Harvey *et al.* (2009) based their assessment of stream EC trend at each catchment on a number of factors, but focussed on the linear trend calculation, and the standard error associated with that calculation (Table 13). Also taken into account was the cyclicity of the GAM curve, with consideration of whether the site had gone through a full cycle and the period of record. It was noted that the smaller eastern catchments were on a much shorter cycle, and likely to fluctuate between positive and negative trends over a relatively small number of years. Rather than separate the catchments into rising and falling trends, it was decided to divide them into three categories (Figure 31). The equilibrium category included sites with no trend or a falling trend. The rising trend catchments are subdivided into statistically significant or insignificant. In the north, only the rising catchments have been highlighted (pink in Figure 32).

In the southern half of the State, rising trends are widespread and are occurring in all but the steep areas. In the north, rising trend catchments are less frequent and more scattered. Figure 31 indicates areas where stream salinity could continue to worsen in the future. For some sites, the rising trends have been quite dramatic for the period of record, for example in Jugiong Creek, Houligans Creek, Little River and Billabong Creek at Walbundrie. For some parts of the State, the last 5 to10 years have provided some abatement to the previously steady rising trends, and the Murray and Murrumbidgee valleys are examples of this. For other parts of the State, such as the Macquarie and perhaps the Castlereagh, the last 10 years have produced sharp rises in the GAM curves. The equilibrium catchments are mainly located in higher rainfall areas, but it appears that catchment slope is the best descriptor for stream EC behaviour (Figure 33).

**Figure 30:** Spatial pattern of model performance ($R^2$). Top left – Model 3 (flow and seasonality); Top right – Model 5 (time); Bottom – Model 7 (the full GAM). (Harvey *et al.* 2009)

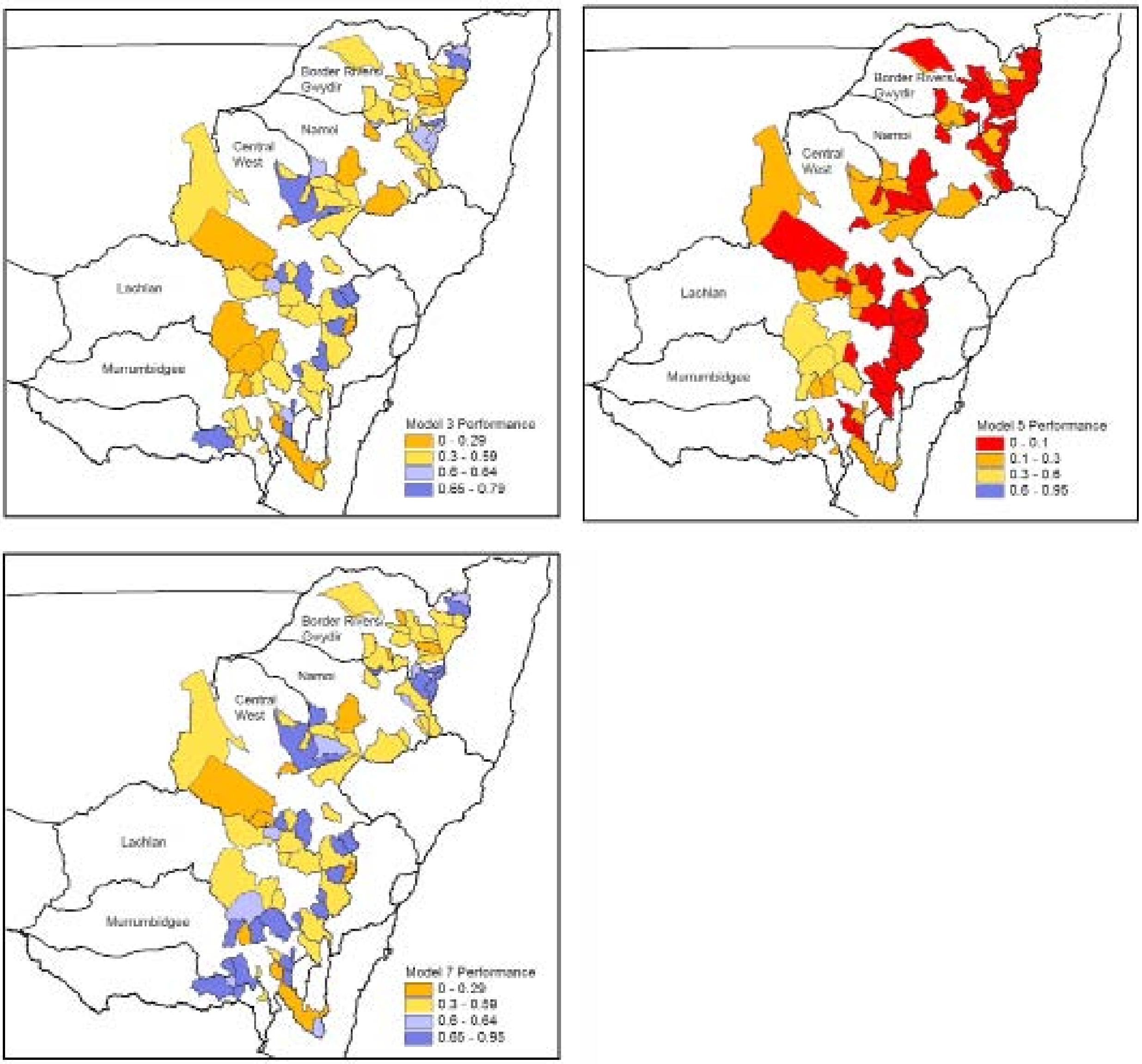


**Table 13:** Trend, catchment characteristics and model performance indicators for each catchment (Harvey *et al.* 2009)

| | Station name | Mean annual rainfall (mm) | Elevation at gauge (m) | Average slope catchment | Linear coefficient | Std error of linear coefficient | P (slope) = 0 (stat. signif.) | Cycle ratio | % of cycle | Recovery factor | Mean EC | Area (km2) | Upness midpoint | Hypsometric integral | Percentage forested | Model 3 R^2 | Model 5 R^2 | Model 7 R^2 | Flow %ile highest flow |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Snowy Sub-group** | | | | | | | | | | | | | | | | | | |
| 401009 | Maragle Ck at Maragle | 1012 | 377 | 9.1 | 0.0007 | 0.0019 | Nil | 1.08 | 37.0 | 0.96 | 108 | 216 | 0.00264 | 0.470 | 65.5 | 0.45 | 0.21 | 0.56 | 12 |
| 401013 | Jingellic Ck at Jingellic | 920 | 219 | 10.4 | -0.0007 | 0.0009 | Nil | 1.03 | 12.9 | 0.98 | 114 | 394 | 0.00139 | 0.385 | 62.6 | 0.59 | 0.14 | 0.65 | 8 |
| 410038 | Adjungbilly Ck at Darbalara | 1135 | 242 | 10.5 | -0.0015 | 0.0026 | Nil | 1.04 | 21.3 | 1.11 | 160 | 386 | 0.00212 | 0.475 | 17.0 | 0.46 | 0.04 | 0.49 | 4 |
| 410057 | Goobarragandra R. at Lacmalac | 1214 | 295 | 14.8 | 0.0015 | 0.0020 | Nil | 1.04 | 16.7 | 1.00 | 59 | 665 | 0.00106 | 0.469 | 2.4 | 0.22 | 0.04 | 0.25 | 9 |
| 410061 | Adelong Ck at Batlow Rd. | 1090 | 352 | 9.4 | -0.0008 | 0.0015 | Nil | 1.03 | 16.3 | 1.10 | 125 | 146 | 0.00526 | 0.484 | 36.6 | 0.46 | 0.05 | 0.49 | 25 |
| 410088 | Goodradigbee R. at Brindabella | 1200 | 638 | 15.6 | 0.0007 | 0.0018 | Nil | 1.04 | 17.6 | 1.00 | 100 | 431 | 0.00097 | 0.458 | 3.2 | 0.66 | 0.10 | 0.69 | 2 |
| | **Upper Murrumbidgee** | | | | | | | | | | | | | | | | | | |
| 410024 | Goodradigbee R. at Wee Jasper | 1146 | 381 | 15.4 | -0.0043 | 0.0013 | 0.01 | 1.06 | 25.8 | 1.12 | 86 | 990 | * | * | 11.9 | 0.63 | 0.20 | 0.71 | 16 |
| 410033 | Murrumbidgee R. at Mittagang X'ing | 889 | 732 | 10.8 | -0.0100 | 0.0025 | 0.01 | 1.10 | 37.8 | 1.79 | 76 | 1891 | 0.00063 | 0.401 | 3.8 | 0.08 | 0.14 | 0.22 | * |
| 410050 | Murrumbidgee R. at Billilingra | 759 | 696 | 9.3 | -0.0087 | 0.0019 | 0.01 | 1.08 | 35.1 | 1.29 | 100 | 3745 | * | * | 34.6 | 0.09 | 0.18 | 0.27 | 19 |
| 410062 | Numeralla R. at Numeralla Sch. | 680 | 734 | 8.1 | -0.0074 | 0.0017 | 0.01 | 1.07 | 34.2 | 1.24 | 144 | 675 | 0.00020 | 0.528 | 34.8 | 0.56 | 0.16 | 0.63 | 38 |
| 410107 | Mountain Ck at Mountain Ck | 877 | 366 | 15.2 | 0.0101 | 0.0026 | 0.01 | 1.09 | 43.6 | 0.70 | 164 | 167 | 0.00046 | 0.424 | 73.5 | 0.69 | 0.13 | 0.73 | 32 |
| 420003 | Belar Ck at Warkton | 863 | 472 | 15.0 | -0.0124 | 0.0034 | 0.01 | 1.04 | 21.2 | 1.16 | 176 | 131 | 0.00020 | 0.252 | 33.9 | 0.21 | 0.07 | 0.27 | 5 |
| | **Southern Trending Sub-group** | | | | | | | | | | | | | | | | | | |
| 410025 | Jugiong Ck at Jugiong | 685 | 249 | 7.7 | 0.0195 | 0.0016 | 0.01 | 1.08 | 55.0 | 0.57 | 1184 | 2140 | 0.00015 | 0.399 | 20.9 | 0.52 | 0.42 | 0.74 | 5 |
| 410044 | Muttama Ck at Coolac | 683 | 232 | 7.3 | 0.0112 | 0.0023 | 0.01 | 1.06 | 42.0 | 0.90 | 1294 | 1059 | 0.00035 | 0.343 | 39.7 | 0.59 | 0.18 | 0.68 | 14 |
| 410045 | Billabung Ck at Sunnyside | 622 | 215 | 7.7 | 0.0269 | 0.0133 | 0.10 | 1.09 | 46.3 | 0.62 | 257 | 842 | 0.00193 | 0.219 | 12.5 | 0.13 | 0.12 | 0.29 | 20 |
| 410047 | Tarcutta Ck at Old Borambola | 823 | 191 | 7.6 | 0.0127 | 0.0013 | 0.01 | 1.08 | 41.3 | 0.79 | 254 | 1641 | 0.00016 | 0.277 | 3.6 | 0.42 | 0.39 | 0.65 | 1 |
| 410048 | Kyeamba Ck at Ladysmith | 678 | 195 | 8.3 | 0.0213 | 0.0027 | 0.01 | 1.12 | 70.5 | 0.55 | 836 | 550 | 0.00102 | 0.233 | 3.5 | 0.54 | 0.31 | 0.70 | 1 |
| 410091 | Billabong Ck at Walbundrie | 683 | 167 | 7.4 | 0.0195 | 0.0026 | 0.01 | 1.11 | 65.5 | 0.52 | 1324 | 2657 | 0.00200 | 0.204 | 47.1 | 0.73 | 0.27 | 0.81 | 37 |
| 410097 | Billabong Ck at Aberfeldy | 698 | 268 | 7.4 | 0.0109 | 0.0019 | 0.01 | 1.06 | 37.4 | 0.72 | 507 | 346 | 0.00037 | 0.290 | 90.1 | 0.55 | 0.18 | 0.63 | 23 |
| 410103 | Houligans Ck at Downside | 567 | 192 | 2.7 | 0.1852 | 0.0115 | 0.01 | 1.90 | 195.0 | 0.01 | 4707 | 1144 | 0.00357 | 0.396 | 0.9 | 0.59 | 0.37 | 0.95 | 0 |
| 412099 | Manna Ck near Lake Cowal | 531 | 202 | 3.1 | 0.0223 | 0.0069 | 0.01 | 1.12 | 64.5 | 0.67 | 451 | 10857 | 0.00432 | 0.154 | 8.4 | 0.29 | 0.38 | 0.57 | 15 |
| 412103 | Bland Ck at Morangarell | 576 | 231 | 4.9 | 0.0871 | 0.0176 | 0.01 | 1.23 | 106.0 | 0.35 | 326 | 3050 | 0.00307 | 0.232 | 7.6 | 0.26 | 0.46 | 0.61 | 23 |
| | **Lachlan Mountains Sub-group** | | | | | | | | | | | | | | | | | | |
| 412028 | Abercrombie R. at Abercrombie | 805 | 420 | 9.8 | -0.0023 | 0.0017 | Nil | 1.01 | 4.0 | 1.08 | 280 | 2625 | 0.00014 | 0.512 | 37.2 | 0.58 | 0.01 | 0.58 | 14 |
| 412050 | Crookwell R. at Narrawa North | 789 | 455 | 6.5 | -0.0008 | 0.0021 | Nil | 1.01 | 5.5 | 1.11 | 418 | 756 | 0.00047 | 0.625 | 10.6 | 0.66 | 0.00 | 0.65 | 12 |
| 412083 | Tuena Ck at Tuena | 820 | 477 | 10.0 | -0.0100 | 0.0027 | Nil | 1.01 | 9.1 | 1.03 | 483 | 320 | 0.00019 | 0.437 | 50.3 | 0.68 | 0.01 | 0.69 | 20 |
| | **Lachlan Rising Sub-group** | | | | | | | | | | | | | | | | | | |
| 410026 | Yass R. at Yass | 685 | 478 | 7.1 | 0.0080 | 0.0036 | 0.05 | 1.04 | 25.6 | 0.83 | 688 | 2171 | 0.00029 | 0.295 | 92.0 | 0.36 | 0.03 | 0.37 | 2 |
| 412009 | Belubula R. at Canowindra | 821 | 293 | 8.1 | 0.0045 | 0.0018 | 0.05 | 1.02 | 13.5 | 0.86 | 643 | 2133 | 0.00023 | 0.418 | 9.9 | 0.48 | 0.08 | 0.52 | 15 |
| 412030 | Mandagery Ck at U/S Eugowra | 698 | 280 | 8.3 | 0.0138 | 0.0032 | 0.01 | 1.04 | 30.1 | 0.61 | 987 | 1689 | 0.00043 | 0.239 | 22.1 | 0.42 | 0.23 | 0.57 | 40 |
| 412043 | Goobang Ck at Darbys Dam | 547 | 201 | 4.0 | 0.0284 | 0.0092 | 0.01 | 1.04 | 21.9 | 0.69 | 364 | 4172 | 0.00304 | 0.113 | 13.2 | 0.43 | 0.14 | 0.51 | * |
| 412055 | Belubula R. at Bangaroo Bridge | 789 | 259 | 7.8 | 0.0056 | 0.0040 | Nil | 1.03 | 18.1 | 0.76 | 624 | 2550 | 0.00018 | 0.379 | 8.9 | 0.40 | 0.12 | 0.48 | * |

*continued/*

**Table 13 (cont.):** Trend, catchment characteristics and model performance indicators for each catchment (Harvey *et al.* 2009)

| | Station name | Mean annual rainfall (mm) | Elevation at gauge (m) | Average slope catchment | Linear coefficient | Std error of linear coefficient | P (slope) = 0 (stat. signif.) | Cycle ratio | % of cycle | Recovery factor | Mean EC | Area (km2) | Upness midpoint | Hypsometric integral | Percentage forested | Model 3 R^2 | Model 5 R^2 | Model 7 R^2 | Flow %ile highest flow |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 412065 | Lachlan R. at Narrawa | 688 | 443 | 4.8 | 0.0044 | 0.0022 | 0.05 | 1.03 | 17.3 | 0.87 | 855 | 2252 | 0.00033 | 0.350 | 11.8 | 0.56 | 0.06 | 0.59 | 8 |
| 412072 | Back Ck at Koorawatha | 609 | 318 | 4.8 | 0.0162 | 0.0079 | 0.05 | 1.02 | 15.9 | 0.74 | 1665 | 800 | 0.00050 | 0.393 | 14.0 | 0.38 | 0.05 | 0.41 | 11 |
| 412086 | Goobang Ck at Parkes | 626 | 287 | 4.7 | -0.0146 | 0.0064 | 0.05 | 1.06 | 32.7 | 1.15 | 573 | 653 | 0.00162 | 0.338 | 36.4 | 0.60 | 0.08 | 0.63 | 19 |
| 412096 | Pudmans Ck at Kennys Rd | 687 | 462 | 4.6 | 0.0028 | 0.0038 | Nil | 1.02 | 10.8 | 0.84 | 1294 | 331 | 0.00033 | 0.429 | 6.5 | 0.71 | 0.00 | 0.71 | 6 |
| | **Upper Macquarie Sub-group** | | | | | | | | | | | | | | | | | | |
| 420004 | Castlereagh R. at Mendooran | 706 | 341 | 9.3 | 0.0018 | 0.0019 | Nil | 1.03 | 16.7 | 0.83 | 676 | 3451 | 0.00078 | 0.241 | 28.7 | 0.59 | 0.10 | 0.63 | 17 |
| 421025 | Macquarie R. at Bruinbun | 785 | 470 | 8.1 | 0.0024 | 0.0015 | Nil | 1.03 | 15.5 | 0.90 | 318 | 4507 | 0.00059 | 0.504 | 26.5 | 0.53 | 0.03 | 0.55 | 22 |
| 421026 | Turon R. at Sofala | 803 | 633 | 12.1 | -0.0025 | 0.0021 | Nil | 1.03 | 19.1 | 0.94 | 378 | 880 | 0.00024 | 0.474 | 51.6 | 0.66 | 0.03 | 0.67 | 6 |
| 421035 | Fish R. at Tarana | 909 | 831 | 8.8 | 0.0012 | 0.0087 | Nil | 1.05 | 21.9 | 0.88 | 124 | 593 | 0.00047 | 0.579 | 41.3 | 0.21 | 0.00 | 0.21 | 21 |
| 421056 | Coolaburragundy Ck at Coolah | 684 | 538 | 10.5 | 0.0005 | 0.0025 | Nil | 1.01 | 8.7 | 0.95 | 834 | 212 | 0.00024 | 0.384 | 9.1 | 0.32 | 0.04 | 0.34 | 39 |
| 421072 | Winburndale Rivlt at Howards Bdge | 778 | 543 | 11.1 | 0.0119 | 0.0101 | Nil | 1.04 | 23.0 | * | 297 | 720 | 0.00041 | 0.446 | 38.1 | 0.67 | 0.20 | 0.73 | 2 |
| 421073 | Meroo Ck at Yarrabin 2 | 818 | 398 | 11.8 | -0.0008 | 0.0083 | Nil | 1.00 | 1.9 | 1.02 | 392 | 729 | 0.00006 | 0.505 | 35.2 | 0.59 | 0.00 | 0.57 | * |
| 421101 | Campbells R. U/S Ben Chifley Dam | 830 | 727 | 6.5 | 0.0027 | 0.0025 | Nil | 1.01 | 8.3 | 0.94 | 440 | 918 | 0.00032 | 0.465 | 22.1 | 0.78 | 0.00 | 0.78 | 21 |
| | **Central Macquarie Sub-group** | | | | | | | | | | | | | | | | | | |
| 420012 | Butheroo Ck at Neilrex | 688 | 387 | 5.6 | 0.0035 | 0.0070 | Nil | 1.08 | 62.5 | 0.85 | 4994 | 405 | 0.00191 | 0.325 | 41.3 | 0.79 | 0.15 | 0.82 | 67 |
| 421018 | Bell R. at Newrea | 757 | 312 | 7.9 | 0.0027 | 0.0012 | 0.05 | 1.01 | 9.2 | 0.92 | 651 | 1629 | 0.00075 | 0.282 | 89.6 | 0.65 | 0.09 | 0.68 | 15 |
| 421042 | Talbragar R. at Elong Elong | 679 | 339 | 8.2 | 0.0083 | 0.0031 | 0.01 | 1.08 | 51.0 | 0.73 | 1052 | 2963 | 0.00054 | 0.226 | 20.6 | 0.34 | 0.12 | 0.42 | 16 |
| 421048 | Little R. at Obley | 658 | 408 | 5.4 | 0.0223 | 0.0026 | 0.01 | 1.12 | 66.3 | 0.50 | 609 | 577 | 0.00026 | 0.358 | 28.2 | 0.65 | 0.30 | 0.76 | 99 |
| 421059 | Buckinbar Ck at Yeoval | 653 | 347 | 4.5 | 0.0018 | 0.0022 | Nil | 1.04 | 27.0 | 0.90 | 1392 | 701 | 0.00082 | 0.380 | 3.7 | 0.53 | 0.07 | 0.56 | 3 |
| | **Bogan Sub-group** | | | | | | | | | | | | | | | | | | |
| 420005 | Castlereagh R. at Coonamble | 657 | 177 | 8.8 | -0.0009 | 0.0034 | Nil | 1.04 | 26.2 | 0.92 | 434 | 8302 | * | 0.268 | 27.9 | 0.74 | 0.18 | 0.79 | 0 |
| 420015 | Warrena Ck at Warrana | 550 | 181 | 3.7 | 0.0039 | 0.0076 | Nil | 1.19 | 87.3 | 0.57 | 290 | 621 | * | 0.181 | 93.7 | 0.38 | 0.14 | 0.47 | 30 |
| 421023 | Bogan R. at Gongolgon | * | 123 | * | 0.0033 | 0.0025 | Nil | 1.05 | 30.7 | 0.82 | 347 | 27970 | * | * | | 0.32 | 0.11 | 0.39 | 63 |
| 421039 | Bogan R. at Neurie Plains | * | * | * | 0.0014 | 0.0052 | Nil | 1.04 | 19.8 | 1.01 | 131 | 14760 | * | * | | 0.09 | 0.00 | 0.05 | 74 |
| 421055 | Coolbaggie Ck at Rawsonville | 596 | 260 | 0.9 | 0.0025 | 0.0060 | Nil | 1.13 | 56.7 | 1.05 | 153 | 566 | * | 0.408 | 29.6 | 0.10 | 0.07 | 0.16 | 4 |
| 421076 | Bogan R. at Peak Hill 2 | 581 | 252 | 6.4 | 0.0045 | 0.0071 | Nil | 1.06 | 28.2 | 0.84 | 136 | 1099 | * | 0.146 | 9.9 | 0.14 | 0.11 | 0.23 | 31 |
| 421084 | Burrill Ck at Mickibri | 603 | 306 | 6.2 | 0.0076 | 0.0114 | Nil | 1.08 | 39.4 | * | 209 | 71 | * | 0.182 | 2.2 | 0.32 | 0.01 | 0.34 | 51 |
| | **Warrumbungle Sub-group** | | | | | | | | | | | | | | | | | | |
| 419027 | Mooki R. at Breeza | 721 | 283 | 16.0 | 0.0127 | 0.0023 | 0.01 | 1.08 | 52.7 | 0.70 | 975 | 3587 | 0.00098 | 0.160 | 89.5 | 0.23 | 0.24 | 0.42 | 14 |
| 419072 | Baradine Ck at Kienbri | 725 | 262 | 13.0 | 0.0056 | 0.0049 | Nil | 1.06 | 33.5 | 0.78 | 289 | 982 | 0.00165 | 0.205 | 72.5 | 0.60 | 0.20 | 0.70 | 35 |
| 420010 | Wallumburrawang Ck at Bearbung | 688 | 357 | 9.4 | 0.0076 | 0.0081 | Nil | 1.04 | 26.0 | 0.80 | 491 | 434 | 0.00057 | 0.231 | 21.7 | 0.36 | 0.07 | 0.41 | 28 |
| 420017 | Castlereagh R. at Hidden Valley | 762 | 420 | 11.9 | 0.0095 | 0.0055 | 0.10 | 1.06 | 37.1 | * | 389 | 1147 | 0.00058 | 0.201 | 26.6 | 0.31 | 0.11 | 0.38 | 43 |

| | Station name | Mean annual rainfall (mm) | Elevation at gauge (m) | Average slope catchment | Linear coefficient | Std error of linear coefficient | P (slope) = 0 (stat. signif.) | Cycle ratio | % of cycle | Recovery factor | Mean EC | Area (km2) | Upness midpoint | Hypsometric integral | Percentage forested | Model 3 R^2 | Model 5 R^2 | Model 7 R^2 | Flow %ile highest flow |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Northern Falling Sub-group** | | | | | | | | | | | | | | | | | | |
| 416008 | Beardy R. at Haystack | 796 | 335 | 9.6 | -0.0098 | 0.0021 | 0.01 | 1.09 | 32.3 | 1.13 | 233 | 903 | 0.00057 | 0.534 | 46.4 | 0.37 | 0.22 | 0.51 | 33 |
| 418005 | Copes Ck at Kimberley | 875 | 756 | 5.3 | -0.0066 | 0.0021 | 0.01 | 1.03 | 15.2 | 1.17 | 178 | 235 | 0.00232 | 0.262 | 29.8 | 0.51 | 0.05 | 0.54 | 38 |
| 418014 | Gwydir R. at Yarrowych | 798 | 738 | 5.5 | -0.0044 | 0.0017 | 0.01 | 1.02 | 12.0 | 1.12 | 357 | 827 | 0.00035 | 0.441 | 14.0 | 0.63 | 0.03 | 0.65 | 30 |
| 418025 | Halls Ck at Bingara | 779 | 313 | 11.0 | -0.0045 | 0.0013 | 0.01 | 1.02 | 16.9 | 1.10 | 1039 | 171 | 0.00402 | 0.368 | 23.6 | 0.02 | 0.12 | 0.14 | 44 |
| 418027 | Horton R. at DamSite | 912 | 420 | 13.8 | -0.0183 | 0.0030 | 0.01 | 1.10 | 53.7 | 1.69 | 506 | 207 | 0.00087 | 0.355 | 46.9 | 0.64 | 0.22 | 0.72 | 22 |
| 419005 | Namoi R. at North Cuerindi | 816 | 366 | 9.2 | -0.0116 | 0.0038 | 0.01 | 1.07 | 33.1 | 1.44 | 278 | 2524 | 0.00070 | 0.512 | 23.9 | 0.55 | 0.08 | 0.59 | 22 |
| 419016 | Cockburn R. at Mulla Crossing | 841 | 454 | 12.2 | -0.0100 | 0.0021 | 0.01 | 1.03 | 16.8 | 1.34 | 434 | 893 | 0.00080 | 0.444 | 37.6 | 0.27 | 0.11 | 0.36 | 28 |
| 419029 | Halls Ck at Ukalon | 783 | 393 | 13.4 | -0.0065 | 0.0025 | 0.05 | 1.04 | 25.5 | 1.08 | 669 | 357 | 0.00053 | 0.394 | 39.5 | 0.58 | 0.14 | 0.64 | 25 |
| 416020 | Ottleys Ck at Coolatai | 743 | 346 | 4.1 | 0.0014 | 0.0027 | Nil | 1.03 | 21.8 | 0.89 | 724 | 385 | 0.00060 | 0.462 | 14.0 | 0.22 | 0.04 | 0.25 | 60 |
| 416021 | Frazers Ck at Ashford | 798 | 420 | 5.7 | 0.0081 | 0.0024 | 0.01 | 1.08 | 45.2 | 0.72 | 433 | 821 | 0.00041 | 0.435 | 25.1 | 0.45 | 0.26 | 0.59 | 62 |
| 416039 | Severn R. at Strathbogie | 864 | 723 | 4.8 | 0.0058 | 0.0023 | 0.05 | 1.04 | 20.5 | 0.72 | 298 | 1747 | 0.00039 | 0.223 | 22.2 | 0.29 | 0.07 | 0.34 | 40 |
| 417001 | Moonie R. at Gundablouie | * | 149 | * | 0.0004 | 0.0040 | Nil | 1.06 | 30.2 | 1.05 | 141 | 15810 | * | * | * | 0.03 | 0.06 | 0.08 | 27 |
| 418008 | Gwydir at Bundarra | 814 | 643 | 6.2 | 0.0028 | 0.0012 | 0.05 | 1.02 | 8.8 | 0.93 | 284 | 4048 | 0.00079 | 0.362 | 19.4 | 0.58 | 0.08 | 0.61 | 40 |
| 418021 | Laura Ck at Laura | 819 | 672 | 7.8 | 0.0007 | 0.0020 | Nil | 1.01 | 4.5 | 0.97 | 266 | 344 | 0.00076 | 0.640 | 18.8 | 0.79 | 0.00 | 0.78 | 43 |
| 418023 | Moredun Ck at Bundarra | 880 | 653 | 7.6 | 0.0034 | 0.0053 | Nil | 1.04 | 22.3 | * | 238 | 668 | 0.00086 | 0.449 | 28.0 | 0.48 | 0.05 | 0.50 | 36 |
| 418029 | Gwydir R. at Stoneybatter | 777 | 663 | 5.6 | 0.0009 | 0.0038 | Nil | 1.07 | 38.6 | * | 301 | 1986 | 0.00053 | 0.330 | 17.2 | 0.60 | 0.19 | 0.68 | 31 |
| | **Northern Insignificant Sub-group** | | | | | | | | | | | | | | | | | | |
| 416003 | Tenterfield Ck at Clifton | 858 | 655 | 8.8 | -0.0007 | 0.0015 | Nil | 1.02 | 9.7 | 0.97 | 332 | 557 | 0.00107 | 0.353 | 33.1 | 0.63 | 0.02 | 0.64 | 31 |
| 416010 | Macintyre R. at Wallangra | 800 | 415 | 6.8 | -0.0033 | 0.0023 | Nil | 1.03 | 17.5 | 1.04 | 515 | 2020 | 0.00049 | 0.283 | 17.1 | 0.37 | 0.06 | 0.41 | 48 |
| 416016 | Macintyre R. at Inverell | 861 | 586 | 7.7 | -0.0027 | 0.0029 | Nil | 1.04 | 23.4 | 1.00 | 493 | 754 | 0.00107 | 0.332 | 31.1 | 0.25 | 0.05 | 0.28 | 48 |
| 416023 | Deepwater Ck at Bolivia | 899 | 783 | 9.3 | -0.0007 | 0.0025 | Nil | 1.03 | 15.5 | 0.96 | 159 | 536 | 0.00067 | 0.340 | 34.2 | 0.46 | 0.07 | 0.49 | 30 |
| 416027 | Gil Gil Ck at Weemelah | 579 | 159 | * | 0.0027 | 0.0033 | Nil | 1.03 | 14.7 | 0.90 | 420 | 3627 | * | 0.175 | 4.4 | 0.54 | 0.01 | 0.54 | 47 |
| 416032 | Mole R. at Donaldson | 881 | 370 | 11.0 | -0.0022 | 0.0012 | 0.10 | 1.01 | 6.6 | 1.03 | 204 | 1583 | 0.00056 | 0.455 | 43.0 | 0.69 | 0.05 | 0.70 | 8 |
| 418015 | Horton R. at Killara | 827 | 287 | 12.5 | -0.0010 | 0.0011 | Nil | 1.03 | 19.4 | 1.00 | 622 | 1955 | 0.00099 | 0.249 | 24.9 | 0.48 | 0.21 | 0.59 | 55 |
| 418016 | Warialda Ck at Warialda | 722 | 310 | 3.8 | -0.0008 | 0.0021 | Nil | 1.01 | 6.2 | 0.92 | 833 | 535 | 0.00080 | 0.472 | 14.8 | 0.54 | 0.03 | 0.56 | 27 |
| 418017 | Myall Ck at Molroy | 755 | 293 | 4.5 | -0.0018 | 0.0019 | Nil | 1.04 | 24.7 | 0.98 | 1046 | 871 | 0.00099 | 0.463 | 14.5 | 0.36 | 0.09 | 0.42 | 60 |
| 418018 | Keera Ck at Keera | 781 | 328 | 8.4 | -0.0069 | 0.0060 | Nil | 1.06 | 35.8 | * | 611 | 556 | 0.00050 | 0.482 | 31.2 | 0.31 | 0.09 | 0.37 | 41 |
| 418032 | Tycannah Ck at Horseshoe Lagoon | 715 | 251 | 15.7 | -0.0010 | 0.0023 | Nil | 1.04 | 22.6 | 0.97 | 749 | 882 | 0.00098 | 0.161 | 37.6 | 0.52 | 0.09 | 0.56 | 36 |
| 418052 | Carole Ck near Garah | 556 | 177 | * | -0.0055 | 0.0048 | Nil | 1.05 | 30.6 | 1.05 | 400 | 120 | * | 0.445 | 2.7 | 0.30 | 0.14 | 0.40 | 17 |
| 419032 | Coxs Ck at Boggabri | 676 | 243 | 11.4 | -0.0071 | 0.0059 | Nil | 1.09 | 52.3 | 1.33 | 660 | 3803 | 0.00116 | 0.174 | 20.3 | 0.14 | 0.08 | 0.21 | 74 |
| 419033 | Coxs Ck at Tambar Springs | 703 | 342 | 12.1 | -0.0017 | 0.0022 | Nil | 1.02 | 13.6 | 1.05 | 1092 | 1227 | 0.00062 | 0.212 | 30.4 | 0.48 | 0.03 | 0.49 | 74 |
| 419035 | Goonoo Goonoo Ck at Timbumburi | 792 | 430 | 14.9 | -0.0023 | 0.0037 | Nil | 1.03 | 17.5 | 0.97 | 1040 | 459 | 0.00147 | 0.189 | 5.3 | 0.38 | 0.01 | 0.38 | 40 |
| 419051 | Maules Ck At Avoca | 742 | 260 | 14.0 | -0.0011 | 0.0016 | Nil | 1.04 | 22.2 | 1.10 | 363 | 664 | 0.00032 | 0.269 | 56.2 | 0.29 | 0.07 | 0.35 | * |
| 419053 | Manilla R. at Black Springs | 737 | 460 | 7.0 | -0.0014 | 0.0016 | Nil | 1.03 | 18.4 | 0.94 | 875 | 769 | 0.00043 | 0.313 | 7.9 | 0.58 | 0.10 | 0.63 | 31 |
| 419054 | Swamp Oak Ck at Limbri | 847 | 491 | 13.0 | -0.0048 | 0.0038 | Nil | 1.03 | 19.8 | 0.71 | 519 | 393 | 0.00021 | 0.508 | 37.7 | 0.42 | 0.09 | 0.48 | 39 |

The ‘percentage of cyclicity’ indicator provides a measure of the temporal variability in stream EC in the GAM curve over the period of record. High values indicate a large fluctuation in the stream EC trend, suggesting catchment heterogeneity. Although its derivation is far from robust, Table 14 lists the catchments that have percentage of cycle values greater than 50%. Of these 14 catchments, seven have average stream salinities greater than 800 µS/cm.

**Table 14:** Catchments with percentage of cycle values > 50%

| Gauge | Catchment | % of cycle | Mean EC |
|---|---|---|---|
| 410103 | Houligans Ck @ Downside | 195 | 4 707 |
| 412103 | Bland Ck @ Mongarell | 106 | 326 |
| 420015 | Warrena Ck @ Warrana | 87 | 290 |
| 410048 | Kyeamba Ck @ Ladysmith | 71 | 836 |
| 410091 | Billabong Ck @ Walbundrie | 66 | 1 324 |
| 421048 | Little R. @ Obley | 66 | 609 |
| 412099 | Manna Ck Nr Lake Cowal | 65 | 451 |
| 420012 | Butheroo Ck @ Neilrex | 63 | 4 994 |
| 421055 | Coolbaggie Ck @ Rawsonville | 57 | 153 |
| 410025 | Jugiong Ck @ Jugiong | 55 | 1 184 |
| 418027 | Horton R. @ DamSite | 54 | 506 |
| 419027 | Mooki R. @ Breeza | 53 | 975 |
| 419032 | Coxs Ck @ Boggabri | 52 | 660 |
| 421042 | Talbragar R. @ Elong Elong | 51 | 1 052 |

The 1999 Audit and this Audit used two completely different approaches to generate stream salinity trends. The main difference is that in this audit, emphasis has been placed on the cyclical character of the GAM curves. For many sites, this approach leads to the conclusion that the linear trends may not be as large as first thought. But for sites that have not gone through a full cycle, interpretation is difficult, and assessment defaults to the linear trend calculation.

The 1999 Audit calculated ratios for future salt loads versus the 1998 salt load. Harvey *et al.* 2009) explored the extrapolation of the observed EC linear trends and found that only 20 sites were useable because the remainder had cyclic components that were statistically significant. Comparisons between this study and the 1999 Audit are shown in Table 15. The 4th column is the ratio of the ECs for 2020 to 1999, based on this current Audit. The 5th column is the ratio of salt loads for 2020/1999 from the earlier work. The last column is the table number from which the information was drawn within the 1999 Audit. If the value in column 4 is less than one, the EC trend is falling, but should be assumed as zero. Table 15 highlights the philosophical difference between the two Audits. The current Audit suggests that the steeper catchments are either in equilibrium or their EC is not going to rise at anywhere near the rate that was first considered. What is interesting is the comparison of the flatter slope catchments. The Lachlan Rising Sub-group is a case in point. Several of the sites in Table 13 have short or broken records, but are showing comparable trends with the 1999 Audit. There are also comparable figures between the two Audits for Gil Gil Creek at Weemelah (416027) and Laura Creek at Laura (418021). Sites with low outlet elevations are showing very steep rises when compared with the Audit 1999 predictions, including Billabung Creek at Sunnyside (410045) and Bland Creek at Mongarell (412103).

**Figure 31:** The spatial pattern of rising, falling and no trend catchments, based on linear coefficients in Model 7 and significance of $P < 0.1$ (Harvey *et al.* 2009)

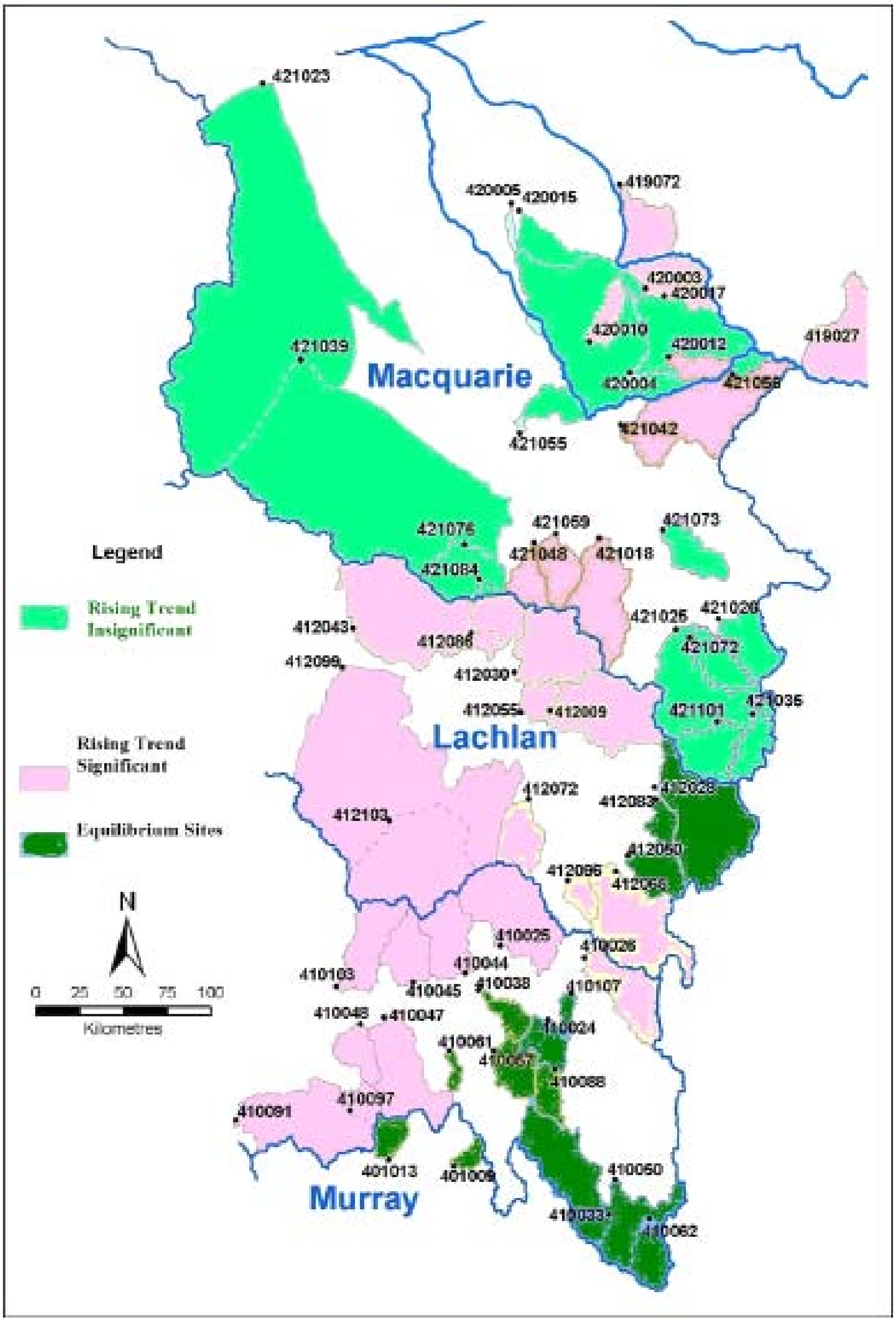


**Figure 32:** The spatial pattern of rising trend catchments in northern NSW (pink). Assessment based on a combination of linear trends and cyclicity (Harvey *et al.* 2009)

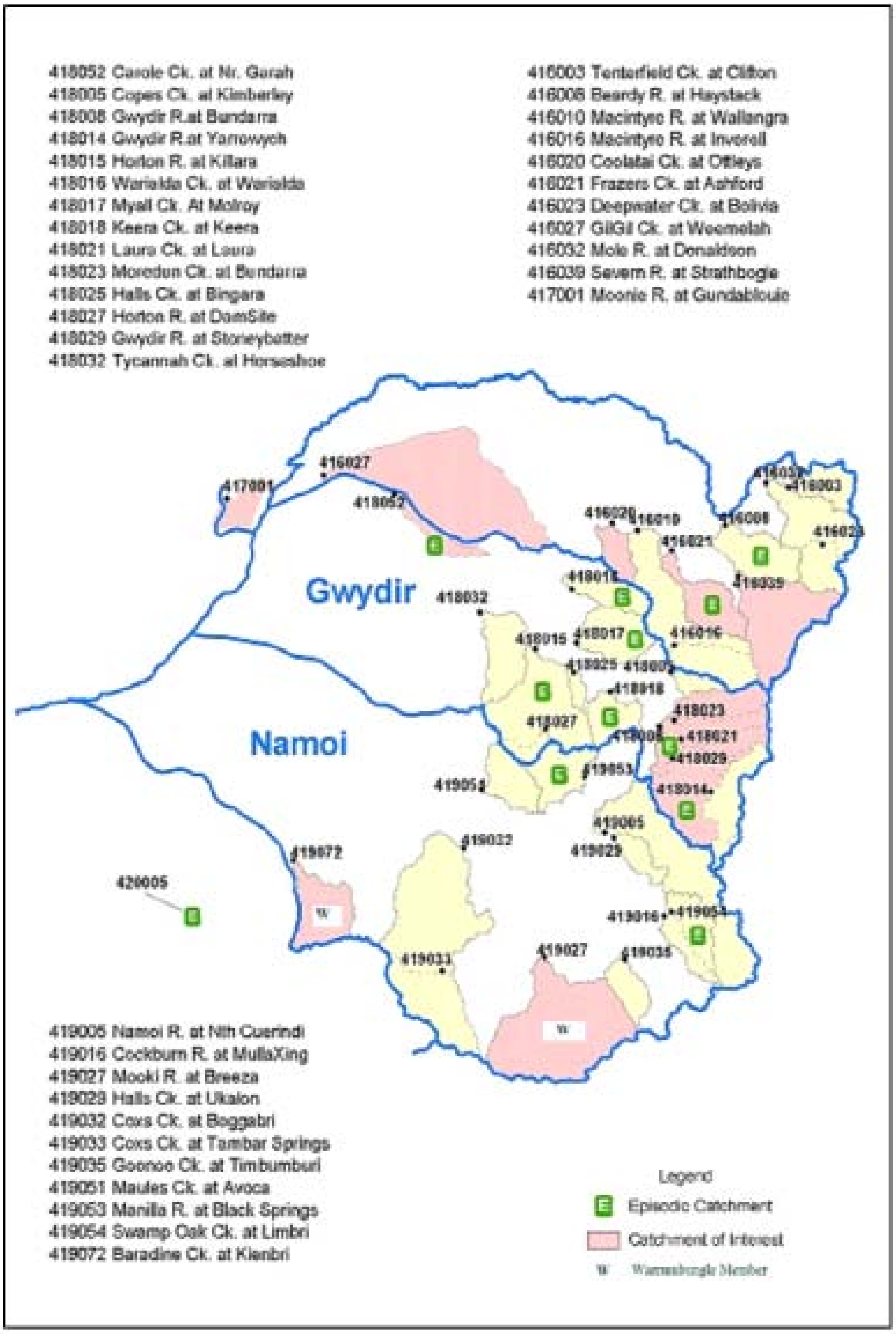
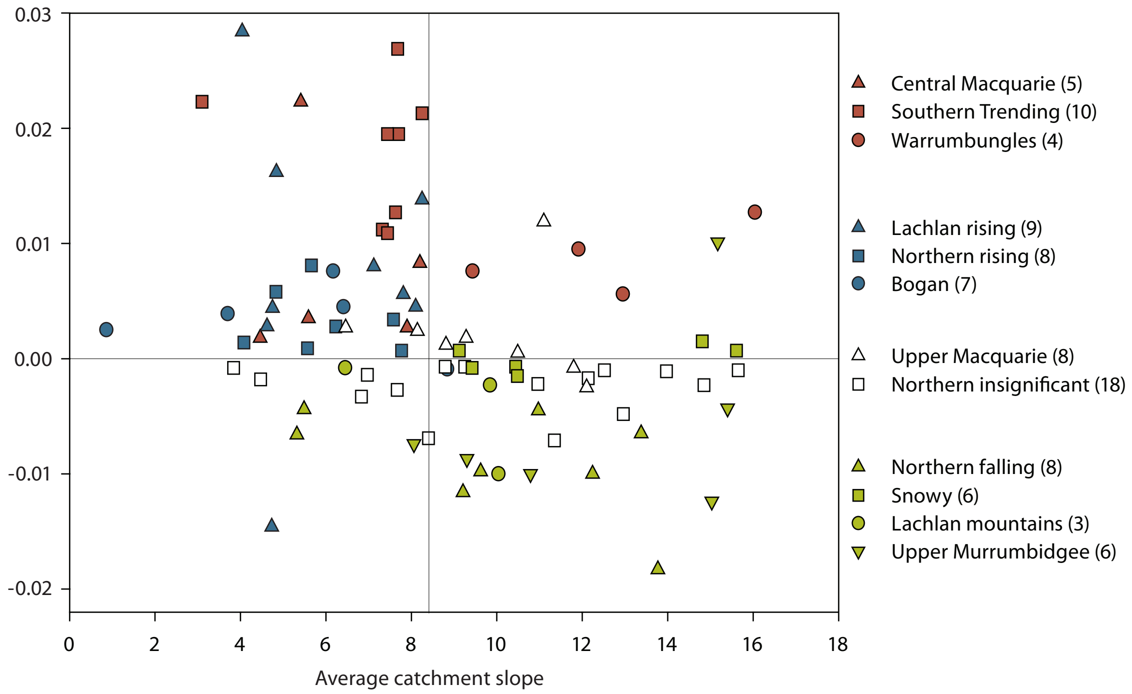


**Table 15:** Comparison between the current and 1999 Audits for 2020/1998 EC ratios (Harvey *et al.* 2009)

| No. | Station name | Code | 2020/1998 Ratio Audit 2006 | 2020/1998 Ratio Audit 2000 | Source – Audit 2000 tables |
|---|---|---|---|---|---|
| 412050 | Crookwell R. at Narrawa North | Lachlan Mountains | 0.98 | 1.28 | Table 6.9 |
| 412083 | Tuena Ck. at Tuena | Lachlan Mountains | 0.80 | 1.30 | Table 6.9 |
| 410026 | Yass River at Yass | Lachlan Rising | 1.19 | 1.35 | Table 6.1 |
| 412043 | Goobang Ck. at Darbys Dam | Lachlan Rising | 1.87 | 1.16 | Table 6.9 |
| 412072 | Back Ck. at Koorawatha | Lachlan Rising | 1.43 | 1.27 | Table 6.9 |
| 412096 | Pudman's Ck. at Kenny Rd. | Lachlan Rising | 1.06 | 1.20 | Table 6.1 |
| 412103 | Bland Ck. at Mongarell | Lachlan Rising | 6.80 | 1.20 | Table 6.1 |
| 418005 | Copes Ck. at Kimberley | Northern Falling | 0.86 | 1.07 | Table 6.6 |
| 418014 | Gwydir R. at Yarrowych | Northern Falling | 0.91 | 2.36 | Table 6.1 |
| 419016 | Cockburn R. at Mulla Xing | Northern Falling | 0.80 | 1.33 | Table 6.7 |
| 416027 | GilGil Ck. at Weemelah | Northern Insignif. | 1.06 | 1.08 | Table 6.3 |
| 419035 | Goonoo Ck. at Timbumburi | Northern Insignif. | 0.95 | 1.38 | Table 6.7 |
| 418021 | Laura Ck. at Laura | Lachlan Rising | 1.02 | 1.07 | Table 6.6 |
| 410045 | Billabung Ck. at Sunnyside | Southern Trending | 1.80 | 1.22 | Table 6.1 |
| 420003 | Belar Ck. at Warkton | Upper Murrumbidgee | 0.76 | 1.13 | Table 6.1 |
| 421035 | Fish R. at Tarana | Upper Macquarie | 1.03 | 2.15 | Table 6.8 |
| 421073 | Merro Ck. at Yarrabin 2 | Upper Macquarie | Negligible | 2.09 | Table 6.8 |
| 421101 | Campbell's R. – Ben Chifley Dam | Upper Macquarie | 1.06 | 2.15 | Table 6.8 |
| 421039 | Bogan R. at Neurie Plains | Bogan | 1.03 | 2.07 | Table 6.1 |
| 421084 | Burrill Ck. at Mickibri | Bogan | 1.18 | 2.07 | Table 6.1 |

**Figure 33:** Catchment groupings relative to linear trend and catchment slope (Harvey *et al.* 2009)



The EC trend for many catchments is cyclical (non-linear). In order to understand the salinity processes (and estimate the trends), the magnitude and length of the cycle needs to be assessed. Consequently it is not a simple matter to finalise the estimates of long term trends. It is not unreasonable to assume that catchments with long EC cycles and which are currently exhibiting low stream EC levels may return to previous high EC levels once they wet up again. On a positive note, the trend results (Table 20) suggest that many problem catchments are not rising at anywhere near the rate indicated by studies undertaken prior to the mid 1990s.

The cyclical nature of EC for some catchments is probably linked to pronounced variations in mean annual rainfall, catchment slope, water chemistry, and/or flat hydraulic gradients.

As with Jolly *et al.* (2001), the 800 mm rainfall isohyet could be used as one indicator. Harvey *et al*. (2009) showed that catchment slope and catchment outlet elevation were also major drivers. Catchments or part catchments that were above the 800mm isohyet, were likely to be in equilibrium. Contrary to Jolly *et al.* (2001), there were indications that several sites in the Border Rivers system and the upper Gwydir tableland had rising EC trends. Results from other sites were similar for both studies and comparison of results at these sites was quite favourable.

Apparent episodic behaviour was observed for twelve sites in northern New South Wales. It was speculated that similar episodic behaviour might be underway in catchments in the south with prolonged cycles.

Most of the steeper catchments across the State were considered to have minimal risk of increased salinity over the next 15 years as the available data indicate they are most probably in dynamic equilibrium. This applies to catchments in the Snowy, Upper Murrumbidgee and Lachlan Mountain sub-groups, and in the northern and eastern parts of the Namoi. However, in the Upper Macquarie sub-group, because the data show recent rising trends, it was decided not to classify catchments in this sub-group as being in dynamic equilibrium.

From the sites analysed (Figure 31), areas with rising stream EC behaviour were identified as being the Southern Trending sub-group, nearly all the study sites in the Lachlan, the Central Macquarie sub-group, parts of the Border Rivers, the Upper Gwydir, and the Warrumbungle Sub-group. The Bogan and lower Castlereagh River also showed rising stream EC trends.

## 3.4 Groundwater trends

This section summarises the groundwater analyses undertaken by Rancic *et al.* (2009) which was undertaken as part of this Salinity Audit. The primary aim was to quantify trends in groundwater levels and compare these trends with trends in climate. These analyses investigated the validity of the theory that rises in groundwater tables, resulting from massive land clearing at the end of the nineteenth century, were great enough and persisted long enough to trigger an increase in discharge of saline water to streams and at the land surface before groundwater levels peaked in the second part of the twentieth century. If the climatic influence on groundwater levels can be isolated from the overall groundwater level behaviour, it should be possible to detect trends caused by other drivers, such as land cover change, and test the validity of the rising groundwater theory.

Under the simple groundwater rising model, salts that have formed or accumulated in the soil-regolith below the rooting depth of the native vegetation can be remobilised and discharged to the draining stream as groundwater levels rise. In some parts of southern Australia, there is strong evidence of these processes for some landscapes. In earlier Audits, this simplified model of salt mobilisation was usually applied because a lack of data and computational capacity precluded application of more complex models based on landscape water movement.

Conservation of mass means that any increase in recharge to an aquifer must be compensated by an increase in groundwater storage and the rate of discharge of ground water from that aquifer. If the rate of discharge is limited by properties of the aquifer that restrict lateral flow, then groundwater levels will rise until the rate of discharge is in equilibrium with the rate of recharge to the aquifer. This new equilibrium represents a balance between adjustments in the size of the discharge area and the rate of discharge from the increased hydraulic head. The discharge area can expand via the development of a larger seepage face within the draining stream and/or by the development of new and/or expansion of existing seepage faces at the land surface. This results in an increase in base flow to the draining stream, which affects the volume and duration of flow, and the stream flow-EC relationship.

Rancic *et al.* (2009) investigated groundwater level changes over the last 100 years for shallow fractured rock aquifers within the metamorphosed fold belt areas which form vast areas of the New South Wales Murray-Darling Basin (Figure 34). The study area incorporates parts of the New England Fold Belt, the Gunnedah Basin and the Lachlan Fold Belt, which span the head waters of the Border Rivers, and of the Gwydir, Namoi, Macquarie, Lachlan, Murrumbidgee and Murray River Systems. Despite their considerable extent, the areas of high recharge are relatively small, and concentrated in areas of higher rainfall and steeper terrain in eastern areas.

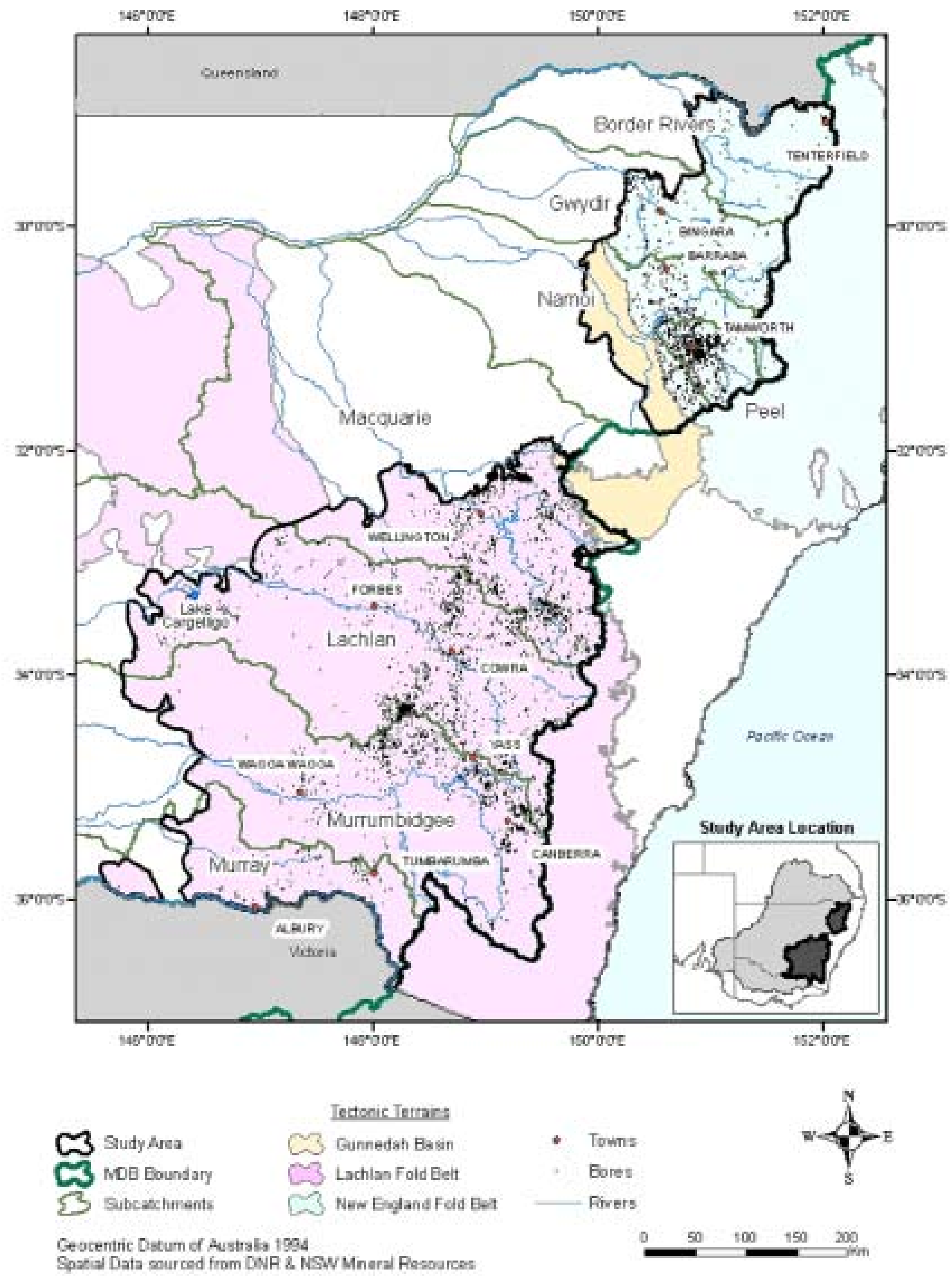
There are few regularly monitored groundwater bores in the upland areas. In general, the fractured rock aquifers are unconfined to semi-confined, have low primary porosity and permeability, but more variable secondary porosity and permeability, which reflects the amount and connectivity of fracturing. Compared with the regional aquifers of the Murray-Darling Basin, the fractured rock aquifers have a low resource potential and are unlikely to have been impacted by groundwater pumping, river regulation, river diversions and irrigated agriculture. Therefore, groundwater trends in fractured rock aquifers are likely to be caused by either climate or land use change in the recharge areas.

Standing water levels (SWL) in bores located in fractured rock aquifers at the time of construction were obtained from bore records held within the NSW Department of Water and Energy Groundwater Data System. The data set was subjected to a comprehensive quality assurance process with the aim of selecting records from shallow fractured rock bores of Palaeozoic to Triassic origin, unaffected by alluvial aquifers. Records from alluvial bores, shallow unconsolidated sediments and Tertiary volcanics were eliminated from the data set. Records from deep fractured rock bores, bores which appeared to be influenced by adjacent alluvial aquifers and bores with insufficient information to determine the aquifer represented by the SWL record were also eliminated.

Longer, southern catchments (Lachlan, Murrumbidgee and Murray) were further subdivided into smaller units. Standing water level time series were derived for each catchment/division geological class combination, using the median value in each year of record. Medians were used to minimise the influence of outlier data points. The disaggregation of the bore data set into groupings based on catchment-division geological class and year meant that the number of records in any one group was often limited, particularly before 1950. Rancic *et al*. (2009) provides greater details on the lengths of record, sparseness of records and missing years for each of the segments.

Monthly and annual rainfall records were obtained from the Bureau of Meteorology for stations which opened before 1900 and had reliable records (<5% missing data). In some areas where insufficient rainfall records were available, the data set was supplemented by the inclusion of sites with shorter periods of record. The rainfall data were grouped by division sub-region and used to derive a single, area-weighted time-series of average annual rainfall for each division sub-region.

**Figure 34:** Areas covered in the groundwater trends analysis (Rancic *et al.* 2009). Black dots are locations of bores used to investigate watertable level trends since the early 20th century



Rainfall data were plotted as residual mass curves (i.e. cumulative sum of deviations from the long-term average). Time series data were fitted with different moving averages to look for evidence of cycles operating at longer time-steps. A 21-year moving average was determined to best reflect wet and dry periods in the residual mass curves.

Bore data were grouped and analysed by sub-region to establish whether there were any geographic influences (e.g. elevation, wetness index) on the relationships between standing water level and rainfall. In addition, any biases in the trend data due to the timing and positioning within the landscape of new bores were explored.

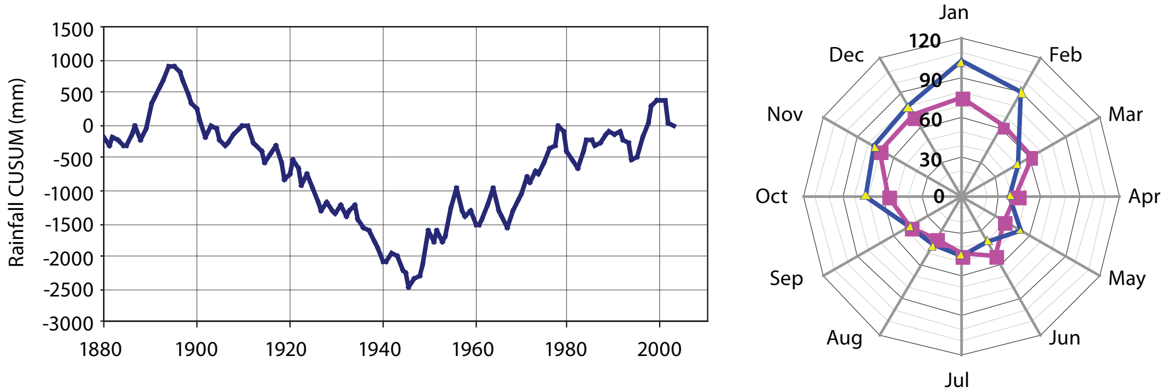
The analyses of rainfall records across the State identified a distinct shift in rainfall regime after 1947 to wetter conditions (Table 16). The residual mass curves for Barraba and Forbes in Figure 35, which are representative of summer-dominant (northern NSW) and uniform (central and southeast NSW) rainfall zones, clearly illustrate the rainfall shift. However, the example from Tumburumba, representing the winter-dominant rainfall zone (southwest NSW), shows a less distinctive change after 1947, and evidence of shorter wet-dry cycles (<20 years) throughout the last 100 years. In general, the post-1947 rainfall shift was most pronounced in the uniform rainfall zone and in areas of higher elevation.

In most cases where a shift in the rainfall regime was detected, it was generally accompanied by a significant increase in rainfall variability. The change from relatively dry conditions prior to 1947 to relatively wet conditions after 1947 is well-established in climate and hydrologic studies in New South Wales.

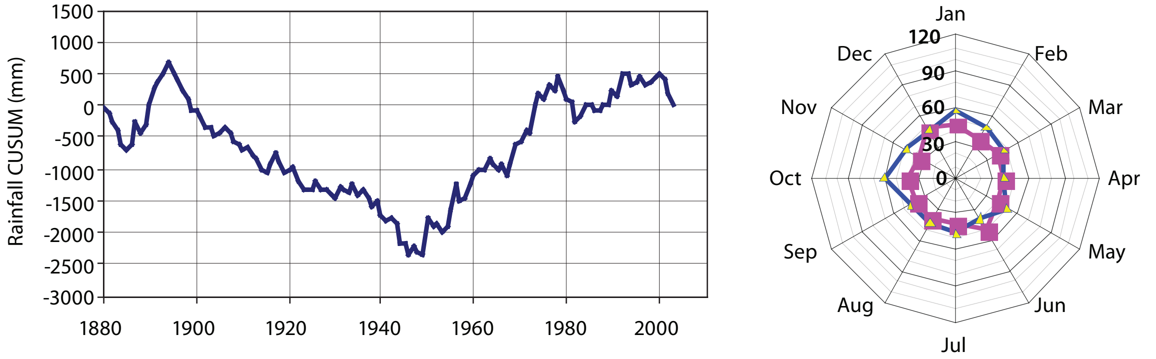
**Table 16:** Results of change-point analysis for rainfall and groundwater time-series data, with associated confidence levels (Rancic *et al.* 2009)

| Catchment/sub-catchment | Rainfall Year of change | Confidence level (%) | Ground water Year of change | Confidence level (%) | Lag (years) |
|---|---|---|---|---|---|
| Border Rivers | 1947 | >99 | Insufficient data | | |
| Gwydir | No significant change | | No significant change | | |
| Namoi | 1947 | 97 | 1949 | > 99 | 2 |
| | | | 1955 | 95 | 8 |
| Peel | 1922 | 98 | | | |
| | 1947 | 98 | 1952 | > 99 | 5 |
| Macquarie | 1947 | 98 | 1953 | > 99 | 6 |
| Lachlan East | 1947 | 99 | 1952 | 92 | 5 |
| Lachlan Mid | 1947 | 98 | No significant change | | |
| Lachlan West | | | 1937 | > 99 | |
| | 1947 | | 1963 | > 99 | 16 |
| | | | 1993 | 97 | |
| Murrumbidgee East | | | | | |
| (North) | 1947 | 96 | 1965 | 93 | |
| (South) | 1947 | >99 | 1997 | > 99 | |
| (Combined) | 1947 | | | | |
| Murrumbidgee West | 1895 | 96 | | | |
| | 1916 | 94 | 1937 | 94 | 21 |
| Murray East | No significant change | | Insufficient data | | |
| Murray West | No significant change | | Insufficient data | | |

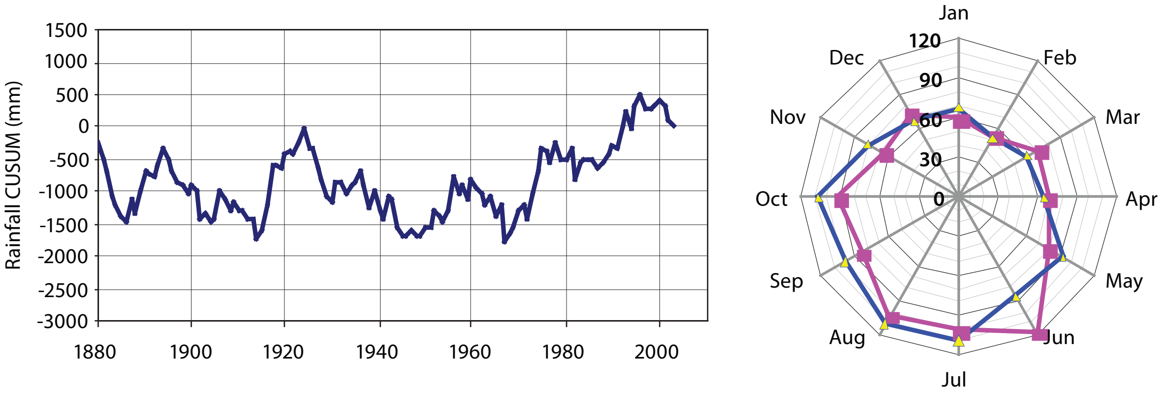
**Figure 35:** Residual mass curves of rainfall, and radar graphs showing pre-1947 (pink line) and post-1947 (blue line) average monthly rainfalls for Barraba, Forbes and Tumbarumba rainfall stations (Rancic *et al.* 2009)



Summer rainfall zone – Barraba (CBM 54003)
(Border Rivers; Gwydir; Namoi; Peel)



Uniform rainfall zone – Forbes (CBM 65016)
(Macquarie; Lachlan; Murrumbidgee east)



Winter rainfall zone – Tumbarumba (CBM 72043)
(Murrumbidgee west; Murray)

In all areas in which the 1947 rainfall shift was detected, with the exception of the Mid Lachlan where early records were limited, groundwater levels showed significant change points, with the groundwater level change-points occurring some years after the rainfall change points (Table 16). The early Lachlan West record shows a rising groundwater trend that finished in 1947 (year of the detected shift), consistent with a rise caused by clearing.

Cross-correlation analyses indicated significant correlations between rainfall and lagged SWL trends. The longest lag times of 16–19 years were found in the Lachlan Mid, Lachlan West and Murrumbidgee West sub-regions. Shorter lag times (between 1 and 10 years) were found in the Namoi, Peel, Macquarie, and Murrumbidgee East sub-regions (Table 17).

**Table 17:** Results of cross-correlation analysis showing the significant correlation values and the corresponding lags (Rancic *et al.* 2009)

| Sub-region | Cross correlation | Lag (years) |
|---|---|---|
| Gwydir | Not significant | |
| Namoi | -0.25<br>-0.24<br>-0.26 | 1<br>7<br>10 |
| Peel | -0.24 | 3 |
| Macquarie | -0.24<br>-0.21<br>-0.21 | 1<br>2<br>7 |
| Lachlan East | Not significant | |
| Lachlan Mid | -0.38 | 19 |
| Lachlan West | -0.23<br>-0.27<br>-0.23 | 1<br>16<br>17 |
| Murrumbidgee East | -0.30<br>-0.26 | 0<br>1 |
| Murrumbidgee West | -0.29 | 19 |

The results show that the abrupt change in rainfall regime after 1947, from a relatively dry phase to a significantly wetter one, was the significant driver of the groundwater level rises, which occurred across much of the State. Groundwater response times were found to be spatially variable, but generally conforming to a pattern of increasing lag time with distance from the higher recharge areas. In the Murray-Darling Basin, the main recharge areas are the higher rainfall and steeper upland catchments near the Great Divide. Lag times are generally less than 10 years, and often less than 3 years in these upland groundwater systems. In catchments more distant from the main recharge areas, adjustments in groundwater levels to long-term changes in rainfall regime appear to be lagged by up to 20 years.

Groundwater rises caused by the rainfall shift were superimposed on the rises caused by clearing, although evidence for this additive impact of increased recharge can only be found in the SWL records from the Lachlan West section. Groundwater rises due to clearing were not captured by other records because of their later start or a fast groundwater system response. However, in general, the results suggest that many groundwater systems are currently in equilibrium, responding only to climatic fluctuations.

The rise in groundwater levels in fractured rock aquifers due to the shift from dry conditions in the first half of the 20th century to wetter conditions after 1947 may have caused salts stored within overlying unconsolidated alluvial aquifers to be mobilised and expressed as saline outbreaks. Unfortunately, aerial photograph records that could be used to support identification of resulting new or enlarged saline outbreaks are generally unavailable prior to 1947.

## 3.5 Salt mobilisation modelling

Salt mobilisation models can be used to forecast future stream salinity, prioritise areas for investment into managing dryland salinity, and quantify the impacts of management interventions on salinity. Models can be used to identify locations where salinity is an issue; they can also indicate when it is likely to become an issue, how bad it is likely to get and the likely impacts of intervention strategies. One such model is 2CSalt, which was developed within the CRC for Catchment Hydrology and combines aspects of existing salt balance modelling within CSIRO and the three State Government Departments (the Victorian Department of Primary Industries, New South Wales Department of Natural Resources and Queensland Department of Natural Resources and Mines). 2CSalt was designed to provide consistent and comparable results across all States in the Murray-Darling Basin, as part of their salinity target reporting obligations to the Murray-Darling Basin Commission.

2CSalt (Stenson *et al*. 2005) is built on concepts from many existing models. The major models are the CSIRO BC2C model (Dawes *et al*. 2004) with hydrology based on the Zhang curves (Zhang *et al*. 2001), Groundwater Flow Systems (Walker *et al*. 2003), the CSIRO MrVBF model (Gallant and Dowling 2003), the Victorian Catchment Analysis Tool or CAT (Beverly *et al.* 2003), the New South Wales CATSALT model (Tuteja *et al.* 2003) and unsaturated zone models such as HowLeaky, Grasp and PERFECT (Littleboy *et al.* 1992, Owens *et al.* 2003).

As part of this Audit, 2CSalt was applied for all sub-catchments across the entire study area (Figure 1). Spatial data used to set up 2Csalt included land use mapping (Figure 4), digital elevation models for topographical analyses (Figure 7); soils mapping, including soil hydraulic properties for each soil type; climatic zones; and groundwater flow systems mapping (Figure 9), including attributes for groundwater salinity, hydraulic conductivity, specific yield, aquifer depth and depth to watertable.

For this preliminary and initial application of 2CSalt across the upland Murray-Darling Basin in NSW, there was no calibration of hydrological parameters. A 'default' set of parameters obtained from the previous evaluation of 2Csalt in NSW was applied to all sub-catchments (Littleboy 2006). A full calibration of the model across all 113 sub-catchments is planned but was beyond the scope of this preliminary rollout. However, model performance was investigated by comparing measured and estimated stream flow and salt loads for all sub-catchments on an average annual basis. The Murray-Darling Basin Commission benchmark period of 1975–2000 was used for all comparisons.

Daily stream flow and salt loads were obtained from the Integrated Quantity-Quality Model (IQQM) for each sub-catchment (cf. Figures 12 and 13). Stream flow data consisted of measured data from stream gauging in-filled with flow from a calibrated Sacramento model for any gaps in the measured data record. Salt load data in IQQM are derived using flow: salinity relationships derived from measured flow and stream EC data.

Figure 36 shows the comparison between estimated and measured stream flow across all sub-catchments on an average annual basis. The model explained approximately 90% of the variability in average annual stream flow, which is considered an excellent result for an uncalibrated model.

Figure 37 shows the comparison between estimated and measured salt loads across all sub-catchments on an average annual basis. The model explained approximately 80% of the variability in average annual salt loads. While poorer than the model predictions for stream flow, this level of prediction is acceptable given that accurate predictions of salt load require accurate predictions of both stream flow and salinity. It is anticipated that these predictions will be significantly enhanced once a full model calibration is undertaken.

**Figure 36:** Measured versus estimated stream flow on an average annual basis (Littleboy 2006)

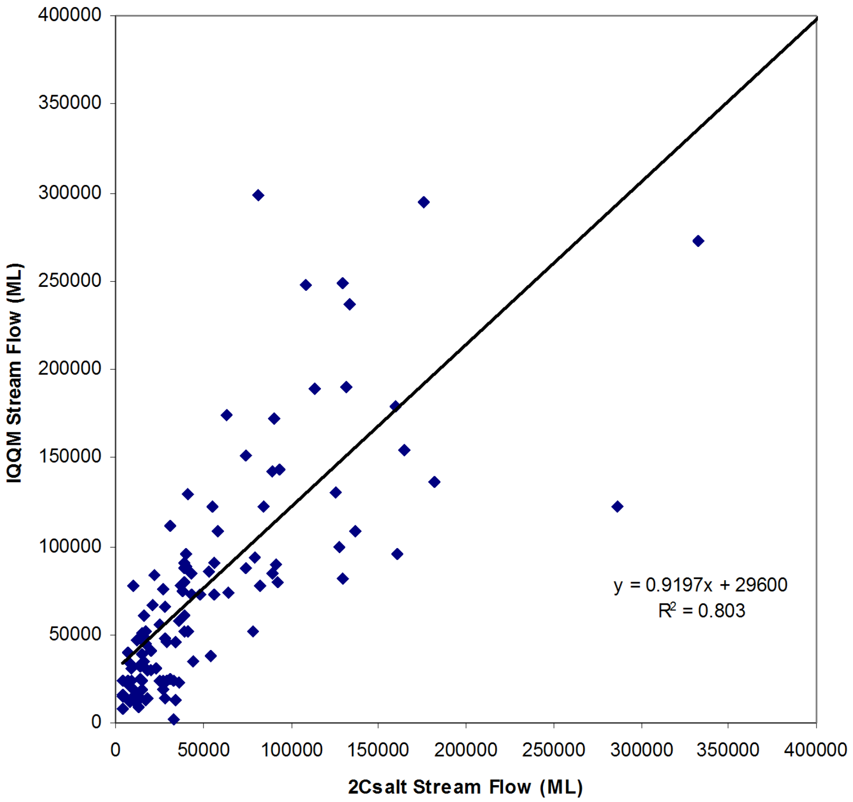
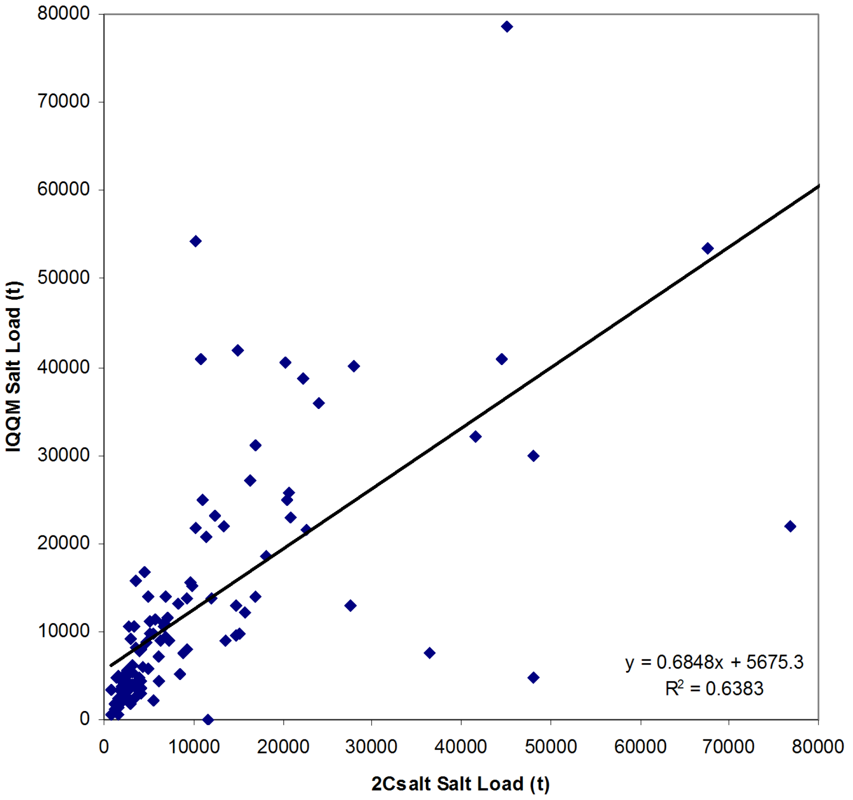


**Figure 37:** Measured versus estimated salt loads on an average annual basis (Littleboy 2006)



In 2Csalt, water and salt movement is influenced by climate, soil properties, land use, topography and groundwater characteristics. Pathways of water and salt predicted by 2Csalt are valuable to characterise catchments based on the dominant pathways of water and salt to stream. 2Csalt estimates a number of water and salt pathways to streams:

- surface runoff from hillslopes
- shallow subsoil lateral flow from hillslopes
- surface discharge from hillslope aquifers
- direct hillslope discharge to streams
- surface runoff from alluvial store
- shallow subsoil lateral flow from alluvial store
- alluvial store discharge to streams
- surface discharge from alluvial stores.

The proportions of stream flow from surface runoff, sub-surface lateral flow, surface discharge of ground water and groundwater discharge to streams are shown in Figures 38 to 41. Surface runoff is a major contributor to stream flow, especially in central and northern New South Wales (Figure 38). Sub-surface lateral flow through the soil to streams is generally highest in northern sub-catchments adjacent to the Dividing Range (Figure 39). Groundwater discharges to either the surface or to streams are substantial in southern sub-catchments (Figures 40 and 41).

**Figure 38:** Proportion of stream flow from surface runoff

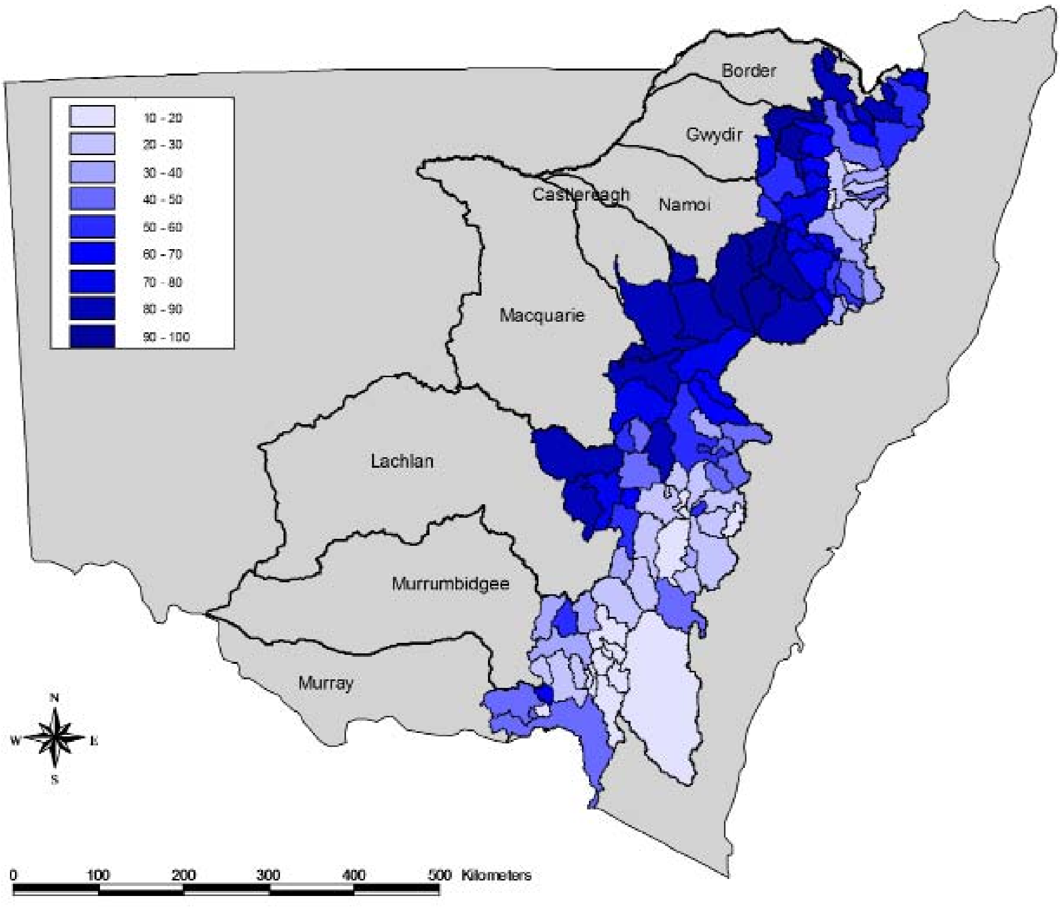


**Figure 39:** Proportion of stream flow from sub-surface lateral flow

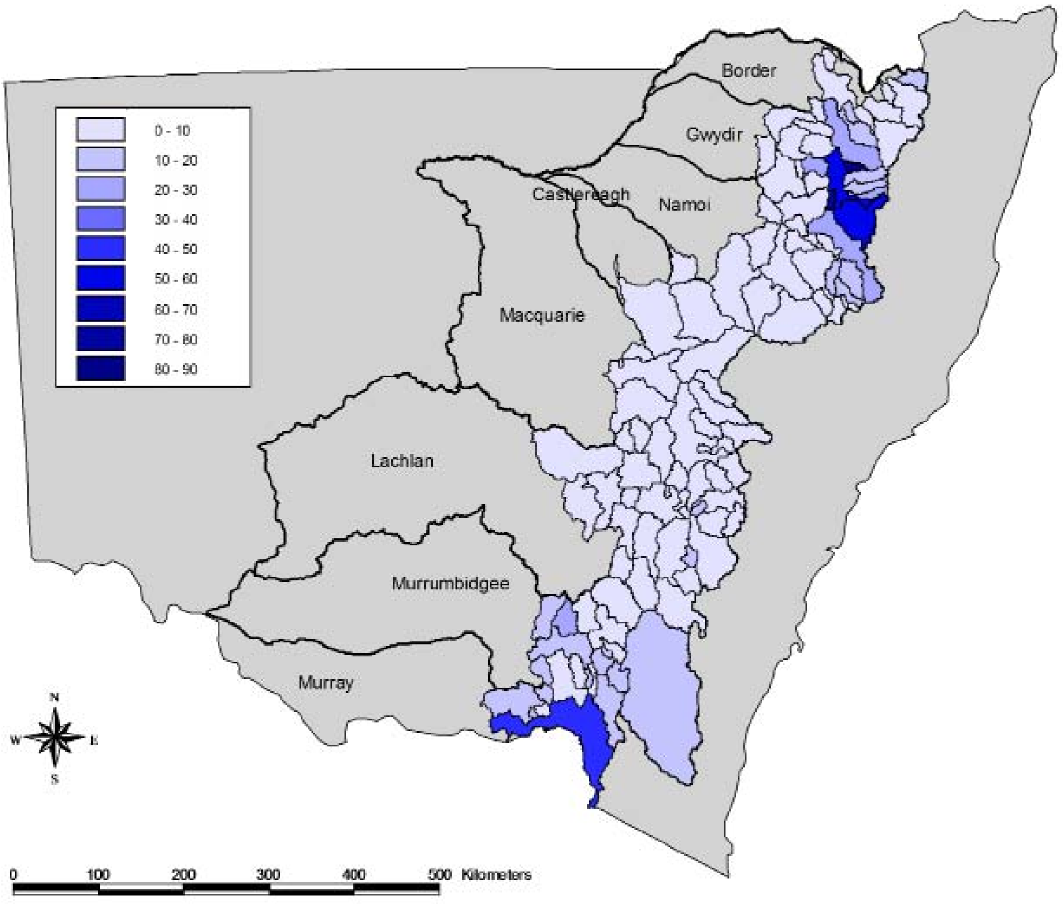


**Figure 40:** Proportion of stream flow from groundwater discharge to the surface

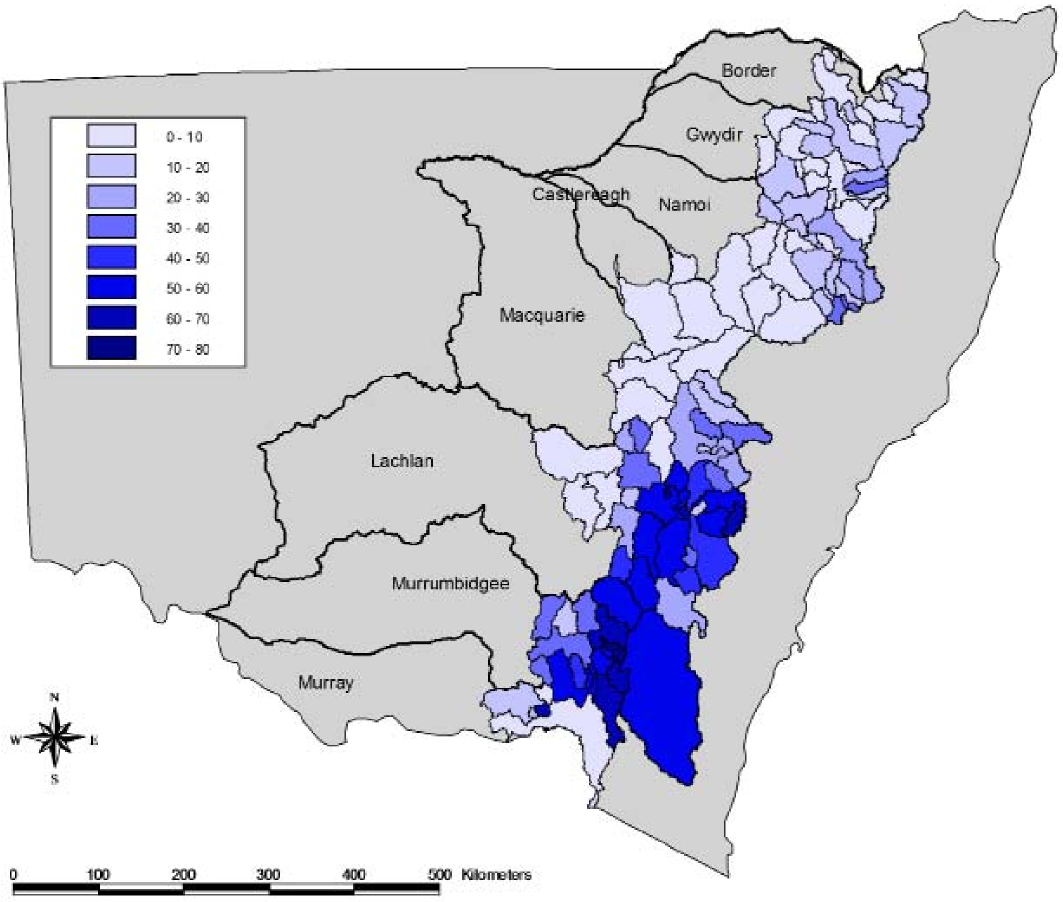
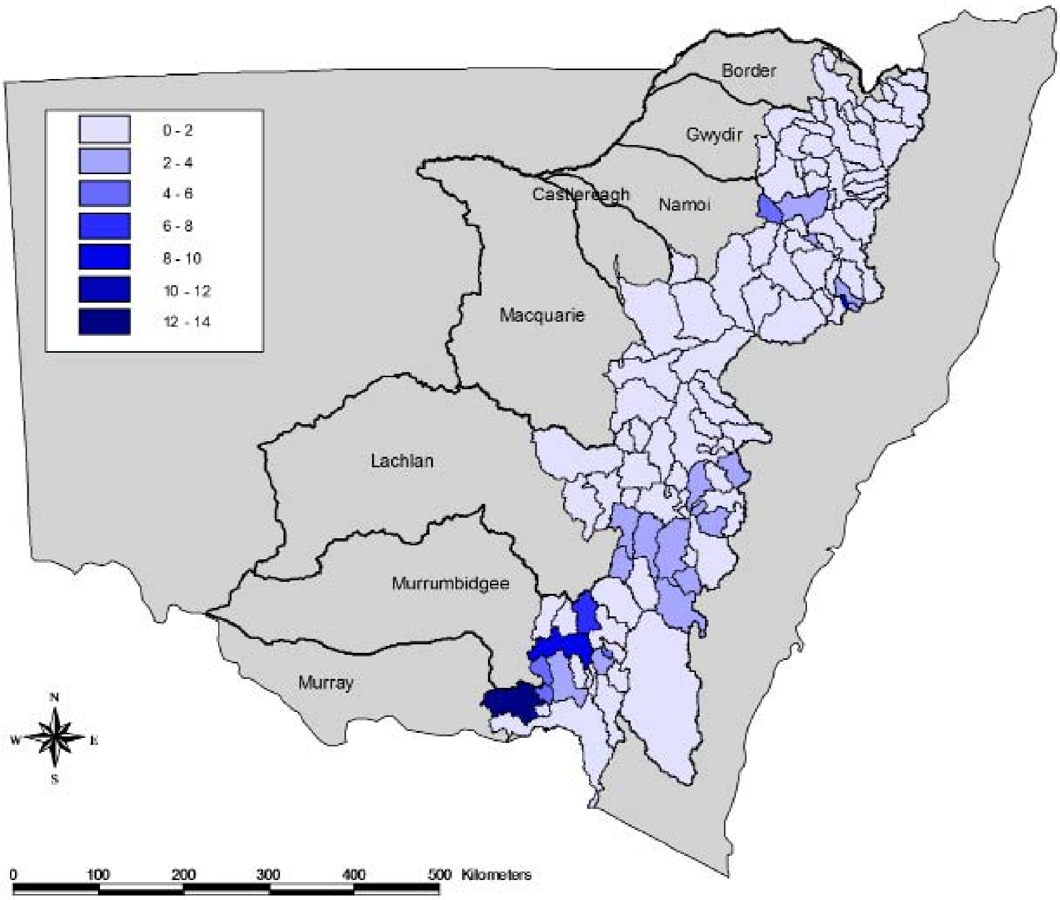


**Figure 41:** Proportion of stream flow from groundwater discharge to streams



Estimated pathways of salt export to streams via surface runoff and shallow lateral flow are shown in Figures 42 and 43. In northern New South Wales, surface wash-off of salt was found to contribute over 80% of salt export to streams (Figure 42). The proportion of salt export via surface runoff tends to decrease for southern catchments. Salt export to streams via lateral flow through the soil profile varied from less than 10% to greater than 30% of total salt load (Figure 43). For many sub-catchments, lateral flow accounted for between 10% and 20% of total salt loads.

**Figure 42:** Proportion of salt load from surface wash-off

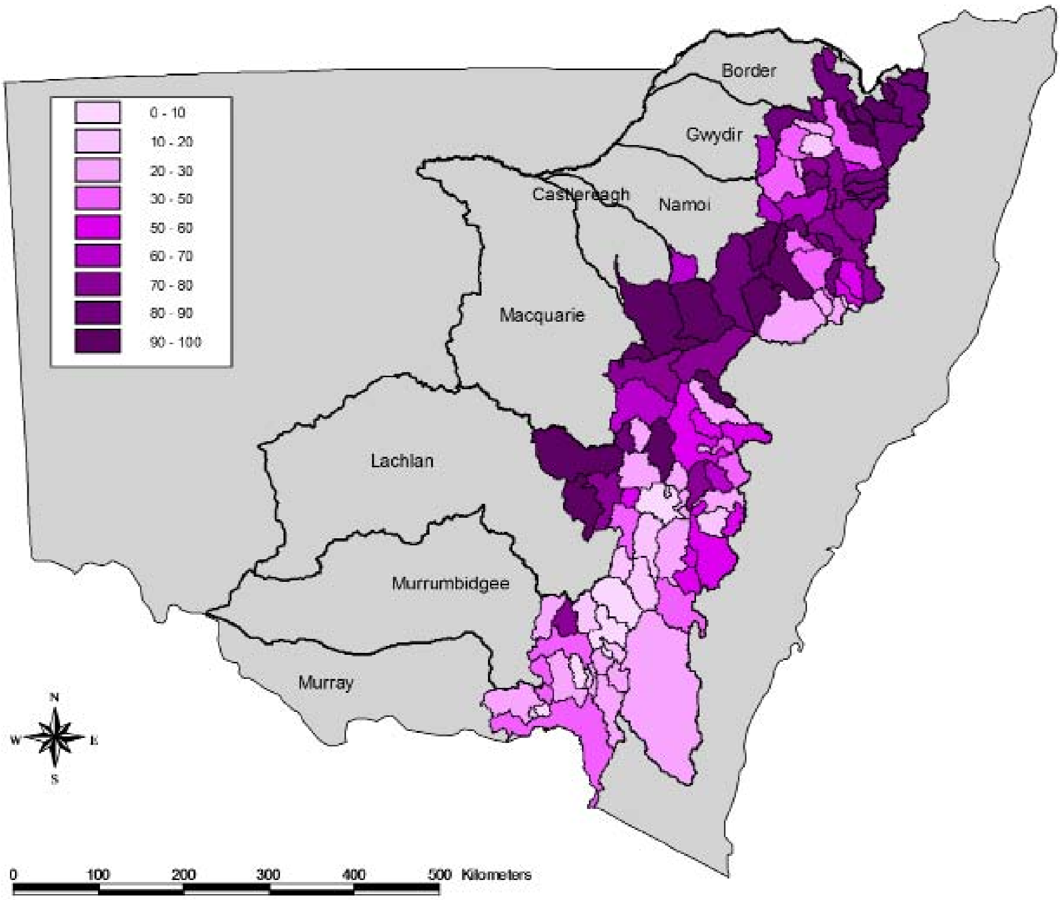
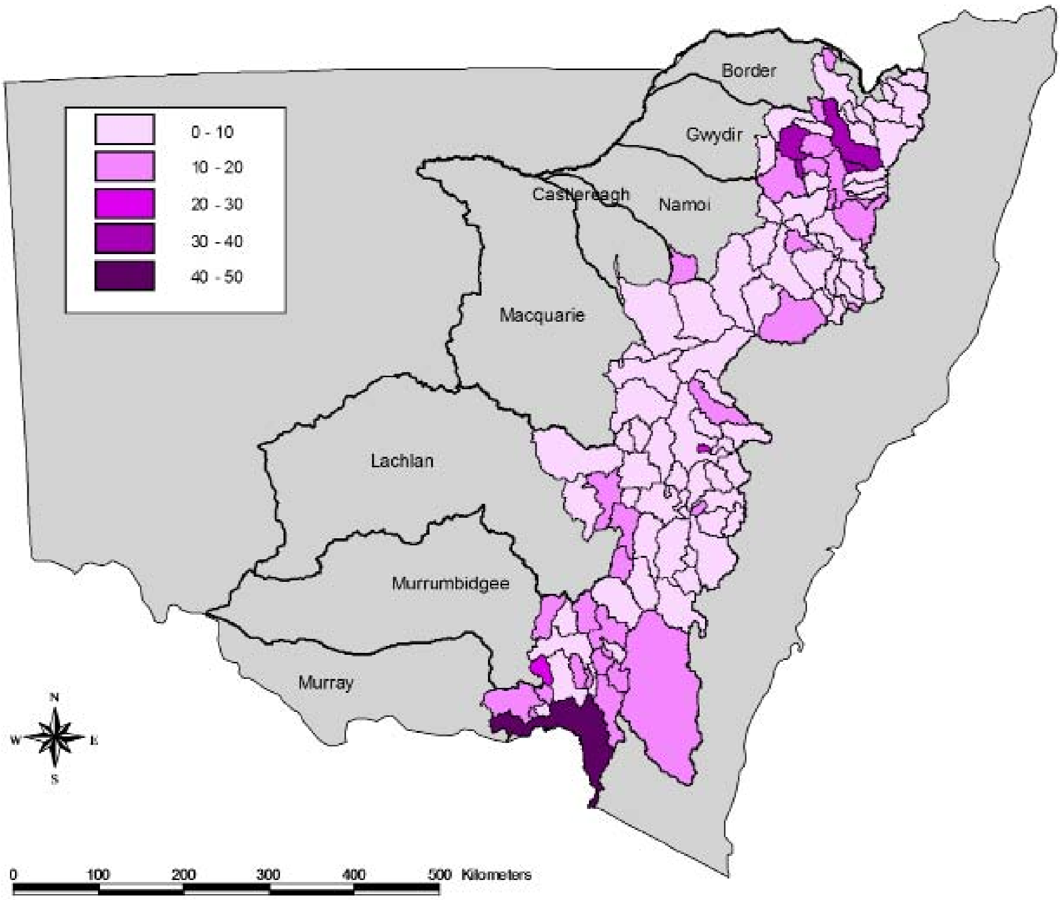


**Figure 43:** Proportion of salt load from sub-surface lateral flow



Estimated pathways of salt export to streams via surface discharge of ground water and groundwater discharge direct to streams are shown in Figures 44 and 45. Salt exports from ground water tend to be highest for southern sub-catchments.

**Figure 44:** Proportion of salt load from groundwater discharge to the surface

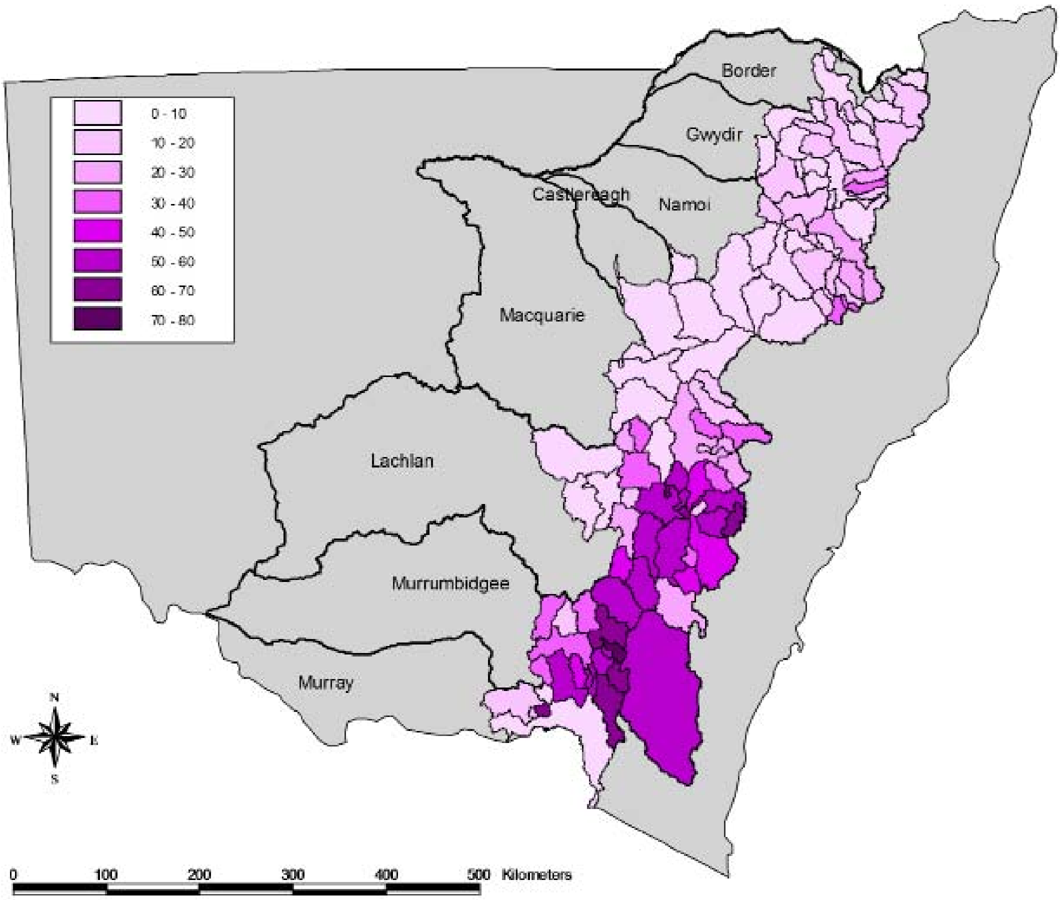
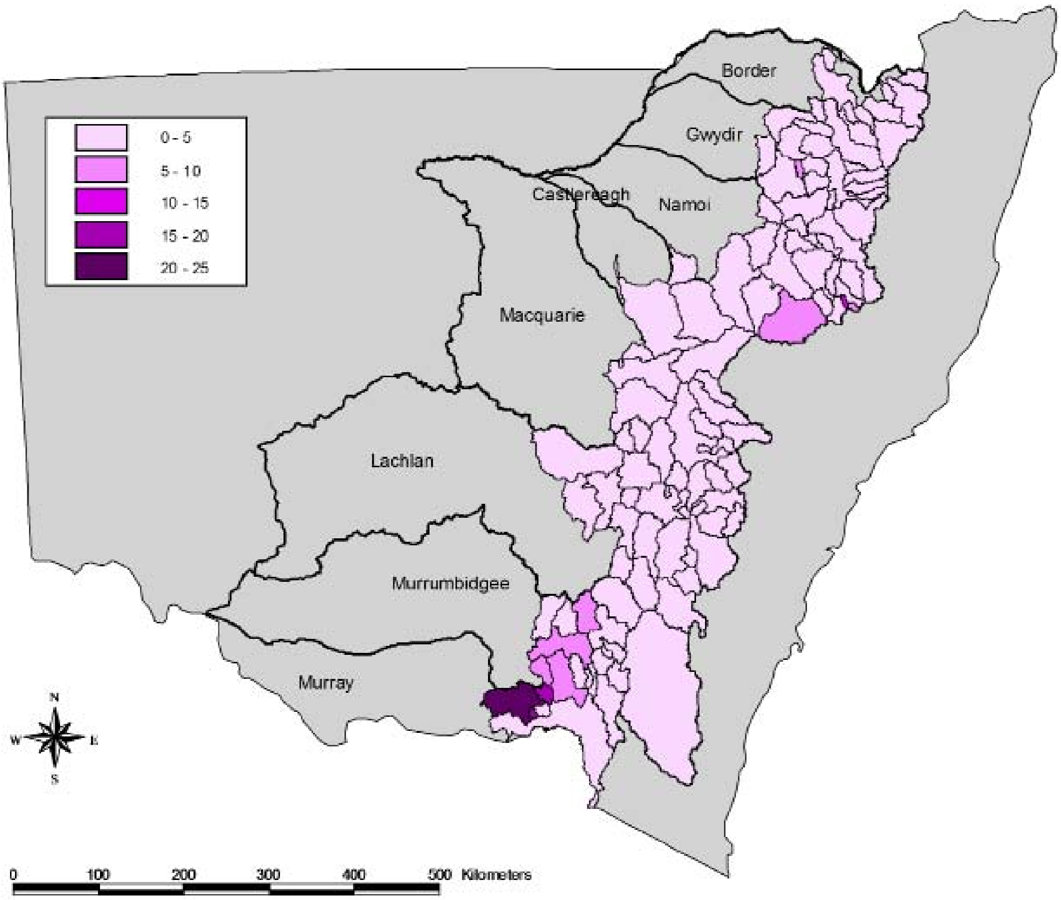


**Figure 45:** Proportion of salt load from groundwater discharge to the stream



The results from 2Csalt in the above figures reflect pathways of water and salt to stream based on current land use and are average for the Murray-Darling Basin Commission Benchmark period (1975–2000). Additional simulations were also undertaken to predict future trends in stream flow and salt loads for 2020, 2050 and 2100. Model predictions for the year 2100 are presented in Figures 46 and 47 for stream flow and stream EC. For some sub-catchments in central and northern New South Wales, small increases in stream flow (<5%) are predicted for 2100 due to increases in groundwater discharge.

The results for year 2100 stream EC trends are more complex (Figure 47). Approximately 30% of all sub-catchments show a falling stream EC trend for the year 2100. This occurs because fresher recharge water is diluting groundwater systems, resulting in fresher groundwater discharges. Many sub-catchments show a rising stream EC trend but generally these increases are small (<10% to the year 2100). A small number of sub-catchments have predicted stream EC increases of 10–30% for the year 2100.

Time series of flow and EC from 2Csalt were imported into IQQM so that the 2020, 2050 and 2100 time series of flow and salinity can be accumulated to an end-of-valley prediction. The results are presented in Table 18 and show that the predicted year 2100 increase in stream EC at end-of-valley is small (<10%) for all valleys.

**Figure 46:** Trend in stream flow for 2100

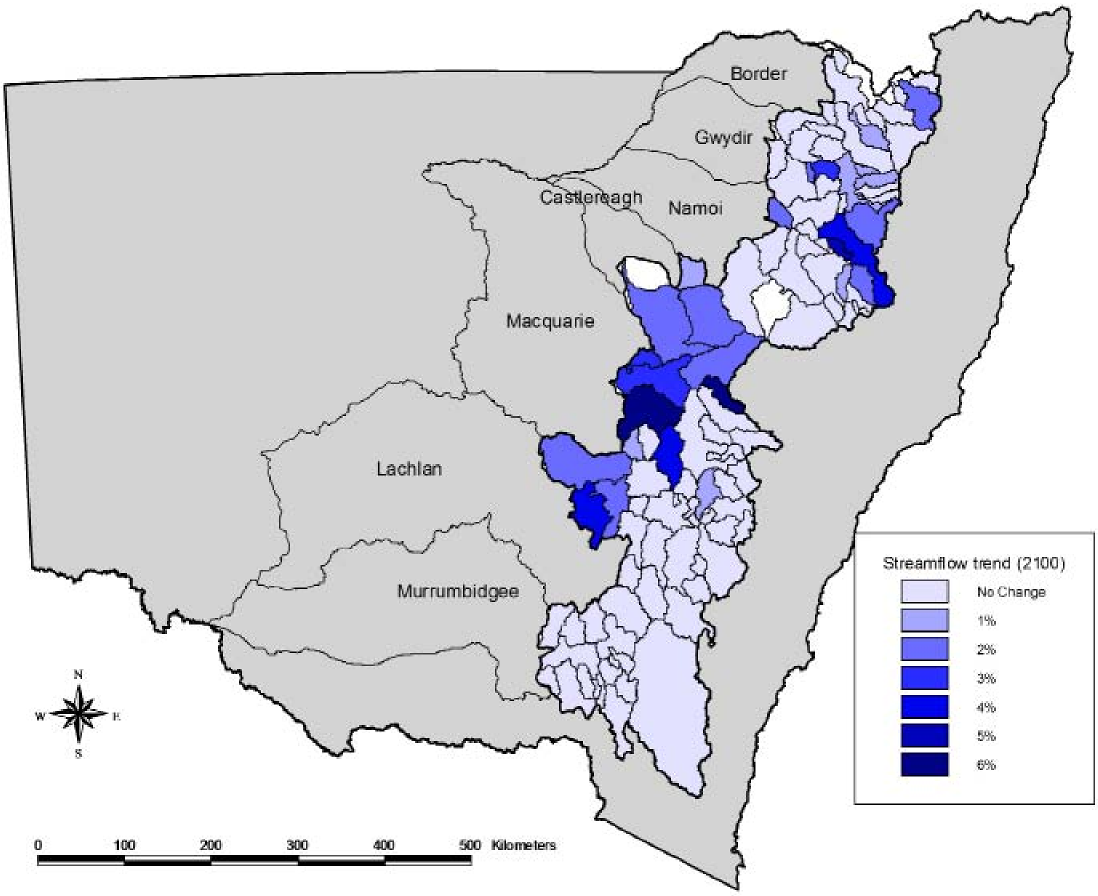


**Figure 47:** Trend in stream EC for 2100

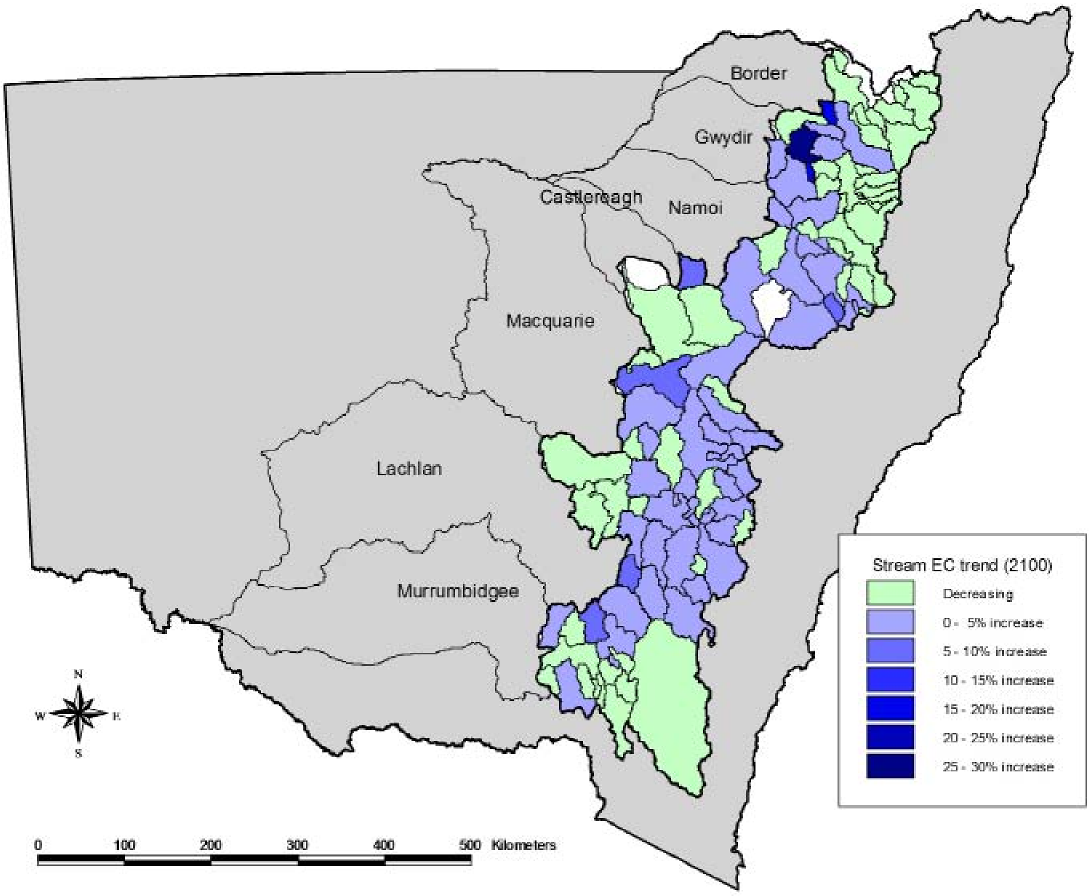


**Table 18:** Predicted increases in salt loads for 2020, 2050 and 2100 for each valley

| Valley | 2020 | 2050 | 2100 |
|---|---|---|---|
| Border Rivers | 0.62 | 1.13 | 1.85 |
| Gwydir | 4.39 | 6.46 | 8.62 |
| Namoi Peel | 1.46 | 2.22 | 3.43 |
| Macquarie | 2.33 | 2.88 | 3.50 |
| Lachlan | 1.11 | 1.81 | 2.79 |
| Murrumbidgee | 0.32 | 0.53 | 0.85 |

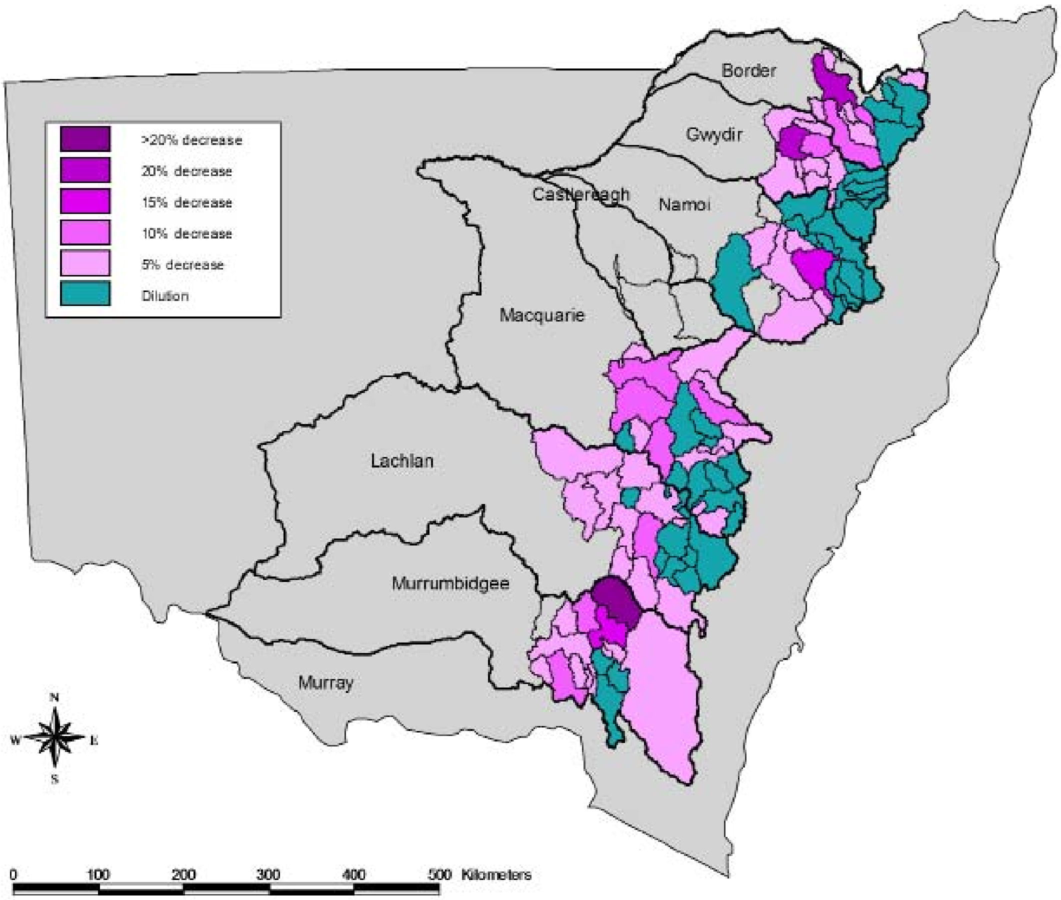
These results are a preliminary rollout of the 2CSalt model. As part of this rollout, linkages to IQQM have been completed, providing the modelling capability to assess the impacts of a land use change in an upland sub-catchment on mid-valley or end-of-valley salinity targets, downstream water allocations and downstream environmental flows. A detailed calibration and evaluation of the 2CSalt model across the 113 sub-catchments is planned over the next 2 to 3 years.

## 3.6 End-of-valley contributions

The IQQM model is a water and salt accounting model that maintains a mass balance of water and salt through a river network. This is achieved by calibrating the model using stream gauging data to ensure that the water and salt inputs and extractions throughout the valley balance at the end-of-valley. The relative contributions from each sub-catchment to end-of-valley flow and salt load were determined using IQQM. In this set of 109 simulations, each of the 109 sub-catchments was removed individually from the model. Comparisons between IQQM simulations with and without each sub-catchment included, clearly identifies those sub-catchments that provide dilution flow to the valley and those sub-catchments that are salt exporters.

The results from this analysis, presented in Figure 48, show the relative contributions of water and salt to end-of-valley flows and salt loads. The sub-catchments highlighted in blue are the areas producing dilution flows to each valley. The remaining sub-catchments are the areas that export a higher proportion of salt than water to each valley. The sub-catchments with the highest increases to end-of-valley salt loads are those with the highest proportional contributions to end-of-valley salt loads.

**Figure 48:** Relative impact of each sub-catchment on end-of-valley saltloads



# 4 Current status of salinity

This chapter presents a synthesis of information that is relevant to defining the current status of salinity in upland areas of the New South Wales Murray-Darling Basin. Initially, the current status of three salinity indicators—land area salinised, stream salinity and groundwater levels—will be described separately. Appropriate data sets from Chapter 3 will be used to define the current status of each indicator on a sub-catchment basis. Sub-catchments are ranked to provide the relative status of each sub-catchment across the upland areas of the New South Wales Murray-Darling Basin. These rankings are combined in Section 4.4 to identify the sub-catchments that multiple data sources identify as having highest expressions of both stream and landscape salinity.

## 4.1 Land area salinised

The most important data source for quantifying the current status of land area salinised is the salt outbreak mapping described in Section 3.1. A summary of current salt outbreaks for each valley is provided in Table 19. The three southern valleys of the Macquarie, Lachlan and Murrumbidgee have highest areas of mapped salt outbreaks.

**Table 19:** Summary of saline outbreaks for each valley

| Valley | Salt outbreaks (ha) |
|---|---|
| Border Rivers | 158 |
| Gwydir | 1 575 |
| Namoi | 1 326 |
| Lachlan | 22 153 |
| Macquarie | 18 559 |
| Murrumbidgee | 18 222 |
| Murray | 379 |

The salt outbreak mapping is further summarised and ranked on a sub-catchment basis in Table 20. Salt outbreaks within non stream gauged areas (i.e. IQQM residual areas) are also included. Approximately 60% of all sub-catchments or residual areas contain mapped salt outbreaks. This also means that 40% of sub-catchments or residual areas have no mapped salt outbreaks and hence no evidence of current land salinisation. Of the 67 sub-catchments with salt outbreaks, the 27 highest ranked areas are all within the Macquarie, Lachlan and Murrumbidgee valleys. Jugiong Creek in the Murrumbidgee has the highest percentage area of salt outbreaks at 3.16% or 6756 ha.

**Table 20:** Summary of saline outbreaks for each sub-catchment

| | Salt outbreaks (ha) | Percentage |
|---|---|---|
| 410025 Jugiong Creek at Jugiong | 6756 | 3.16 |
| 412050 Crookwell River at Narrawa North | 2071 | 2.74 |
| 412072 Back Creek at Koorawatha | 2049 | 2.57 |
| 412029 Boorowa River at Prossers Crossing | 3693 | 2.39 |
| 421059 Buckinbah Creek at Yeoval | 1651 | 2.36 |
| 412065 Lachlan River at Narrawa | 4647 | 2.08 |
| 410044 Muttama Creek at Coolac | 2156 | 2.04 |
| 421048 Little River at Obley No. 2 | 915 | 1.59 |
| Macquarie Residual 4 | 2263 | 1.49 |
| Lachlan Residual 2 | 2126 | 1.31 |
| Macquarie Residual 7 | 3368 | 1.19 |
| 421058 Wyaldra Creek at Gulgong | 981 | 1.17 |
| 421018 Bell River at Newrea | 1802 | 1.11 |
| Macquarie Residual 3 | 3190 | 1.02 |
| 412030 Mandagery Creek at U/S Eugowra | 1541 | 0.91 |
| Murrumbidgee Residual 2 | 1248 | 0.89 |
| Lachlan Residual 3 | 1060 | 0.82 |
| 410103 Houligans Creek at Downside | 917 | 0.81 |
| 421041 Crudine River at Turon River junction | 275 | 0.79 |
| 421042 Talbragar River at Elong Elong | 2325 | 0.78 |
| Lachlan Residual 2 | 1558 | 0.69 |
| 421073 Meroo Creek at Yarrabin 2 | 468 | 0.64 |
| Murrumbidgee Residual 3 | 1014 | 0.61 |
| 410045 Billabung Creek at Sunnyside | 507 | 0.60 |
| Lachlan Residual 4b | 245 | 0.59 |
| Lachlan Residual 4a | 970 | 0.58 |
| 421079 Cudgegong River at Windamere Dam | 626 | 0.57 |
| Gwydir Residual 4 | 571 | 0.52 |
| 421066 Green Valley Creek at Hill End | 57 | 0.49 |
| 412083 Tuena Creek at Tuena | 148 | 0.46 |
| 410008 Murrumbidgee River at Burrinjuck Dam | 4949 | 0.38 |
| 418017 Myall Creek at Molroy | 301 | 0.35 |
| 410097 Billabong Creek at Aberfeldy | 115 | 0.33 |
| 421052 Lewis Ponds Creek at Ophir | 182 | 0.29 |
| 418032 Tycannah Creek at Horseshoe Lagoon | 231 | 0.28 |
| 410047 Tarcutta Creek at Old Borambola | 448 | 0.27 |
| 421053 Queen Charlottes Creek at Georges Plains | 54 | 0.27 |
| Murrumbidgee Residual 2 | 137 | 0.26 |
| Gwydir Residual 5 | 296 | 0.25 |
| 419032 Coxs Creek at Boggabri | 900 | 0.24 |
| Lachlan Residual 6 | 462 | 0.24 |

| | Salt outbreaks (ha) | Percentage |
|---|---|---|
| Lachlan Residual 5 | 376 | 0.23 |
| 419043 Manilla River at Split Rock Dam | 361 | 0.22 |
| 412077 Belubula River at Carcoar | 45 | 0.19 |
| 412028 Abercrombie River at Abercrombie | 503 | 0.19 |
| 412043 Goobang Creek at Darbys Dam | 638 | 0.16 |
| Macquarie Residual 1 | 153 | 0.15 |
| 410048 Kyeamba Creek at Ladysmith | 78 | 0.14 |
| 410098 Ten Mile Creek at Holbrook No. 2 | 12 | 0.12 |
| 412092 Coombin Creek near Neville | 14 | 0.11 |
| Macquarie Residual 2 | 85 | 0.08 |
| 421072 Winburndale Rivulet at Howards Bridge | 60 | 0.08 |
| 412080 Flyers Creek at Beneree | 7 | 0.08 |
| 418015 Horton River at Rider | 136 | 0.07 |
| 418016 Warialda Creek at Warialda No.3 | 36 | 0.07 |
| 419072 Baradine Creek at Kienbri | 59 | 0.06 |
| 421101 Campbells River U/S Ben Chifley Dam | 52 | 0.06 |
| 421035 Fish River at Tarana | 28 | 0.05 |
| 416010 Macintyre River at Wallangra | 95 | 0.04 |
| 410091 Billabong Creek at Walbundrie | 76 | 0.04 |
| Lake Hume | 164 | 0.03 |
| 410099 Yarra Yarra Creek at Yarra Yarra | 7 | 0.03 |
| 421026 Turon River at Sofala | 24 | 0.03 |
| 416003 Tenterfield Creek at Clifton | 12 | 0.02 |
| 416039 Severn River at Strathbogie | 35 | 0.02 |
| 410059 Gilmore Creek at Gilmore | 4 | 0.01 |
| 410043 Hillas Creek at Mount Adrah | 8 | 0.01 |
| 416032 Mole River at Donaldson | 16 | 0.01 |
| Gwydir Residual 3 | 2 | 0.00 |
| 418018 Keera Creek at Keera | 2 | 0.00 |
| Namoi Lake Goran | 6 | 0.00 |

## 4.2 Stream salinity

A number of the data sources presented in Chapters 2 and 3 are appropriate for use in quantifying the current status of stream salinity across the study area. These data sources are

- stream flows, salt loads and salt exports from IQQM catchments (Section 2.9);
- stream EC cyclicity from stream EC analyses (Section 3.3); and
- end-of-valley water and salt contributions from IQQM (Section 3.6).

In Table 21, sub-catchments are grouped on the basis of salt exports (t km$^{-2}$) and mean stream salinity. Six sub-catchments (Halls Creek, Jugiong Creek, Muttama Creek, Green Valley Creek, Flyers Creek and Peel River at Chaffey Dam) are the highest ranked sub-catchments having both high salt exports and high stream salinities. Salt exports and stream salinities must be considered simultaneously because some sub-catchments (e.g. Tumut River) have a high salt export but a low stream EC because of the high volumes of stream flow. Simply ranking sub-catchments on salt exports only, can be misleading to characterise sub-catchments for their current status of stream salinity.

In Table 22, sub-catchments across the study area are grouped on the basis of stream salinity and cyclicity of stream salinity. Sub-catchments with higher stream cyclicity are important because of the potential for high temporal variability in salt exports. Five sub-catchments ( Houligans Creek, Butheroo Creek, Billabong Creek, Jugiong Creek and Talbragar River) are the highest ranked sub-catchments, having both the highest stream salinities and the highest cyclicity in stream salinity.

**Table 21:** Groupings of IQQM sub-catchments for salt exports

| Salt export | Stream salinity concentration | | | | |
|---|---|---|---|---|---|
| | High | Medium to high | Medium | Low to medium | Low |
| High | 418025: Halls Creek Bingara<br>410025: Jugiong Creek<br>410044: Muttama Creek<br>421066: Green Valley Creek<br>412080: Flyers Creek<br>419045: Peel R Chaffey Dam | 412092: Coombin Creek<br>419077: Dungowan Creek<br>419036: Duncans Creek<br>410071: Brungle Creek | 410043: Hillas Creek | | 410073: Tumut River |
| Medium to high | 419035: Goonoo Goonoo Creek<br>421018: Bell River<br>412029: Boorowa River<br>412065: Lachlan R Narrawa<br>412077: Belubula R Carcoar<br>410048: Kyeamba Creek<br>418015: Horton R at Rider | 421041: Crudine River | 412050: Crookwell River | 410061: Adelong Creek | |
| Medium | 412072: Back Creek<br>418017: Myall Creek<br>421059: Buckinbah Creek<br>412030: Mandagery Creek<br>419029: Halls Creek at Ukolan | 418018: Keera Creek<br>421101: Campbells River | 419016: Cockburn River<br>412083: Tuena Creek<br>421026: Turon River<br>410047: Tarcutta Creek<br>421052: Lewis Ponds Creek<br>416021: Frazers Creek<br>421073: Meroo Creek<br>421072: Winburndale Rivulet | 410038: Adjungbilly Creek | 410059: Gilmore Creek<br>410057: Goobarragandra R |
| Low to medium | 416020: Ottleys Creek<br>419027: Mooki River at Breeza<br>421079: Cudgegong River<br>419043: Manilla River | 418016: Warialda Creek | 416010: Macintyre R Wallangra<br>421053: Queen Charlottes Creek<br>419051: Maules Creek<br>418029: Gwydir R Stoneybatter | 419005: Namoi R Nth Cuerindi<br>412028: Abercrombie River<br>416003: Tenterfield Creek<br>410008: Murrumbidgee Burrunjuck<br>416039: Severn River<br>421048: Little River<br>416026: Reedy Creek<br>418023: Moredun Border<br>416032: Mole River<br>416008: Beardy River<br>418021: Laura Creek<br>418022: Georges Creek<br>418005: Copes Creek | 421035: Fish River |
| Low | | 416036: Campbells Creek<br>421042: Talbragar River<br>419072: Baradine Creek<br>421058: Wyaldra Creek | 410045: Billabung Creek<br>412043: Goobang Creek | 418033: Bakers Creek | 421055: Coolbaggie Creek |

**Table 22:** Groupings of sub-catchments for stream EC

| Salt export | Stream salinity concentration | | | | |
|---|---|---|---|---|---|
| | High | Medium to high | Medium | Low to medium | Low |
| High | 410103: Houligans Ck | | | | 412103: Bland Ck at Mongarell |
| Medium to high | 420012: Butheroo Ck | 410091: Billabong Ck Wallabundrie<br>410025: Jugiong Ck at Jugiong<br>421042: Talbragar R. at Elong Elong | 419027: Mooki R. at Breeza<br>410048: Kyeamba Ck at Ladysmith | 419032: Coxs Ck at Boggabri<br>421048: Little R. at Obley<br>418027: Horton R. at Dam Site | 412099: Manna Ck Nr Lake Cowal<br>420015: Warrena Ck at Warrana<br>421055: Coolbagie Ck Rawsonville |
| Medium | | 421059: Buckinbar Ck at Yeoval<br>410044: Muttama Ck at Coolac | 412030: Mandagery Ck | 410026: Yass R. at Yass<br>419029: Halls Ck at Ukalon<br>418018: Keera Ck at Keera<br>412086: Goobang Ck at Parkes<br>410097: Billabong Ck at Aberfeldy | 420010: Wallum Ck at Bearbung<br>420005: Castlereagh R Coonamble<br>416021: Frazers Ck at Ashford<br>418052: Carole Ck at Nr. Garah<br>420017: Castlereagh R. Hidden V<br>421023: Bogan R. at Gongolgon<br>418029: Gwydir R. at Stoneybatter<br>419072: Baradine Ck at Kienbri<br>419005: Namoi R. at Nth Cuerindi<br>410045: Billabung Ck at Sunnyside<br>410047: Tarcutta Ck<br>416008: Beardy R. at Haystack<br>421084: Burrill Ck at Mickibri<br>410107: Mountain Ck<br>410062: Numeralla R.<br>421076: Bogan R. at Peak Hill 2<br>401009: Maragle Ck at Maragle<br>410050: Murrumbidgee R. at Billilingra<br>410024: Goodradidgbee R.<br>410033: Murrumbidgee R. Mittagang |

| Salt export | Stream salinity concentration | | | | |
|---|---|---|---|---|---|
| | High | Medium to high | Medium | Low to medium | Low |
| Low to medium | | 412072: Back Ck at Koorawatha<br>418017: Myall Ck at Molroy<br>419035: Goonoo Ck at Timbumburi<br>418025: Halls Ck at Bingara | 412065: Lachlan R. at Narrawa | 418032: Tycannah Ck<br>416020: Ottleys Ck at Coolatai<br>420004: Castlereagh R. at Mendooran<br>412055: Belubula R. at Bangaroo Bdge<br>418015: Horton R. at Killara<br>419054: Swamp Oak Ck at Limbri<br>416010: Macintyre R. at Wallangra | 416016: Macintyre R. at Inverell<br>419016: Cockburn R. at Mulla Xing<br>421026: Turon R. at Sofala<br>412043: Goobang Ck at Darbys Dam<br>419051: Maules Ck At Avoca<br>421025: Macquarie R. at Bruinbuin<br>416039: Severn R. at Strathbogie<br>421072: Winburndale Rivlt<br>418023: Moredun Ck at Bundarra<br>418005: Copes Ck at Kimberley<br>420003: Belar Ck at Warkton<br>410038: Adjungbilly Ck at Darbalara<br>416023: Deepwater Ck at Bolivia<br>421039: Bogan R. at Neurie Plains<br>410061: Adelong Ck at Batlow Rd.<br>421035: Fish R. at Tarana<br>410088: Goodradigbee R. Brindabella<br>410057: Goobaragandra R. Lacmalac |
| Low | | 412096: Pudmans Ck at Kennys Rd<br>419033: Coxs Ck at Tambar Springs | 421056: Coolaburragundy Ck Coolah<br>418016: Warialda Ck at Warialda | 421018: Bell R. at Newrea<br>412009: Belubula R. at Canowindra | 412083: Tuena Ck at Tuena<br>421101: Campbells R. U/S Ben Chifley Dam<br>416027: Gil Gil Ck at Weemelah<br>412050: Crookwell R. at Narrawa North<br>421073: Meroo Ck at Yarrabin 2<br>418014: Gwydir at Yarrowych<br>416003: Tenterfield Ck at Clifton<br>418008: Gwydir R. at Bundarra<br>412028: Abercrombie R. at Abercrombie<br>418021: Laura Ck at Laura<br>416032: Mole R. at Donaldson<br>401013: Jingellic Ck at Jingellic |

**Table 23:** Groupings of gauged sub-catchments for salt contributions to end-of-valley

| Sub-catchment | | Impact on salinity at end-of-valley (%) |
|---|---|---|
| 410025 | Jugiong Creek at Jugiong | 23 |
| 410044 | Muttama Creek at Coolac | 9 |
| 418017 | Myall Creek at Molroy | 8 |
| 410047 | Tarcutta Creek at Old Borambola | 7 |
| 416010 | Macintyre River at Wallangra | 7 |
| 421018 | Bell River at Newrea | 5 |
| 418015 | Horton River at Rider | 3 |
| 418025 | Halls Creek at Bingara | 3 |
| 410048 | Kyeamba Creek at Ladysmith | 2 |
| 412029 | Boorowa River at Prossers Crossing | 2 |
| 412030 | Mandagery Creek at U/S Eugowra | 2 |
| 416020 | Ottleys Creek at Coolatai | 2 |
| 421042 | Talbragar River at Elong Elong | 2 |
| 421059 | Buckinbah Creek at Yeoval | 2 |
| 410008 | Murrumbidgee River at Burrinjuck Dam | 1 |
| 410038 | Adjungbilly Creek at Darbalara | 1 |
| 410043 | Hillas Creek at Mount Adrah | 1 |
| 410045 | Billabung Creek at Sunnyside | 1 |
| 412065 | Lachlan River at Narrawa | 1 |
| 416021 | Frazers Creek at Westholme | 1 |
| 416036 | Campbells Creek at Deebo | 1 |
| 418016 | Warialda Creek at Warialda No.3 | 1 |
| 418018 | Keera Creek at Keera | 1 |
| 419027 | Mooki River at Breeza | 1 |
| 419035 | Goonoo Goonoo Creek at Timbumburi | 1 |
| 421066 | Green Valley Creek at Hill End | 1 |
| 421079 | Cudgegong River at Windamere Dam | 1 |
| 410059 | Gilmore Creek at Gilmore | Neutral |
| 410061 | Adelong Creek at Batlow Road | Neutral |
| 410071 | Brungle Creek at Red Hill | Neutral |
| 412043 | Goobang Creek at Darbys Dam | Neutral |
| 412072 | Back Creek at Koorawatha | Neutral |
| 416003 | Tenterfield Creek at Clifton | Neutral |
| 418033 | Bakers Creek at Bundarra | Neutral |
| 421041 | Crudine River at Turon River junction | Neutral |

| Sub-catchment | Impact on salinity at end-of-valley (%) |
|---|---|
| 421053 Queen Charlottes Creek at Georges Plains | Neutral |
| 421055 Coolbaggie Creek at Rawsonville | Neutral |
| 421058 Wyaldra Creek at Gulgong | Neutral |
| 421101 Campbells River U/S Ben Chifley Dam | Neutral |
| 412077 Belubula River at Carcoar | -1 |
| 412080 Flyers Creek at Beneree | -1 |
| 412092 Coombin Creek near Neville | -1 |
| 416008 Beardy River at Haystack | -1 |
| 416026 Reedy Creek at Dumaresq | -1 |
| 418005 Copes Creek at Kimberley | -1 |
| 418021 Laura Creek at Laura | -1 |
| 419029 Halls Creek at Ukolan | -1 |
| 419032 Coxs Creek at Boggabri | -1 |
| 419036 Duncans Creek at Woolomin | -1 |
| 419043 Manilla River at Split Rock Dam | -1 |
| 419077 Dungowan Creek at Dungowan Dam | -1 |
| 421048 Little River at Obley No. 2 | -1 |
| 412083 Tuena Creek at Tuena | -2 |
| 418022 Georges Creek at Clerkness | -2 |
| 419016 Cockburn River at Mulla Crossing | -2 |
| 421026 Turon River at Sofala | -2 |
| 421052 Lewis Ponds Creek at Ophir | -2 |
| 421072 Winburndale Rivulet at Howards Bridge | -2 |
| 421073 Meroo Creek at Yarrabin 2 | -2 |
| 412050 Crookwell River at Narrawa North | -3 |
| 418023 Moredun Creek at Bundarra | -3 |
| 418029 Gwydir River at Stoneybatter | -3 |
| 419045 Peel River Chaffey Dam | -3 |
| 416032 Mole River at Donaldson | -4 |
| 421035 Fish River at Tarana | -4 |
| 416039 Severn River at Strathbogie | -5 |
| 410057 Goobarragandra River at Lacmalac | -6 |
| 412028 Abercrombie River at Abercrombie | -12 |
| 419005 Namoi River at North Cuerindi | -26 |
| 410073 Tumut River at Oddys Bridge | -72 |

In Table 23, sub-catchments across the study area are ranked on the basis of their impacts on stream salinity at end-of-valley. Sub-catchments with positive impacts at end-of-valley are those that supply more salt than water to end-of-valley. Sub-catchments with negative impacts at end-of-valley are those that supply more water than salt to end-of-valley. This analysis identifies the sub-catchments that are salt contributors and those that produce dilution flows. The highest salt contributor is Jugiong Creek while the highest dilution flows come from the Tumut River.

## 4.3 Groundwater levels

Information on the current status of current groundwater levels is sparse. The focus for groundwater monitoring in New South Wales has been irrigation areas. Hence, for many upland areas there are only isolated networks of groundwater monitoring bores.

The groundwater analyses described in Section 3.4 revealed that trends in groundwater level have generally been closely following trends in rainfall with variable delay, maintaining a state of dynamic equilibrium. The study provided evidence indicating that a 1947 climate shift to a higher rainfall regime caused a rise in the groundwater levels and played an important part in the outbreaks of salinity. Ground water appears to have been in dynamic equilibrium with rainfall over the last four decades.

Given the paucity of bore data, any spatial estimates of groundwater levels must be considered as illustrative only. Depth to watertable maps that were described in Section 2.10 are useful to provide generalised information on groundwater levels. This information is summarised on a sub-catchment basis in Table 24, which presents the percentage areas of each depth to watertable class for each sub-catchment, ranked for area with depth to watertable less than 5 m. These areas should not be viewed as absolute areas of depth to watertable. Instead, the relativities between sub-catchments should be viewed as useful information to rank and characterise sub-catchments.

**Table 24:** Percentages of area for each depth to watertable class

| Sub-catchment | <5 m | 5–10 m | 10–15 m | 15–20 m | >20 m |
|---|---|---|---|---|---|
| 410025 Jugiong Creek at Jugiong | 28 | 37 | 26 | 10 | 0 |
| 419027 Mooki River at Breeza | 22 | 25 | 25 | 13 | 16 |
| 410048 Kyeamba Creek at Ladysmith | 20 | 18 | 22 | 40 | 0 |
| 412077 Belubula River at Carcoar | 18 | 33 | 21 | 16 | 13 |
| 421052 Lewis Ponds Creek at Ophir | 18 | 17 | 10 | 5 | 50 |
| 412029 Boorowa River at Prossers Crossing | 17 | 16 | 12 | 14 | 40 |
| 421079 Cudgegong River at Windamere Dam | 17 | 12 | 9 | 10 | 53 |
| 419032 Coxs Creek at Boggabri | 16 | 18 | 13 | 18 | 35 |
| 412065 Lachlan River at Narrawa | 16 | 10 | 8 | 9 | 57 |
| 410047 Tarcutta Creek at Old Borambola | 15 | 10 | 13 | 62 | 0 |
| 410008 Murrumbidgee River at Burrinjuck Dam | 14 | 26 | 24 | 37 | 0 |
| 421053 Queen Charlottes Creek at Georges Plains | 12 | 61 | 11 | 6 | 10 |
| 410097 Billabong Creek at Aberfeldy | 12 | 18 | 20 | 49 | 0 |
| 410044 Muttama Creek at Coolac | 11 | 33 | 32 | 24 | 0 |
| 410099 Yarra Yarra Creek at Yarra Yarra | 10 | 13 | 14 | 61 | 1 |
| 419029 Halls Creek at Ukolan | 9 | 15 | 14 | 13 | 49 |

| Sub-catchment | | <5 m | 5–10 m | 10–15 m | 15–20 m | >20 m |
|---|---|---|---|---|---|---|
| 421059 | Buckinbah Creek at Yeoval | 9 | 21 | 31 | 23 | 16 |
| 421018 | Bell River at Newrea | 8 | 12 | 25 | 28 | 28 |
| 416003 | Tenterfield Creek at Clifton | 8 | 8 | 8 | 9 | 68 |
| 412050 | Crookwell River at Narrawa North | 7 | 9 | 9 | 11 | 64 |
| 421101 | Campbells River U/S Ben Chifley Dam | 7 | 16 | 19 | 13 | 45 |
| 418017 | Myall Creek at Molroy | 7 | 16 | 17 | 17 | 43 |
| 412072 | Back Creek at Koorawatha | 6 | 12 | 12 | 14 | 56 |
| 418022 | Georges Creek at Clerkness | 6 | 9 | 10 | 10 | 66 |
| 421058 | Wyaldra Creek at Gulgong | 6 | 16 | 28 | 15 | 36 |
| 412080 | Flyers Creek at Beneree | 5 | 5 | 33 | 56 | 0 |
| 410071 | Brungle Creek at Red Hill | 5 | 23 | 26 | 46 | 0 |
| | Lake Hume | 5 | 8 | 9 | 8 | 70 |
| 410091 | Billabong Creek at Walbundrie | 4 | 19 | 18 | 59 | 0 |
| 419051 | Maules Creek at Avoca East | 4 | 8 | 8 | 8 | 72 |
| 419043 | Manilla River at Split Rock Dam | 4 | 9 | 23 | 16 | 47 |
| 412043 | Goobang Creek at Darbys Dam | 4 | 9 | 7 | 5 | 75 |
| 421042 | Talbragar River at Elong Elong | 4 | 8 | 11 | 17 | 61 |
| 421035 | Fish River at Tarana | 4 | 8 | 19 | 17 | 53 |
| 419045 | Peel River Chaffey Dam | 3 | 12 | 28 | 22 | 34 |
| 419036 | Duncans Creek at Woolomin | 3 | 11 | 0 | 25 | 60 |
| 416026 | Reedy Creek at Dumaresq | 3 | 4 | 5 | 5 | 83 |
| 419005 | Namoi River at North Cuerindi | 2 | 5 | 10 | 18 | 64 |
| 418032 | Tycannah Creek at Horseshoe Lagoon | 2 | 13 | 18 | 28 | 39 |
| 410045 | Billabung Creek at Sunnyside | 2 | 10 | 28 | 59 | 0 |
| 416010 | Macintyre River at Wallangra | 2 | 8 | 17 | 12 | 60 |
| 416021 | Frazers Creek at Westholme | 2 | 3 | 3 | 19 | 73 |
| 418029 | Gwydir River at Stoneybatter | 2 | 7 | 9 | 12 | 70 |
| 418015 | Horton River at Rider | 2 | 10 | 13 | 18 | 57 |
| 412028 | Abercrombie River at Abercrombie | 2 | 3 | 4 | 6 | 85 |
| 418005 | Copes Creek at Kimberley | 2 | 11 | 27 | 23 | 38 |
| 412030 | Mandagery Creek at U/S Eugowra | 2 | 8 | 17 | 18 | 55 |
| 421073 | Meroo Creek at Yarrabin 2 | 1 | 9 | 14 | 10 | 66 |
| 410059 | Gilmore Creek at Gilmore | 1 | 6 | 18 | 75 | 0 |
| 421072 | Winburndale Rivulet at Howards Bridge | 1 | 8 | 17 | 22 | 53 |
| 416032 | Mole River at Donaldson | 1 | 7 | 8 | 8 | 77 |
| 418016 | Warialda Creek at Warialda No.3 | 1 | 4 | 18 | 16 | 61 |

*continued/*

**Table 24 (cont.):** Percentages of area for each depth to watertable class

| Sub-catchment | | <5 m | 5–10 m | 10–15 m | 15–20 m | >20 m |
|---|---|---|---|---|---|---|
| 410103 | Houligans Creek at Downside | 1 | 6 | 7 | 86 | 1 |
| 410057 | Goobarragandra River at Lacmalac | 0 | 4 | 6 | 89 | 0 |
| 410098 | Ten Mile Creek at Holbrook No 2 | 0 | 0 | 21 | 78 | 0 |
| 418021 | Laura Creek at Laura | 0 | 0 | 1 | 3 | 96 |
| 416008 | Beardy River at Haystack | 0 | 0 | 3 | 11 | 86 |
| 418023 | Moredun Creek at Bundarra | 0 | 4 | 6 | 6 | 84 |
| 418025 | Halls Creek at Bingara | 0 | 0 | 5 | 22 | 73 |
| 410038 | Adjungbilly Creek at Darbalara | 0 | 4 | 7 | 89 | 0 |
| 410043 | Hillas Creek at Mount Adrah | 0 | 4 | 25 | 71 | 0 |
| 410061 | Adelong Creek at Batlow Road | 0 | 6 | 16 | 78 | 0 |
| 410073 | Tumut River at Oddys Bridge | 0 | 8 | 10 | 81 | 0 |
| 412083 | Tuena Creek at Tuena | 0 | 0 | 0 | 0 | 100 |
| 412092 | Coombin Creek near Neville | 0 | 0 | 15 | 18 | 67 |
| 416020 | Ottleys Creek at Coolatai | 0 | 9 | 17 | 20 | 54 |
| 416036 | Campbells Creek at Deebo | 0 | 3 | 7 | 9 | 80 |
| 416039 | Severn River at Strathbogie | 0 | 17 | 18 | 13 | 52 |
| 418018 | Keera Creek at Keera | 0 | 12 | 11 | 10 | 67 |
| 418033 | Bakers Creek at Bundarra | 0 | 0 | 0 | 23 | 77 |
| 419016 | Cockburn River at Mulla Crossing | 0 | 1 | 10 | 24 | 65 |
| 419035 | Goonoo Goonoo Creek at Timbumburi | 0 | 26 | 36 | 21 | 16 |
| 419072 | Baradine Creek at Kienbri | 0 | 0 | 0 | 0 | 100 |
| 419077 | Dungowan Creek at Dungowan Dam | 0 | 0 | 0 | 0 | 100 |
| 421026 | Turon River at Sofala | 0 | 1 | 22 | 26 | 51 |
| 421041 | Crudine River at Turon River junction | 0 | 10 | 20 | 22 | 48 |
| 421048 | Little River at Obley No. 2 | 0 | 2 | 18 | 8 | 71 |
| 421055 | Coolbaggie Creek at Rawsonville | 0 | 0 | 0 | 0 | 100 |
| 421066 | Green Valley Creek at Hill End | 0 | 0 | 0 | 1 | 99 |

## 4.4 Current status using combined indicators

Information from a range of data sources that illustrates the current status of salinity across the upland areas of the New South Wales Murray-Darling Basin was presented in Sections 4.1, 4.2 and 4.3. This information has been integrated into a simple assessment procedure that uses multiple criteria including the three salinity indicators, various sources and modelling to provide an overall picture of the current status of salinity across the study area.

Individual data sources and analyses all have inherent limitations owing to paucity of data, data unreliability and uncertainty in analyses. However, combining these information sources using a weight of evidence approach provides a powerful tool to rank and prioritise sub-catchments. The sub-catchment analyses for stream EC, salt exports, end-of-valley impacts, groundwater levels and land salinisation were combined and ranked to develop a single ranking of the current status of salinity. The overall ranking of the current status of salinity for each sub-catchment is presented in Table 25. Jugiong Creek in the Murrumbidgee was consistently ranked as high for current status of salinity across most of the data sources and analyses. When all data sources are combined, Jugiong Creek is the highest ranked sub-catchment across all upland areas of the New South Wales Murray-Darling Basin.

Other sub-catchments that ranked as high for current status of salinity are Muttama Creek, Boorowa River, Bell River, Lachlan River, Myall Creek, Kyeamba Creek, Buckinbah Creek, Back Creek and Mandagery Creek. In many cases, sub-catchments with high areas of land salinisation are also high stream salinity sub-catchments. However, this is not consistent as some sub-catchments; for example Little River and Crookwell River have high levels of land salinisation but this is not reflected in stream salinities. The relevance of each of the data sources across New South Wales would be dependent on the dominant salt mobilisation processes occurring within each sub-catchment. Some data sources and indicators would be appropriate in some areas but totally inappropriate in other areas.

**Table 25:** Rankings of current salinity status for each gauged sub-catchment

| Sub-catchment | EC | Export | Scalds | End-of-valley | DWT < 5m |
|---|---|---|---|---|---|
| 410025 Jugiong Creek at Jugiong | 2 | 7 | 1 | 1 | 1 |
| 410044 Muttama Creek at Coolac | 3 | 8 | 7 | 2 | 13 |
| 412029 Boorowa River at Prossers Crossing | 11 | 19 | 4 | 10 | 6 |
| 421018 Bell River at Newrea | 10 | 16 | 10 | 6 | 16 |
| 412065 Lachlan River at Narrawa | 13 | 15 | 6 | 19 | 9 |
| 418017 Myall Creek at Molroy | 5 | 24 | 21 | 3 | 20 |
| 410048 Kyeamba Creek at Ladysmith | 17 | 18 | 31 | 9 | 3 |
| 421059 Buckinbah Creek at Yeoval | 7 | 37 | 5 | 14 | 15 |
| 412072 Back Creek at Koorawatha | 4 | 35 | 3 | 33 | 21 |
| 412030 Mandagery Creek at U/S Eugowra | 9 | 29 | 11 | 11 | 43 |
| 410047 Tarcutta Creek at Old Borambola | 43 | 26 | 23 | 4 | 10 |
| 421079 Cudgegong River at Windamere Dam | 15 | 41 | 16 | 27 | 7 |
| 418025 Halls Creek at Bingara | 1 | 4 | 48 | 8 | 54 |
| 412077 Belubula River at Carcoar | 20 | 20 | 28 | 44 | 4 |
| 418015 Horton River at Rider | 22 | 14 | 36 | 7 | 40 |
| 412080 Flyers Creek at Beneree | 16 | 3 | 34 | 45 | 24 |
| 421066 Green Valley Creek at Hill End | 6 | 1 | 18 | 26 | 74 |

*continued/*

**Table 25 (cont.):** Rankings of current salinity status for each gauged sub-catchment

| Sub-catchment | EC | Export | Scalds | End-of-valley | DWT < 5m |
|---|---|---|---|---|---|
| 410071 Brungle Creek at Red Hill | 35 | 5 | 49 | 30 | 25 |
| 410008 Murrumbidgee River at Burrinjuck Dam | 56 | 43 | 20 | 15 | 11 |
| 412050 Crookwell River at Narrawa North | 46 | 22 | 2 | 64 | 18 |
| 421042 Talbragar River at Elong Elong | 30 | 67 | 13 | 13 | 29 |
| 419027 Mooki River at Breeza | 14 | 50 | 64 | 24 | 2 |
| 421052 Lewis Ponds Creek at Ophir | 45 | 23 | 22 | 61 | 5 |
| 421053 Queen Charlottes Creek at Georges Plains | 38 | 46 | 24 | 38 | 12 |
| 421101 Campbells River U/S Ben Chifley Dam | 33 | 27 | 38 | 41 | 19 |
| 412092 Coombin Creek near Neville | 23 | 2 | 32 | 46 | 60 |
| 416010 Macintyre River at Wallangra | 37 | 45 | 40 | 5 | 37 |
| 419035 Goonoo Goonoo Creek at Timbumburi | 8 | 13 | 54 | 25 | 67 |
| 419036 Duncans Creek at Woolomin | 27 | 6 | 50 | 53 | 32 |
| 419043 Manilla River at Split Rock Dam | 18 | 42 | 27 | 54 | 27 |
| 410043 Hillas Creek at Mount Adrah | 41 | 10 | 45 | 17 | 56 |
| 421058 Wyaldra Creek at Gulgong | 34 | 64 | 9 | 40 | 23 |
| 421041 Crudine River at Turon River junction | 32 | 17 | 14 | 37 | 71 |
| 419029 Halls Creek at Ukolan | 19 | 38 | 59 | 51 | 14 |
| 418016 Warialda Creek at Warialda No.3 | 26 | 51 | 35 | 22 | 48 |
| 419045 Peel River Chaffey Dam | 21 | 11 | 52 | 67 | 31 |
| 410045 Billabung Creek at Sunnyside | 44 | 69 | 17 | 18 | 36 |
| 418032 Tycannah Creek at Horseshoe Lagoon | 25 | 74 | 25 | 35 | 35 |
| 416020 Ottleys Creek at Coolatai | 12 | 49 | 63 | 12 | 61 |
| 412083 Tuena Creek at Tuena | 40 | 25 | 19 | 57 | 59 |
| 421073 Meroo Creek at Yarrabin 2 | 48 | 30 | 15 | 63 | 44 |
| 416003 Tenterfield Creek at Clifton | 55 | 55 | 42 | 34 | 17 |
| 418018 Keera Creek at Keera | 29 | 40 | 47 | 23 | 64 |
| 416021 Frazers Creek at Westholme | 47 | 39 | 60 | 20 | 38 |
| 419032 Coxs Creek at Boggabri | 52 | 68 | 26 | 52 | 8 |
| 419077 Dungowan Creek at Dungowan Dam | 24 | 9 | 51 | 55 | 69 |
| 412043 Goobang Creek at Darbys Dam | 50 | 71 | 30 | 32 | 28 |
| 410059 Gilmore Creek at Gilmore | 70 | 32 | 44 | 28 | 45 |
| 410038 Adjungbilly Creek at Darbalara | 65 | 28 | 56 | 16 | 55 |
| 410061 Adelong Creek at Batlow Road | 66 | 21 | 55 | 29 | 57 |
| 421072 Winburndale Rivulet at Howards Bridge | 51 | 36 | 33 | 62 | 46 |
| 410103 Houligans Creek at Downside | 74 | 73 | 12 | 31 | 49 |

| Sub-catchment | | EC | Export | Scalds | End-of-valley | DWT < 5m |
|---|---|---|---|---|---|---|
| 419051 | Maules Creek at Avoca East | 39 | 63 | 71 | 42 | 26 |
| 412028 | Abercrombie River at Abercrombie | 54 | 48 | 29 | 72 | 41 |
| 421026 | Turon River at Sofala | 42 | 33 | 41 | 60 | 70 |
| 416036 | Campbells Creek at Deebo | 28 | 65 | 72 | 21 | 62 |
| 419016 | Cockburn River at Mulla Crossing | 36 | 31 | 57 | 59 | 66 |
| 419072 | Baradine Creek at Kienbri | 31 | 70 | 37 | 43 | 68 |
| 421048 | Little River at Obley No. 2 | 58 | 62 | 8 | 56 | 72 |
| 421035 | Fish River at Tarana | 69 | 54 | 39 | 69 | 30 |
| 416026 | Reedy Creek at Dumaresq | 59 | 57 | 67 | 48 | 33 |
| 419005 | Namoi River at North Cuerindi | 53 | 47 | 62 | 73 | 34 |
| 410073 | Tumut River at Oddys Bridge | 73 | 12 | 53 | 74 | 58 |
| 418022 | Georges Creek at Clerkness | 64 | 58 | 68 | 58 | 22 |
| 418029 | Gwydir River at Stoneybatter | 49 | 52 | 65 | 66 | 39 |
| 416032 | Mole River at Donaldson | 61 | 59 | 46 | 68 | 47 |
| 418021 | Laura Creek at Laura | 63 | 53 | 66 | 50 | 51 |
| 418023 | Moredun Creek at Bundarra | 60 | 44 | 61 | 65 | 53 |
| 410057 | Goobarragandra River at Lacmalac | 72 | 34 | 58 | 71 | 50 |
| 418005 | Copes Creek at Kimberley | 67 | 60 | 69 | 49 | 42 |
| 416039 | Severn River at Strathbogie | 57 | 56 | 43 | 70 | 63 |
| 416008 | Beardy River at Haystack | 62 | 61 | 70 | 47 | 52 |
| 418033 | Bakers Creek at Bundarra | 68 | 66 | 73 | 36 | 65 |
| 421055 | Coolbaggie Creek at Rawsonville | 71 | 72 | 74 | 39 | 73 |

# 5 Future trends in salinity

Future trends in salinity can be estimated from statistical analyses or from simulation modelling. However, trend analysis is a simplistic representation of a complex system and has a number of different interpretations over different timeframes. Trends in salinity can occur within timeframes of seasons to years to decades to centuries. The drivers that cause trends over different timeframes also vary considerably. Over the shorter seasonal to annual timeframes, salinity can vary considerably with climatic patterns and local land use change influences. These types of short-term variations have been termed cyclicity in the stream EC trend analyses described in Section 3.3 of this report. Salinity trends over decades to centuries reflect the hydrological system adjusting to a new equilibrium. Many of the trends that can be derived from monitoring data are more likely to be locally observed fluctuations in land salinisation or stream EC rather than a longer term trend.

While there can be little doubt that many areas of the upland New South Wales Murray-Darling Basin are in hydrological equilibrium, there is conjecture whether all these systems have reached equilibrium in salinity. Hydrological equilibrium occurs when groundwater discharge from an aquifer is in equilibrium to the recharge inputs. This is often caused by pressure responses and not the time it takes for individual molecules of water to move through an aquifer. In a small groundwater system in a higher rainfall area, the local recharge at any given location has a significant and rapid influence on the local watertable level. In large groundwater systems, such as intermediate and regional systems, the influence of the lateral water flux on local watertable position assumes increasing significance with distance away from the principal recharge zone. Thus the time for the groundwater level to adjust to changes occurring across the wider recharge area is a function of the contributing volume and transmissivity of the aquifer. Other factors, such as confinement of the aquifer, will also affect how quickly changes in hydraulic head are propagated through the system.

Preliminary modelling suggests that a hydrologic equilibrium does not necessarily mean salinity equilibrium. The response times for salt stores to reach a new equilibrium across a landscape tend to be much longer than hydrological response times. For salinity equilibrium to be reached, molecules of salt must be mobilised, moved and redistributed; a hydrological pressure response alone will not produce the same effect.

For the purpose of reporting, salinity trends are the background trends independent of climatic fluctuations, land use change and climate change. As such, a trend is a derived statistic that cannot be continuously compared with measured data, which have inherent fluctuations resulting from climate and land use changes. In order to better define trends, the Murray-Darling Basin Commission Schedule C introduced some major concepts.

The *benchmark period* is used to standardise climate variability. It is an observed climatic sequence over a defined period, which is currently 1 May 1975 to 30 April 2000. The benchmark period is used consistently in the Basin Salinity Management Strategy as a basis for simulating groundwater movements and river behaviour at other scenario dates (for example 2015, 2050 and 2100).

*Baseline conditions* are defined as an agreed suite of conditions in place within the catchments and rivers on 1 January 2000 for land use, water use (level of diversions from the rivers), land and water management policies and practices, river operating regimes and groundwater status and condition.

Analyses are undertaken to predict the trends in daily flows, salinities and salt loads at a target site under baseline conditions. Further simulations of 'no further intervention' daily flows, salinities and salt loads at key dates (for example, 2000, 2015, 2050, 2100) can then be undertaken. The preferred approach under the Basin Salinity Management Strategy is to employ accredited models that use the *benchmark period* as the period of simulation.

To produce trend estimates for future dates up to 2100, simulation models have been set up for six consecutive cycles of the benchmark period. This is an artificial simulation of 150 years where results are extracted on a probabilistic basis for future dates. The first cycle of the benchmark period (1975–2000) is used for model calibration. The second cycle of the benchmark period is the simulation for baseline conditions as it will automatically have 2000 starting conditions. The third cycle of the benchmark period provides trends for 2025 starting conditions. The fourth, fifth and sixth cycles can be used to derive trends for 2050, 2075 and 2100 starting conditions.

## 5.1 Land area salinised

For land area salinised, it is not possible to produce any estimates of future trends. However, the analyses described in Section 3.2, did produce estimates of the potential minimum and maximum extents of land salinisation. These estimates are summarised on a sub-catchment basis in Table 26. However, this analysis is a preliminary attempt to predict spatial extents of land salinisation. The results should be viewed with caution because they only consider salt outbreaks that have currently been mapped and not the initiation of new saline sites in other areas. The analyses assume that the expansion potential of salt outbreak sites is limited by topography. Other factors such as geological constrictions are not included, nor can they currently be included owing to paucity of appropriate data. The additional limitations as discussed in Section 3.2 must also be considered.

**Table 26:** Estimated minimum and maximum land salinisation extents (ha)

| Sub-catchment | | Minimum | Maximum |
|---|---|---|---|
| 410008 | Murrumbidgee River at Burrinjuck Dam | 4136 | 4718 |
| 410025 | Jugiong Creek at Jugiong | 6227 | 7943 |
| 410043 | Hillas Creek at Mount Adrah | 40 | 44 |
| 410044 | Muttama Creek at Coolac | 2925 | 3345 |
| 410045 | Billabung Creek at Sunnyside | 854 | 1170 |
| 410047 | Tarcutta Creek at Old Borambola | 30 | 45 |
| 410048 | Kyeamba Creek at Ladysmith | 179 | 320 |
| 410059 | Gilmore Creek at Gilmore | 25 | 29 |
| 410103 | Houligans Creek at Downside | 491 | 825 |
| 412028 | Abercrombie River at Abercrombie | 207 | 261 |
| 412077 | Belubula River at Carcoar | 74 | 87 |
| 412080 | Flyers Creek at Beneree | 6 | 9 |
| 412083 | Tuena Creek at Tuena | 92 | 124 |
| 412092 | Coombin Creek near Neville | 6 | 9 |
| 416003 | Tenterfield Creek at Clifton | 6 | 12 |
| 416032 | Mole River at Donaldson | 6 | 95 |
| 416039 | Severn River at Strathbogie | 3 | 51 |
| 418015 | Horton River at Rider | 57 | 136 |
| 418016 | Warialda Creek at Warialda No.3 | 22 | 36 |
| 418017 | Myall Creek at Molroy | 182 | 301 |
| 418018 | Keera Creek at Keera | 1 | 2 |

*continued/*

**Table 26 (cont.):** Estimated minimum and maximum land salinisation extents (ha)

| Sub-catchment | | Minimum | Maximum |
|---|---|---|---|
| 418032 | Tycannah Creek at Horseshoe Lagoon | 535 | 1131 |
| 419072 | Baradine Creek at Kienbri | 24 | 59 |
| 421018 | Bell River at Newrea | 1025 | 1802 |
| 421026 | Turon River at Sofala | 13 | 24 |
| 421035 | Fish River at Tarana | 12 | 28 |
| 421041 | Crudine River at Turon River junction | 153 | 275 |
| 421042 | Talbragar River at Elong Elong | 1538 | 2325 |
| 421048 | Little River at Obley No. 2 | 546 | 915 |
| 421052 | Lewis Ponds Creek at Ophir | 56 | 182 |
| 421053 | Queen Charlottes Creek at Georges Plains | 23 | 54 |
| 421058 | Wyaldra Creek at Gulgong | 808 | 981 |
| 421059 | Buckinbah Creek at Yeoval | 1037 | 1651 |
| 421066 | Green Valley Creek at Hill End | 13 | 57 |
| 421072 | Winburndale Rivulet at Howards Bridge | 29 | 60 |
| 421073 | Meroo Creek at Yarrabin 2 | 113 | 468 |
| 421079 | Cudgegong River at Windamere Dam | 422 | 626 |
| 421101 | Campbells River U/S Ben Chifley Dam | 37 | 52 |

## 5.2 Stream salinity

The two potential sources of information to quantify trends in stream salinity were described in Sections 3.3 and 3.5. The stream EC analyses in Section 3.3 fitted statistical models to stream EC data collected across the upland areas of the New South Wales Murray-Darling Basin. The simulation modelling described in Section 3.5 comprised simulations to estimate stream EC trends at 2020, 2050 and 2100 and was based on sub-catchments defined for the IQQM water allocation modelling. Despite the differences in sub-catchment definitions, there are quite a number of similarities.

Both analyses highlighted the fact that many sub-catchments appear to be in hydrological equilibrium with either stable or slightly falling EC trends. It must be remembered that all estimated trends are small in magnitude. Some sub-catchments have been classified on the basis of a ±1% change in stream EC. Given uncertainties in flow data, stream EC data, statistical analyses and modelling, such small differences are virtually meaningless for catchment planning.

The stream EC trend analysis showed that except for the Mooki River catchment, all the Northern catchments have linear coefficients of less than 0.01, with the greater proportion of these less than zero. In the central part of the State, the linear coefficients tend to be positive, although typically not significant. In the south, there is a higher incidence of catchments with significant positive coefficients, indicating more significant rising trends over the period of record.

Predicted increases in end-of-valley salt loads for 2020, 2050 and 2100 are shown in Table 27. Overall, stream salt load trends are small for all valleys, with a maximum increase of 8.62% for the Gwydir valley at 2100.

**Table 27:** Percentage increases in salt loads at 2020, 2050 and 2100

| Valley | 2020 | 2050 | 2100 |
|---|---|---|---|
| Border Rivers | 0.62 | 1.13 | 1.85 |
| Gwydir | 4.39 | 6.46 | 8.62 |
| Namoi Peel | 1.46 | 2.22 | 3.43 |
| Macquarie | 2.33 | 2.88 | 3.50 |
| Lachlan | 1.11 | 1.81 | 2.79 |
| Murrumbidgee | 0.32 | 0.53 | 0.85 |

## 5.3 Groundwater trends

There are insufficient data to apply analytical tools to quantify future groundwater levels across the upland areas of the New South Wales Murray-Darling Basin. The groundwater trend analysis discussed in Section 3.4 showed three distinct phases in overall climate behaviour: a wet phase before 1894, a dry phase between 1895 and 1947, and a wet phase again until the end of the century. The 1947 shift from a relatively dry phase to a significantly wetter one was a significant driver of the groundwater level rises, which appear to have occurred across much of the State in the years following the change. Groundwater response times were found to be spatially variable, but generally conforming to a pattern of increasing lag time with distance from the higher recharge areas. In the Murray-Darling Basin, the main recharge areas are the higher rainfall upland catchments near the Great Divide. Lag times are generally less than 10 years, and often less than 3 years in these upland groundwater systems. In catchments more distant from the main recharge areas, which also tend to be lower in relief and have less annual rainfall, adjustments in groundwater levels to long term changes in rainfall regime appear to be lagged by up to 20 years.

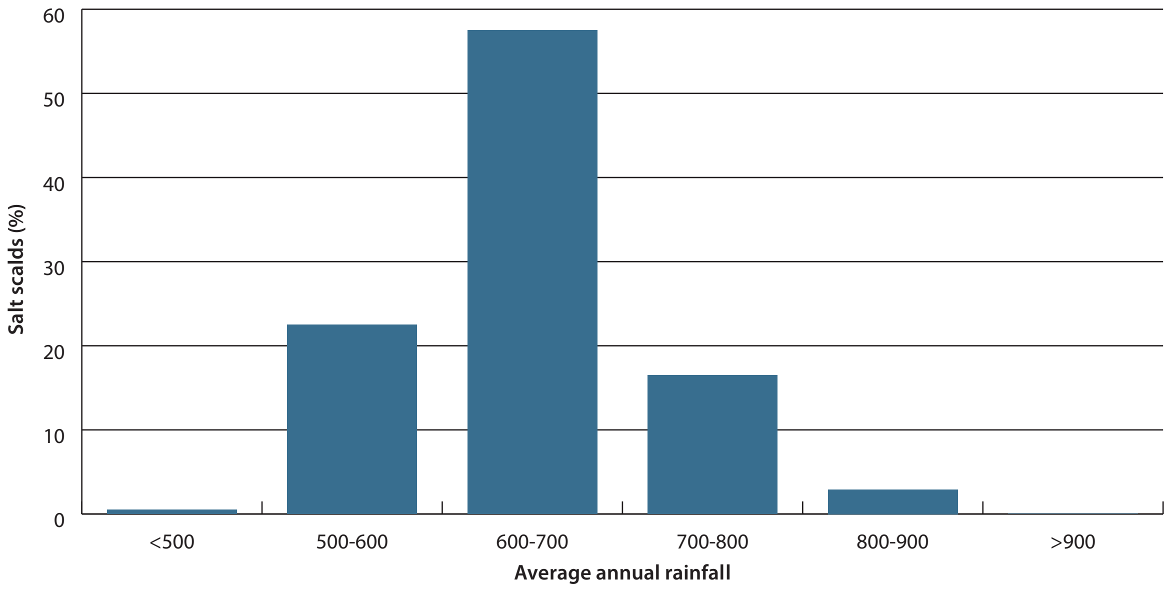
# 6 Spatial variability in salinity processes

This chapter explores the biophysical factors that can illustrate the processes by which salinity in manifested in its various forms across the upland areas of the New South Wales Murray-Darling Basin. This is done by comparing the results for land area salinised, stream salinity and groundwater level against relevant contextual data sources from Chapter 2.

## 6.1 Land area salinised

A major driver of land area salinised is the surplus of rainfall during winter months. Of all the saline outbreaks currently mapped, 82% occur in the winter surplus rainfall zone defined in Figure 3. Figure 49 shows the percentage areas of salt scalds occurring in each average annual rainfall zone. Almost 60% of all salt scalds occur in the 600–700 mm rainfall zone and 97% of all salt scalds occur in the 500–800 mm rainfall zone.

**Figure 49:** Distribution of salt scalds for each rainfall zone



Other factors such as groundwater flow system and soil types can also influence the occurrence of saline outbreaks. Figure 50 shows the distribution of salt scalds across groundwater flow systems and the distribution of groundwater flow systems across the whole study area. Saline outbreaks are more evident in combined intermediate and local flow systems in fractured rock aquifers and less evident in purely local flow systems in fractured rock aquifers and in regional flow systems in alluvial aquifers. Initially, differences between the extents of saline outbreaks between 'intermediate and local flow systems in fractured rock aquifers' and 'local flow systems in fractured rock aquifers' appears confusing. However, it must be remembered that the local flow systems in fractured rock aquifers are clearly defined local systems, while the intermediate and local flow systems in fractured rock aquifers are less well defined and are larger connected systems. Therefore, groundwater flow systems with longer flow paths may drive the development of saline outbreaks because they have greater areas of contribution to the groundwater discharge sites.

**Figure 50:** Distribution of salt scalds for each groundwater flow system

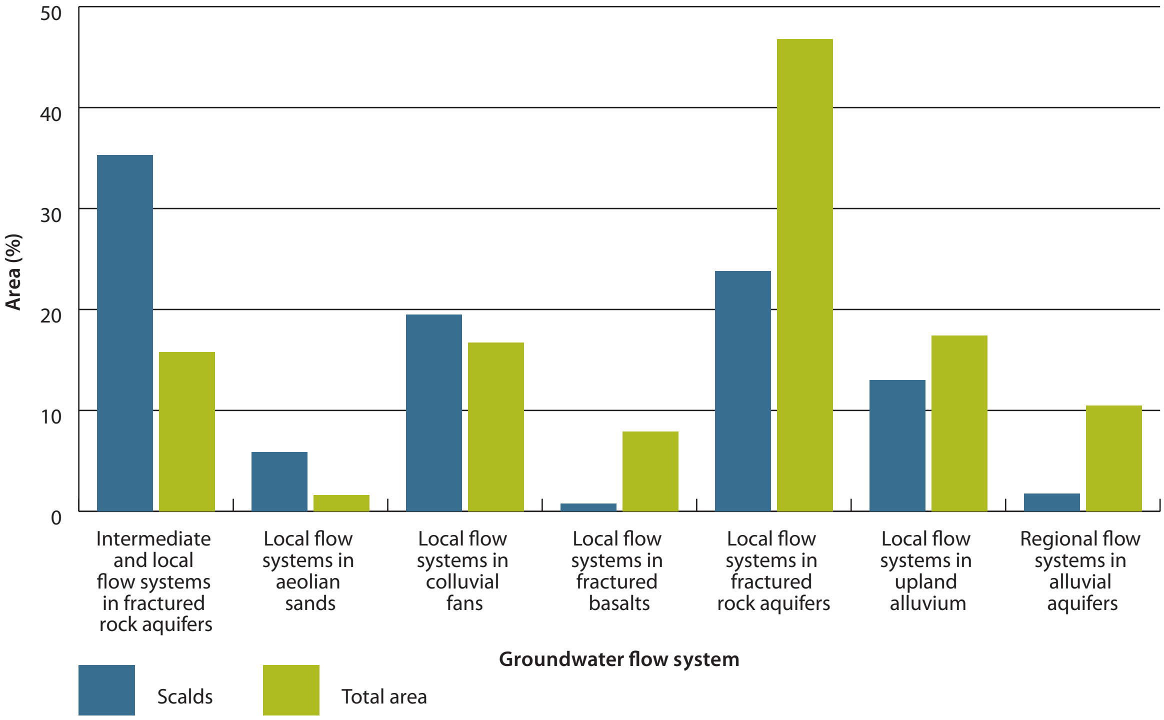
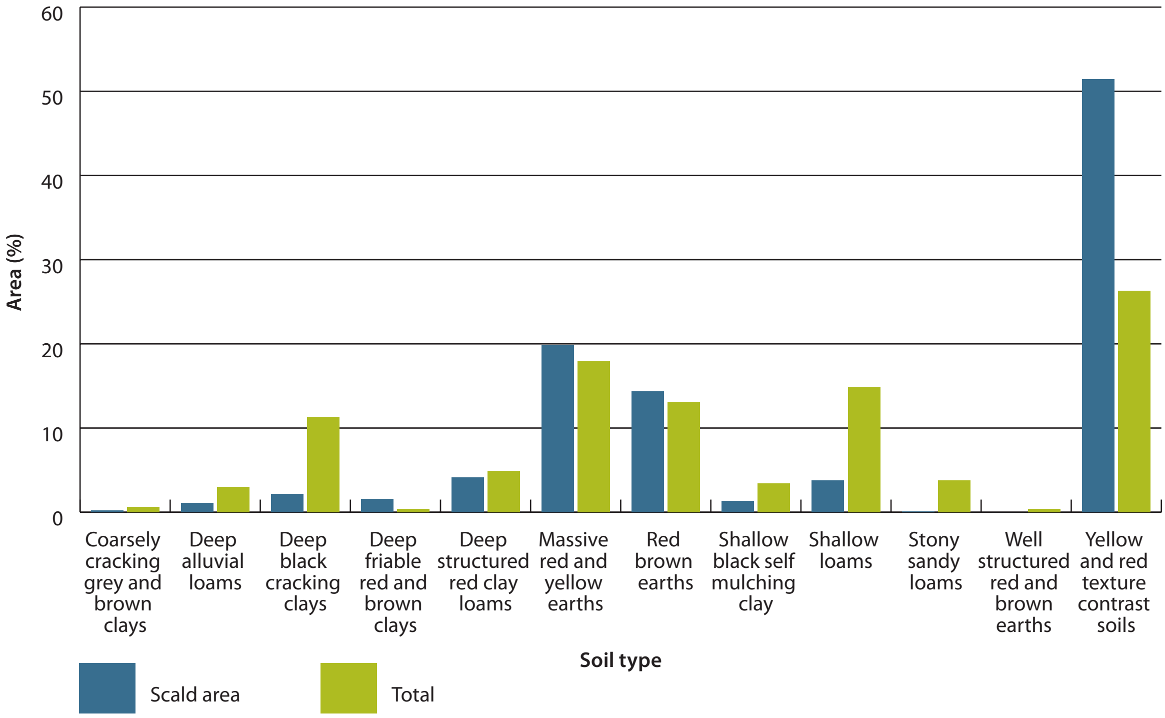


Figure 51 shows the distribution of salt scalds across soil types and the distribution of soils across the whole study area. Saline outbreaks are most evident in the red and yellow texture contrast soils because of the presence of lateral flow pathways at the soil horizon interface and likely subsoil salt stores.

**Figure 51:** Distribution of salt scalds for each soil type



## 6.2 Groundwater levels

Spatial variability in the depth to watertable map presented in Section 2.1 has also been explored. The greatest percentage areas of depth to watertable less than 5 m occur in the 500–600 mm rainfall zone (Figure 52). Smaller areas with shallow watertables in higher rainfall areas suggest that other factors such as topography, land use and groundwater characteristics are also important. Figure 53 compares the distribution of shallow watertables less than 5 m across all groundwater flow systems to the distribution of groundwater flow systems across the whole study area. In absolute terms, the majority of shallow watertables occur in local flow systems in upland alluvium, local flow systems in fractured rock, or intermediate and local flow systems in fractured rock. In relative terms, shallow watertables are less likely to occur in the small local groundwater flow systems in fractured rock than in larger, local to intermediate flow systems in fractured rock, because of the steeper topography, longer flow paths and lower degree of groundwater confinement.

**Figure 52:** Relationship between average annual rainfall and depth to watertable < 5 m

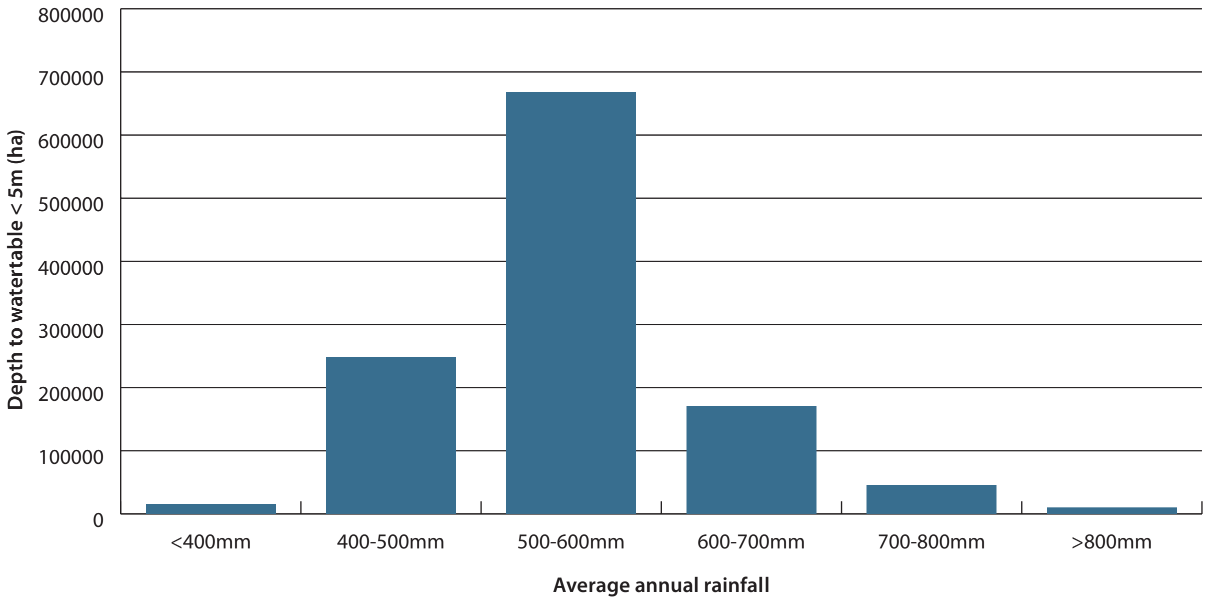
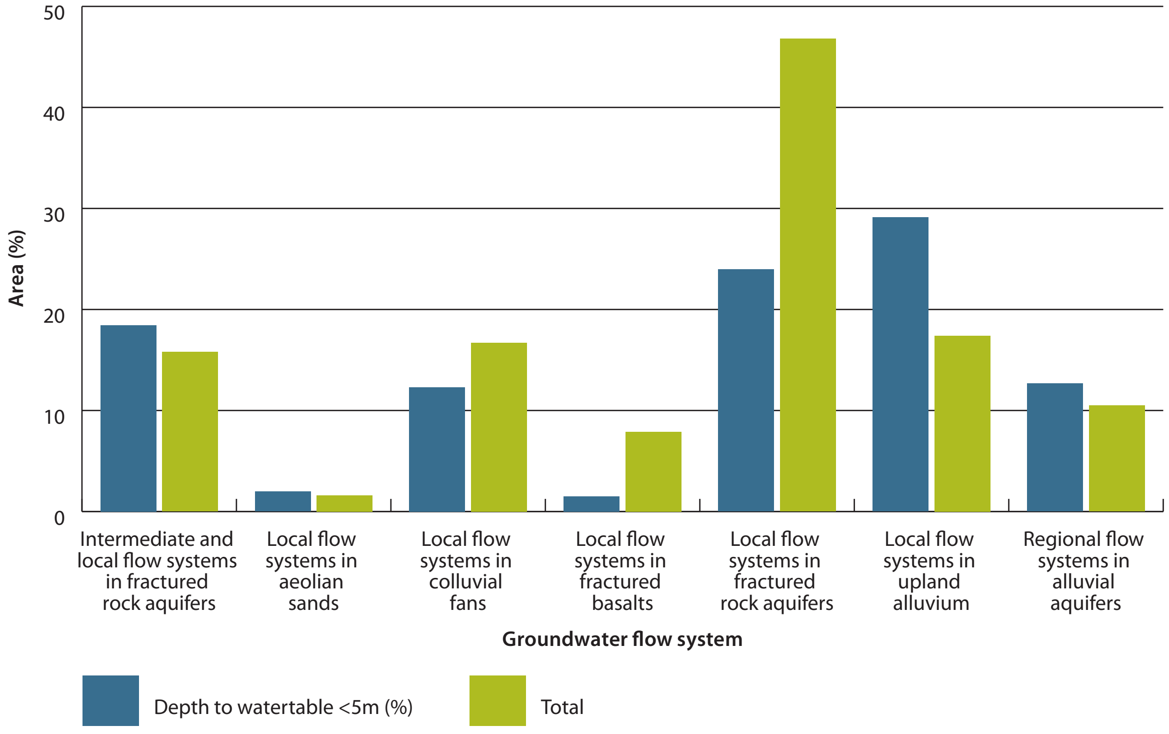


**Figure 53:** Relationship between groundwater flow system and depth to watertable < 5m



## 6.3 Discussion

In the majority of sub-catchments, there is little or no underlying long-term rising trend. Instead, the extent of salinity expression is varying in response to wet and dry conditions. There is evidence of a lag of several years between the wetter periods in our climate and the expression of salinity as surface discharge, or in-stream salinity.

Many conceptual models of salinity assume increases in stream or land salinisation following an increase in recharge regime. If recharge rates increase, then the receiving aquifers must accommodate the increase through some combination of increasing storage and increasing discharge rate. Within the upland areas of the New South Wales Murray-Darling Basin, there are a number of groundwater flow systems models that affect different expressions of salinity record.

- *Connected groundwater – surface water systems in the 500–800 mm rainfall zones*: In areas where local groundwater aquifers permanently or occasionally intersect the stream network, an increase in recharge regime will increase the relative contribution of groundwater flow to stream flow. If the groundwater is more saline than the stream flow contributions from other pathways (either inherently so or through mobilisation of salts from an untapped salt store), then the stream salinity will increase to reflect the greater groundwater contribution.
- *Disconnected groundwater – surface water systems in the <800 mm rainfall zones*: In areas where the groundwater table is disconnected from the stream network and an increase in recharge regime is not sufficient to raise the groundwater levels to intersect the local drainage network, then the stream flow record will not necessarily experience a rise in average stream salinity. Stream salinities will be governed by the export of salts from surface and shallow subsurface pathways. The evidence suggests that the surface – ground water connection becomes less permanent with distance northward and/or westward, as the rainfall distribution becomes more uniform and events more episodic and winter evapotranspiration assumes greater significance.
- *Alluvial aquifers:* In catchments with significant areas of alluvium, the alluvial aquifer can be a significant source of saline water. The alluvial aquifer is recharged by catchment runoff and sub-surface lateral flow from the surrounding hillslopes or by a hydrologic connection with an underlying groundwater aquifer. Low hydraulic gradients in the alluvial sediments mean that under an increased recharge regime, water collects in the alluvial basin at a faster rate than it drains, and the watertable rises. As the watertable approaches the ground surface, evapotranspiration draws water out of the aquifer, leaving the salts behind. The salinity of the remaining groundwater and alluvial discharges to the stream increase. If an increase in the recharge regime of the catchment occurs, groundwater levels will rise in the alluvial aquifer and the underlying hillslope aquifer. The salinity of stream flow will change to reflect the relative significance of catchment inputs, ET losses, horizontal discharge rates and overtopping of the alluvial aquifer under the new recharge regime.
- *Geological structures*: In catchments underlain by fractured rock aquifers, geological structures such as lineaments, dykes, bedrock highs, faults and fracture or shear zones can act as conduits for ground water between aquifers at varying depths and the ground surface. An increase in the recharge regime of these fractured rock aquifers would be expected to increase artesian pressure and/or cause watertables to rise, leading to an increase in the rate of discharge via existing and potentially new geologically-controlled flowpaths. Stream salinities in the Talbragar River, and possibly the neighbouring Butheroo Creek are being influenced by groundwater discharges along geophysical controls.

Every sub-catchment cannot be summarised in terms of just one groundwater flow model. In any given catchment, a range of surface – ground water connections could be occurring, highlighting the difficulty of distilling fundamental salinity processes from data that are integrated across large areas.

The onset of drought conditions during the 1990s has affected salinity levels. For perennial streams, an increase in stream EC due to increasingly dry conditions could be expected, due to lack of surface flow events. This increases the significance of the base flow in terms of flow and salinity. For ephemeral catchments the frequency of runoff events will decrease. The interactions between less runoff and salt wash off are complex. Stream salinities could increase or decrease depending on the level of salt accumulation and its spatial pattern throughout the catchment. Stream salinities could decrease for some catchments that shift from perennial to ephemeral owing to saline groundwater levels receding below the stream bed.

Unfortunately, identifying points in the stream EC data that signal such an impact are hampered by the widespread break in salinity data collection during the 1990s. There is a general pattern of decreasing salinity trends in Murrumbidgee catchments, tending to relatively flat responses in the Lachlan, but switching to increasing trends in the Macquarie and Castlereagh catchments. In the northern catchments, most data sets show slightly decreasing or stable salinities in the last 10 years. The salinity response is likely to reflect a change in the relative significance of each of the flow paths contributing to stream flow.

# 7 Summary and recommendations

The 1999 Salinity Audit predicted large rising trends in salinity across inland New South Wales. The results of the 1999 Audit formed the basis of the interim end-of-valley salinity targets for inland valleys set out in the NSW Salinity Strategy, the Murray-Darling Basin Salinity Strategy and Catchment Action Plans and Investment Strategies. This Salinity Audit update takes advantage of the advances in scientific understanding of salinity and the improvements in data and technology that have become available during the period since the 1999 Audit was completed. This has enabled us to make more reliable estimates of the current status and future trends in salinity.

While the analyses undertaken as part of this Audit indicate that earlier predictions about the severity of dryland salinity impacts in 2020, 2050 and 2100 were over-estimated, the revised predictions should not be interpreted as indicating no salinity problem. There is substantial evidence from across the State that the concentration of salts at or near the land surface and the discharge of salts into streams are contributing to problems of poor water quality, decreasing agricultural productivity, dieback of native vegetation, increasing soil erosion and damage to roads, buildings, and bridges, etc. In addition, the stream salinity trend analyses identified a number of catchments where salinity levels appear to be on the increase, and other catchments where a recent downturn in salinity levels due to drought might be concealing an otherwise rising trend.

Only some sub-catchments are now seen to have increasing salinity trends. For many sub-catchments, salinity management actions would be better focused towards reducing the cyclical variations in stream salinity due to climate variation. As a general rule, the variability in stream salinity as determined by rainfall volume, timing and distribution, catchment morphology and the location of salt stores within the landscape is much greater than the influence from longer-term rising or falling trends.

This Audit update has highlighted the spatial variability of dominant salt mobilisation processes occurring across New South Wales. Some indicators of salinity would be appropriate for use in some areas but totally inappropriate in other areas. It is unlikely that there could be a set of 'standard' indicators that could be uniformly applied across all climatic zones of New South Wales. Salinity management options would be better based on multiple criteria that reflect the inherently large seasonal, annual and decadal fluctuations in salinity rather than an arbitrary trend line derived statistically with limited statistical and scientific confidence.

There are certainly catchments which need to be monitored more closely and there are areas where saline outbreaks are causing problems, but from a management perspective, the challenge is not so much about managing for the advent of future problems, but about containing or reducing existing problems.

## 7.1 Recommendations for further work

The analyses presented in this report can be further improved to overcome some of the limitations with current data and analytical tools. A number of specific recommendations can be made based on the experience of this Audit update. These include:

- Greater efforts should be made to amalgamate groundwater and stream EC data across existing sources and agencies into a single database.
- Modelling should be undertaken to explore the salinity impacts of global warming and different rainfall regimes.
- A pre-European settlement scenario should be modelled to help quantify the magnitude of the post-settlement land use change impact, and help identify areas where management has the greatest potential to reduce salt exports.
- Catchments in which stream salinity levels appear to have undergone a dramatic increase during the period of record should be investigated more fully. In particular the Houligans, Bland, Goobang, Billabung and Yass sub-catchments require longer records of stream EC data.
- An impacts analysis to identify assets at risk from salinity needs to be conducted using the spatial information discussed in this report.
- Irrigation and urban salinity remain significant issues that need better management and increased scientific understanding.

## 7.2 Implications for salinity management

There is no one single cause for dryland salinity because salt mobilisation processes vary considerably across New South Wales. Much of the salinity in the upland areas of the New South Wales Murray-Darling Basin relates to local groundwater systems in fractured rock aquifers that respond to rainfall and recharge much more quickly than previously thought. There is a need to manage these cyclical variations in salinity caused by alternating wet and dry periods in our climate.

The information contained in this report will be valuable to support the identification of priority sub-catchments across the New South Wales Murray-Darling Basin. While in some cases this report will only confirm the existing prioritisation already completed by catchment management authorities, the additional information and analyses that have been compiled as part of this Audit will provide more confidence in catchment prioritisation. Sub-catchments can now be assessed using a wide range of indicators instead of one single indicator, for example stream EC.

In New South Wales, salinity remediation focuses on farm-based options including targeted tree planting on recharge areas, increased perenniality and changes to conservation farming practices. The catchment management authorities have the responsibility to plan and implement these changes and liaise with land managers to implement the best solutions. Land management practices can improve local outbreaks or discharge areas. This in turn may reduce the level of cyclicity seen in stream EC records. Most of the benefits for on-ground actions are likely to be seen at the local scale.

The current drought is not the reason for earlier salinity predictions of rising trends being revised. The drought is causing the current low levels of salt loads, but the revised predictions for salinity are a result of better application of knowledge and improved modelling. When the drought breaks, water will again mobilise salts in the landscape.

## 7.3 Key findings

- Groundwater analyses have confirmed that a large hydrological shift driven by climate occurred around 1947.
- The influence of land use change on this hydrological shift is yet to be quantified but is likely to be a second order effect compared to climate.
- Most areas of the upland Murray-Darling Basin in New South Wales now appear to be in a new hydrological equilibrium.
- Estimates of current salinity in New South Wales are similar to those of the original 1999 Salinity Audit.
- Estimates of future trends in salinity in the 1999 Salinity Audit have now been substantially reduced. The 1999 Audit extrapolated trends into the future, but because of the lack of data and analytical tools in 1999, could not account for systems reaching a new equilibrium and stabilising.
- Results from this report confirm that salinity is currently a major natural resource management issue in New South Wales but suggest that it is unlikely to exponentially increase into the future.
- Previously, the rationale behind salinity implementation was to slow down the rate of increase of salinity. The results from this Audit indicate that rather than slowing down the rate of increase, it is now feasible to implement land management changes that will improve salinity levels in upland areas of the New South Wales Murray-Darling Basin.
- A new management issue that has been identified is the cyclicity of salinity over time and the need to implement works to minimise the peaks of salinity.

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# Appendix A: Sub-catchment summaries of contextual data

**Table A1:** Border Rivers summary of contextual data

| | 416003 | 416008 | 416010 | 416020 | 416021 | 416026 | 416032 | 416036 | 416039 |
|---|---|---|---|---|---|---|---|---|---|
| Area (km$^2$) | 531 | 903 | 2136 | 374 | 821 | 284 | 1583 | 319 | 1746 |
| Average annual rainfall (mm) | 819 | 739 | 761 | 718 | 727 | 735 | 839 | 629 | 850 |
| Winter surplus | No | No | No | No | No | No | No | No | Yes |
| Flow (ML) | 45168 | 65674 | 130176 | 14086 | 66801 | 23659 | 121968 | 8935 | 151318 |
| Saltload (t) | 4142 | 4694 | 18507 | 3631 | 8103 | 1884 | 8946 | 1599 | 13079 |
| Salt export (t km$^{-2}$) | 8 | 5 | 9 | 10 | 10 | 7 | 6 | 5 | 7 |
| Deep alluvial loams ('000 ha) | | | | | | 1 | 1 | | |
| Deep black cracking clays ('000 ha) | | 7 | 110 | 27 | 5 | | | | 24 |
| Deep structured red clay loams ('000 ha) | | 8 | 40 | | 32 | | | | 58 |
| Shallow loams ('000 ha) | | | 6 | 10 | | | | | |
| Stony sandy loams ('000 ha) | 12 | 32 | 11 | | 11 | 12 | 62 | 2 | 5 |
| Structured red & brown earths ('000 ha) | | | | | | | 2 | | |
| Yellow & red texture contrast soils ('000 ha) | 41 | 43 | 47 | | 34 | 15 | 94 | 30 | 87 |
| Lower slopes ('000 ha) | 3 | 6 | 12 | 4 | 5 | 2 | 14 | 12 | 12 |
| Mid slopes ('000 ha) | 23 | 33 | 93 | 15 | 29 | 12 | 65 | 9 | 73 |
| Upper slopes ('000 ha) | 19 | 36 | 70 | 13 | 34 | 11 | 47 | 3 | 60 |
| Crests ('000 ha) | 10 | 15 | 39 | 5 | 13 | 4 | 32 | 7 | 29 |
| Alluvial area (%) | 5 | 3 | 8 | 3 | 0 | 1 | 3 | 49 | 9 |
| Cropping ('000 ha) | 1 | 3 | 74 | 12 | 15 | <1 | 1 | <1 | 8 |
| Pasture ('000 ha) | 24 | 46 | 110 | 22 | 49 | 7 | 74 | 8 | 134 |
| Trees ('000 ha) | 14 | 40 | 27 | 4 | 17 | 22 | 52 | 23 | 28 |
| Other ('000 ha) | <1 | 2 | 3 | | 1 | <1 | <1 | <1 | 3 |

*continued/*

**Table A1 (cont.):** Border Rivers summary of contextual data

| | 416003 | 416008 | 416010 | 416020 | 416021 | 416026 | 416032 | 416036 | 416039 |
|---|---|---|---|---|---|---|---|---|---|
| Intermediate & local flow in fractured rock ('000 ha) | 12 | 15 | 45 | 3 | 27 | 1 | 12 | 1 | 43 |
| Local systems in aeolian sands ('000 ha) | | <1 | 3 | 1 | | <1 | <1 | | <1 |
| Local systems in colluvial fans ('000 ha) | 21 | 22 | 48 | | 1 | 16 | 59 | 5 | 16 |
| Local systems in fractured basalts ('000 ha) | | 10 | 93 | 26 | 19 | <1 | 2 | | 50 |
| Local systems in fractured rock aquifers ('000 ha) | 22 | 42 | 12 | 6 | 29 | 11 | 84 | 25 | 50 |
| Local systems in upland alluvium ('000 ha) | | 1 | 12 | 2 | 7 | <1 | 1 | 1 | 14 |
| Regional systems in alluvial aquifers ('000 ha) | | | | | | | | <1 | |
| Mesozoic sedimentary rocks ('000 ha) | | | 1 | 6 | | | | 22 | |
| Cainozoic alluvium ('000 ha) | | 2 | 12 | 3 | 7 | <1 | 1 | 1 | 14 |
| Cainozoic volcanics ('000 ha) | | 12 | 125 | 29 | 24 | <1 | 2 | | 59 |
| Cainozoic residual and aeolian sands ('000 ha) | | <1 | 3 | 1 | | <1 | <1 | | <1 |
| Late Palaeozoic metasedimentary rocks ('000 ha) | 2 | 27 | 17 | | 15 | 12 | 36 | 4 | 13 |
| Granitoids ('000 ha) | 21 | 22 | 48 | <1 | 1 | 16 | 59 | 5 | 16 |
| Late Palaeozoic volcanics ('000 ha) | 32 | 27 | 7 | | 36 | <1 | 60 | | 72 |
| Depth to watertable <5 m ('000 ha) | 4 | <1 | 4 | | 2 | 1 | 1 | | |
| Depth to watertable 5–10 m ('000 ha) | 4 | <1 | 17 | 3 | 2 | 1 | 10 | 1 | 30 |
| Depth to watertable 10–15 m ('000 ha) | 4 | 3 | 37 | 6 | 3 | 1 | 12 | 2 | 31 |
| Depth to watertable 15–20 m ('000 ha) | 5 | 10 | 26 | 8 | 16 | 1 | 12 | 3 | 23 |
| Depth to watertable >20 m ('000 ha) | 38 | 77 | 128 | 20 | 60 | 24 | 122 | 26 | 91 |
| Number of groundwater monitoring bores | | 1 | 12 | | 2 | | | | 1 |

416003 Tenterfield Creek at Clifton, 416008 Beardy River at Haystack ,416010 Macintyre River at Wallangra, 416020 Ottleys Creek at Coolatai, 416021 Frazers Creek at Westholme, 416026 Reedy Creek at Dumaresq, 416032 Mole River at Donaldson, 416036 Campbells Creek at Deebo, 416039 Severn River at Strathbogie

**Table A2: Gwydir summary of contextual data**

| | 418005 | 418015 | 418016 | 418017 | 418018 | 418021 | 418022 | 418023 | 418025 | 418029 | 418032 | 418033 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area (km$^2$) | 235 | 1954 | 535 | 871 | 556 | 344 | 525 | 668 | 171 | 1986 | 837 | 186 |
| Average annual rainfall (mm) | 875 | 770 | 737 | 750 | 760 | 866 | 861 | 871 | 748 | 792 | 709 | 806 |
| Winter surplus | No | No | No | No | No | Yes | Yes | Yes | No | Yes | No | No |
| Flow (ML) | 23621 | 189036 | 23950 | 34581 | 32376 | 34165 | 48288 | 83623 | 7596 | 143522 | 31148 | 12323 |
| Saltload (t) | 1380 | 38712 | 4482 | 12207 | 5648 | 2387 | 3157 | 6136 | 4296 | 15101 | 5936 | 633 |
| Salt export (t km$^{-2}$) | 6 | 20 | 8 | 14 | 10 | 7 | 6 | 9 | 25 | 8 | 7 | 3 |
| Cracking grey & brown clays ('000 ha) | | | | | | | | | | | 24 | |
| Deep black cracking clays ('000 ha) | 1 | | 31 | 28 | | | | | | | 3 | |
| Deep friable red and brown clays ('000 ha) | | | | | | | | | | | | |
| Deep structured red clay loams ('000 ha) | | | 3 | 10 | | 9 | 14 | 20 | | 6 | | |
| Massive red and yellow earths ('000 ha) | | | | | | | | | | | | |
| Red brown earths ('000 ha) | | 73 | 14 | 25 | | | | | 11 | | 14 | |
| Shallow black self-mulching clay ('000 ha) | | 4 | | | | | | | | | | |
| Shallow loams ('000 ha) | | 76 | | 2 | 37 | 8 | 10 | | 6 | 30 | 19 | 11 |
| Stony sandy loams ('000 ha) | 4 | | | 4 | 3 | | 3 | 18 | | 89 | | |
| Yellow & red texture contrast soils ('000 ha) | 19 | 43 | 6 | 18 | 16 | 17 | 25 | 30 | | 74 | 24 | 7 |
| Lower slopes ('000 ha) | 1 | 13 | 1 | 6 | 4 | 2 | 3 | 3 | 1 | 12 | 4 | 1 |
| Mid slopes ('000 ha) | 10 | 74 | 24 | 38 | 21 | 14 | 22 | 27 | 7 | 70 | 37 | 8 |
| Upper slopes ('000 ha) | 11 | 92 | 22 | 34 | 21 | 14 | 24 | 32 | 8 | 90 | 36 | 9 |
| Crests ('000 ha) | 2 | 16 | 6 | 10 | 10 | 4 | 4 | 5 | 1 | 27 | 7 | 1 |
| Alluvial area (%) | 7 | 6 | 3 | 6 | 1 | 4 | 6 | 7 | 3 | 6 | 15 | 2 |
| Cropping ('000 ha) | <1 | 23 | 25 | 39 | 4 | 1 | 1 | 1 | 4 | 2 | 1 | 1 |
| Pasture ('000 ha) | 17 | 111 | 20 | 40 | 35 | 28 | 42 | 50 | 11 | 169 | 5 | 9 |
| Trees ('000 ha) | 5 | 32 | 8 | 7 | 16 | 5 | 10 | 16 | 2 | 26 | 7 | 9 |
| Other ('000 ha) | 2 | <1 | <1 | <1 | <1 | 1 | <1 | <1 | | 2 | | <1 |

*continued/*

**Table A2 (cont.): Gwydir summary of contextual data**

| | 418005 | 418015 | 418016 | 418017 | 418018 | 418021 | 418022 | 418023 | 418025 | 418029 | 418032 | 418033 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Intermediate & local flow in fractured rock ('000 ha) | 1 | 57 | 7 | 20 | 10 | 10 | 20 | 24 | 4 | 45 | 9 | 1 |
| Local systems in aeolian sands ('000 ha) | <1 | 1 | 1 | 1 | 2 | | <1 | <1 | | 1 | <1 | |
| Local systems in colluvial fans ('000 ha) | 16 | | 1 | 14 | 16 | 9 | 5 | 13 | | 103 | | 13 |
| Local systems in fractured basalts ('000 ha) | 2 | 32 | 27 | 30 | 3 | 5 | 10 | 14 | <1 | 7 | 11 | |
| Local systems in fractured rock aquifers ('000 ha) | 2 | 98 | 16 | 20 | 25 | 11 | 18 | 14 | 13 | 42 | 46 | 4 |
| Local systems in upland alluvium ('000 ha) | 2 | 9 | 1 | 3 | | <1 | <1 | 1 | 1 | <1 | 14 | |
| Regional systems in alluvial aquifers ('000 ha) | | | | | | | | | | | 4 | |
| Mesozoic sedimentary rocks ('000 ha) | | <1 | 16 | 4 | | | | | | | 24 | |
| Cainozoic alluvium ('000 ha) | 2 | 9 | 1 | 3 | | <1 | <1 | 1 | 1 | <1 | 19 | |
| Cainozoic volcanics ('000 ha) | 2 | 34 | 33 | 43 | 3 | 8 | 12 | 16 | <1 | 9 | 14 | |
| Cainozoic residual and aeolian sands ('000 ha) | <1 | 1 | 1 | 1 | 2 | | <1 | <1 | | 1 | <1 | |
| Late Palaeozoic metasedimentary rocks ('000 ha) | 1 | 143 | 1 | 21 | 17 | 13 | 13 | 8 | 12 | 77 | 29 | 5 |
| Granitoids ('000 ha) | 16 | | 1 | 14 | 16 | 9 | 5 | 13 | | 103 | | 13 |
| Siluro-Devonian basic rocks ('000 ha) | | <1 | | | <1 | | | | 1 | | | |
| Late Palaeozoic volcanics ('000 ha) | 2 | 3 | | | | 4 | 22 | 28 | | 8 | 1 | |
| Siluro-Devonian sedimentary rocks ('000 ha) | | 4 | <1 | 3 | 18 | | | | 1 | | | |
| Ultramafics ('000 ha) | | 1 | | | <1 | | | | 2 | | | |
| Mesozoic volcanics ('000 ha) | | <1 | | | | | | | <1 | | | |
| Depth to watertable <5 m ('000 ha) | <1 | 4 | <1 | 6 | | <1 | 3 | <1 | <1 | 4 | 2 | |
| Depth to watertable 5–10 m ('000 ha) | 3 | 20 | 2 | 14 | 7 | <1 | 5 | 3 | <1 | 15 | 11 | |
| Depth to watertable 10–15 m ('000 ha) | 6 | 26 | 10 | 15 | 6 | <1 | 5 | 4 | 1 | 17 | 15 | <1 |
| Depth to watertable 15–20 m ('000 ha) | 5 | 35 | 8 | 15 | 6 | 1 | 5 | 4 | 4 | 23 | 24 | 4 |
| Depth to watertable >20 m ('000 ha) | 9 | 111 | 33 | 38 | 37 | 33 | 34 | 56 | 12 | 139 | 33 | 14 |
| Number of groundwater monitoring bores | | 3 | | 4 | | | | 1 | | 10 | 2 | |

**418005 Copes Creek at Kimberley, 418015 Horton River at Rider, 418016 Warialda Creek at Warialda No.3, 418017 Myall Creek at Molroy, 418018 Keera Creek at Keera, 418021 Laura Creek at Laura, 418022 Georges Creek at Clerkness, 418023 Moredun Creek at Bundarra, 418025 Halls Creek at Bingara, 418029 Gwydir River at Stoneybatter, 418032 Tycannah Creek at Horseshoe Lagoon, 418033 Bakers Creek at Bundarra**

**Table A3:** Namoi/Peel summary of contextual data

| | 419005 | 419027 | 419029 | 419032 | 419043 | 419051 | 419072 | Lake Goran | 419016 | 419035 | 419036 | 419045 | 419077 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area (km$^2$) | 2525 | 3106 | 358 | 3796 | 1636 | 658 | 959 | 1842 | 893 | 459 | 92 | 409 | 95 |
| Average annual rainfall (mm) | 828 | 709 | 797 | 614 | 766 | 772 | 627 | 595 | 828 | 832 | 959 | 965 | 1079 |
| Winter surplus | Yes | No | Yes | No | No | No | No | No | Yes | Yes | Yes | Yes | Yes |
| Flow (ML) | 248474 | 136574 | 23385 | 95349 | 72669 | 23949 | 12714 | | 79283 | 29866 | 12974 | 47861 | 13534 |
| Saltload (t) | 23148 | 32203 | 4991 | 9595 | 15552 | 3306 | 2136 | | 11413 | 9012 | 2393 | 9802 | 2597 |
| Salt export (t km$^{-2}$) | 9 | 10 | 14 | 3 | 10 | 5 | 2 | 0 | 13 | 20 | 26 | 24 | 27 |
| Deep black cracking clays ('000 ha) | | 175 | | 201 | | 5 | 18 | 118 | | 3 | | | |
| Deep structured red clay loams ('000 ha) | 18 | | | 33 | | | | | <1 | | 1 | 9 | 7 |
| Massive red and yellow earths ('000 ha) | | | | 82 | | 1 | 70 | | | | | | |
| Red brown earths ('000 ha) | 10 | 20 | 1 | 33 | 61 | | 4 | | | 17 | | | |
| Shallow black self-mulching clay ('000 ha) | | 54 | | 21 | | 5 | | 14 | | 3 | | 4 | |
| Shallow loams ('000 ha) | 61 | 24 | 23 | 4 | 97 | 38 | 4 | | 79 | 6 | 8 | 18 | 2 |
| Stony sandy loams ('000 ha) | 102 | | 12 | | | | | | 4 | | | | |
| Structured red & brown earths ('000 ha) | 43 | | | | | | | | 4 | | | | |
| Yellow & red texture contrast soils ('000 ha) | 19 | 38 | | 6 | 5 | 17 | | 52 | 2 | 17 | | 10 | |
| Lower slopes ('000 ha) | 8 | 40 | 1 | 48 | 9 | 11 | 3 | 26 | 1 | 1 | <1 | 1 | <1 |
| Mid slopes ('000 ha) | 98 | 108 | 16 | 140 | 65 | 23 | 35 | 73 | 10 | 26 | 4 | 22 | 2 |
| Upper slopes ('000 ha) | 115 | 130 | 14 | 160 | 70 | 25 | 49 | 71 | 67 | 17 | 4 | 16 | 7 |
| Crests ('000 ha) | 31 | 33 | 4 | 32 | 20 | 6 | 9 | 14 | 11 | 2 | <1 | 2 | 1 |
| Alluvial area (%) | 2 | 30 | 1 | 30 | 4 | 9 | 16 | 54 | 0 | 6 | 0 | 1 | 0 |
| Cropping ('000 ha) | 5 | 102 | 2 | 118 | 22 | 15 | 4 | 54 | <1 | 10 | <1 | 1 | |
| Pasture ('000 ha) | 199 | 161 | 28 | 150 | 109 | 17 | 19 | 78 | 72 | 34 | 4 | 35 | <1 |
| Trees ('000 ha) | 48 | 24 | 5 | 79 | 30 | 34 | 76 | 27 | 17 | 1 | 4 | 4 | 9 |
| Other ('000 ha) | 1 | 23 | <1 | 33 | 3 | 1 | <1 | 25 | | | | 1 | |

*continued/*

**Table A3 (cont):** Namoi/Peel summary of contextual data

| | 419005 | 419027 | 419029 | 419032 | 419043 | 419051 | 419072 | Lake Goran | 419016 | 419035 | 419036 | 419045 | 419077 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Intermediate & local flow in fractured rock ('000 ha) | 24 | 27 | 3 | 32 | 43 | 3 | <1 | 4 | 7 | 18 | <1 | 4 | <1 |
| Local systems in aeolian sands ('000 ha) | <1 | | | 13 | 2 | | | | | | | | |
| Local systems in colluvial fans ('000 ha) | 129 | | 7 | | 25 | | | | 7 | | 1 | <1 | <1 |
| Local systems in fractured basalts ('000 ha) | 19 | 98 | | 29 | 6 | 15 | 9 | 33 | <1 | 4 | 1 | 13 | 3 |
| Local systems in fractured rock aquifers ('000 ha) | 80 | 82 | 27 | 164 | 81 | 32 | 80 | 37 | 74 | 24 | 6 | 23 | 6 |
| Local systems in upland alluvium ('000 ha) | | 103 | | 114 | 6 | 16 | 7 | 110 | | 1 | 1 | <1 | |
| Regional systems in alluvial aquifers ('000 ha) | | | | 27 | | 1 | <1 | | | | | | |
| Mesozoic sedimentary rocks ('000 ha) | | 28 | | 118 | | <1 | 81 | 30 | | | | | |
| Cainozoic alluvium ('000 ha) | | 103 | | 141 | 6 | 17 | 8 | 110 | | 1 | 1 | <1 | |
| Cainozoic volcanics ('000 ha) | 21 | 103 | | 29 | 7 | 15 | 9 | 36 | <1 | 4 | 1 | 13 | 3 |
| Cainozoic residual and aeolian sands ('000 ha) | <1 | | | 13 | 2 | | | | | | | | |
| Late Palaeozoic metasedimentary rocks ('000 ha) | 92 | 59 | 27 | <1 | 95 | 29 | <1 | 4 | 81 | 41 | | 18 | 5 |
| Granitoids ('000 ha) | 129 | | 7 | | 25 | | | | 7 | | 1 | <1 | <1 |
| Siluro-Devonian basic rocks ('000 ha) | <1 | | | | <1 | | | | | | | | |
| Late Palaeozoic volcanics ('000 ha) | | 18 | | | <1 | 5 | | | <1 | | | | |
| Siluro-Devonian sedimentary rocks ('000 ha) | 9 | | 1 | | 27 | | <1 | | | | | 6 | |
| Ultramafics ('000 ha) | 1 | | 1 | | 2 | | | | <1 | | | <1 | |
| Early Palaeozoic metasedimentary rocks ('000 ha) | | | | | | | | | <1 | | 6 | 3 | 1 |
| Mesozoic volcanics ('000 ha) | | | | 79 | | | | 5 | | | | | |
| Depth to watertable <5 m ('000 ha) | 6 | 69 | 3 | 62 | 7 | 3 | | 81 | | | <1 | 1 | |
| Depth to watertable 5–10 m ('000 ha) | 14 | 76 | 5 | 67 | 15 | 5 | | 36 | 1 | 12 | 1 | 5 | |
| Depth to watertable 10–15 m ('000 ha) | 25 | 76 | 5 | 50 | 38 | 5 | | 32 | 9 | 17 | <1 | 12 | |
| Depth to watertable 15–20 m ('000 ha) | 46 | 39 | 5 | 67 | 26 | 5 | <1 | 14 | 21 | 10 | 2 | 9 | |
| Depth to watertable >20 m ('000 ha) | 163 | 50 | 17 | 133 | 77 | 48 | 96 | 21 | 58 | 7 | 6 | 14 | 10 |
| Number of groundwater monitoring bores | 4 | 43 | | 57 | 7 | 1 | 3 | 38 | | 2 | | | |

419005 Namoi River at North Cuerindi, 419016 Cockburn River at Mulla Crossing, 419027 Mooki River at Breeza, 419029 Halls Creek at Ukolan, 419032 Coxs Creek at Boggabri, 419035 Goonoo Goonoo Creek at Timbumburi, 419036 Duncans Creek at Woolomin, 419043 Manilla River at Split Rock Dam, 419045 Peel River Chaffey Dam, 419051 Maules Creek at Avoca East, 419072 Baradine Creek at Kienbri, 419077 Dungowan Creek at Dungowan Dam

**Table A4:** Lachlan summary of contextual data

| | 412028 | 412029 | 412030 | 412043 | 412050 | 412065 | 412072 | 412077 | 412080 | 412083 | 412092 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Area (km$^2$) | 2624 | 1547 | 1689 | 4115 | 756 | 2239 | 797 | 233 | 86 | 320 | 132 |
| Average annual rainfall (mm) | 837 | 702 | 679 | 506 | 809 | 702 | 661 | 774 | 973 | 802 | 804 |
| Winter surplus | Yes | Yes | Yes | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Flow (ML) | 294417 | 93847 | 77799 | 73556 | 90333 | 174122 | 23249 | 19078 | 13070 | 34655 | 19314 |
| Saltload (t) | 27179 | 24880 | 21563 | 7665 | 11181 | 41844 | 9807 | 3923 | 2834 | 4783 | 3754 |
| Salt export (t km$^{-}$2) | 10 | 16 | 13 | 2 | 15 | 19 | 12 | 17 | 33 | 15 | 28 |
| Cracking grey & brown clays ('000 ha) | | | | 23 | | | | | | | |
| Deep friable red and brown clays ('000 ha) | | | | | | | 13 | | | | |
| Deep structured red clay loams ('000 ha) | 30 | | 24 | | 18 | 19 | | 4 | 5 | | |
| Massive red and yellow earths ('000 ha) | 111 | 99 | 10 | 55 | | 71 | 46 | 16 | 3 | 10 | 10 |
| Red brown earths ('000 ha) | | | 61 | 275 | | | <1 | | | | |
| Shallow black self-mulching clay ('000 ha) | | | | | | | | | 1 | | |
| Shallow loams ('000 ha) | 81 | 1 | 58 | 58 | 8 | 5 | 10 | | | 20 | |
| Yellow & red texture contrast soils ('000 ha) | 40 | 55 | 16 | | 50 | 129 | 10 | 4 | | 2 | 3 |
| Lower slopes ('000 ha) | 14 | 12 | 13 | 55 | 5 | 16 | 7 | 2 | <1 | 2 | 1 |
| Mid slopes ('000 ha) | 81 | 51 | 64 | 145 | 26 | 85 | 25 | 7 | 3 | 11 | 5 |
| Upper slopes ('000 ha) | 116 | 70 | 73 | 186 | 37 | 101 | 39 | 11 | 4 | 14 | 5 |
| Crests ('000 ha) | 51 | 21 | 19 | 26 | 8 | 22 | 9 | 4 | 1 | 6 | 3 |
| Alluvial area (%) | 2 | 7 | 4 | 52 | 4 | 7 | 11 | 7 | 2 | 0 | 9 |
| Cropping ('000 ha) | <1 | 21 | 21 | 95 | <1 | <1 | 23 | 2 | 1 | | <1 |
| Pasture ('000 ha) | 157 | 130 | 116 | 250 | 70 | 212 | 48 | 21 | 7 | 18 | 13 |
| Trees ('000 ha) | 106 | 3 | 31 | 46 | 5 | 12 | 9 | <1 | <1 | 14 | <1 |
| Other ('000 ha) | <1 | <1 | 1 | 3 | <1 | 1 | 1 | 1 | <1 | <1 | |
| Intermediate & local flow in fractured rock ('000 ha) | 50 | 76 | 48 | 81 | 20 | 72 | 19 | 8 | 2 | 5 | 5 |
| Local systems in aeolian sands ('000 ha) | 2 | 2 | 2 | | 3 | 10 | 19 | | | | |
| Local systems in colluvial fans ('000 ha) | 32 | 11 | 7 | 3 | 25 | 66 | 15 | 2 | | 1 | 2 |
| Local systems in fractured basalts ('000 ha) | 19 | | 18 | | 7 | 8 | | 2 | 3 | | |
| Local systems in fractured rock aquifers ('000 ha) | 156 | 66 | 83 | 58 | 20 | 67 | 26 | 10 | 3 | 26 | 5 |
| Local systems in upland alluvium ('000 ha) | 1 | | 11 | 89 | | | | 1 | | | 1 |
| Regional systems in alluvial aquifers ('000 ha) | | | | 181 | | | | | | | |
| Mesozoic sedimentary rocks ('000 ha) | | | 3 | 19 | | | | | | | |

*continued/*

**Table A4 (cont.):** Lachlan summary of contextual

| | 412028 | 412029 | 412030 | 412043 | 412050 | 412065 | 412072 | 412077 | 412080 | 412083 | 412092 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cainozoic alluvium ('000 ha) | 1 | | 10 | 210 | | | | 1 | | | 2 |
| Cainozoic volcanics ('000 ha) | 21 | | 21 | | 10 | 9 | | 2 | 4 | | <1 |
| Cainozoic residual and aeolian sands ('000 ha) | 2 | 2 | 2 | | 3 | 10 | 19 | | | | |
| Cainozoic duricrusts ('000 ha) | | | | <1 | | | | | | | |
| Cainozoic colluvium ('000 ha) | | | 1 | 63 | | | | | | | |
| Limestones ('000 ha) | <1 | | 12 | <1 | | | | <1 | <1 | | |
| Granitoids ('000 ha) | 32 | 11 | 7 | 3 | 25 | 66 | 15 | 2 | | 1 | 2 |
| Water ('000 ha) | | | | <1 | | | | <1 | | | |
| Siluro-Devonian basic rocks ('000 ha) | <1 | <1 | <1 | <1 | | <1 | | | | | |
| Siluro-Devonian sedimentary rocks ('000 ha) | 41 | 1 | 57 | 57 | 2 | 2 | 29 | 4 | 1 | 17 | 2 |
| Early Palaeozoic metasedimentary rocks ('000 ha) | 140 | 10 | <1 | 33 | 36 | 130 | | 2 | | 6 | 4 |
| Early Palaeozoic volcanics ('000 ha) | 5 | 8 | 12 | 8 | | | | 10 | 3 | | 3 |
| Siluro-Devonian acid volcanics ('000 ha) | 17 | 123 | 43 | 23 | <1 | 6 | 16 | | | 7 | <1 |
| Depth to watertable <5 m ('000 ha) | 5 | 27 | 3 | 17 | 5 | 36 | 5 | 4 | <1 | | |
| Depth to watertable 5–10 m ('000 ha) | 9 | 25 | 13 | 36 | 7 | 21 | 10 | 8 | <1 | | |
| Depth to watertable 10–15 m ('000 ha) | 10 | 19 | 29 | 30 | 7 | 18 | 9 | 5 | 3 | | 2 |
| Depth to watertable 15–20 m ('000 ha) | 15 | 21 | 30 | 22 | 9 | 20 | 11 | 4 | 5 | | 2 |
| Depth to watertable >20 m ('000 ha) | 224 | 62 | 94 | 307 | 48 | 129 | 45 | 3 | | 32 | 9 |
| Number of groundwater monitoring bores | 3 | 31 | 28 | 35 | 3 | 6 | 15 | 4 | 2 | | |

412028 Abercrombie River at Abercrombie, 412029 Boorowa River at Prossers Crossing, 412030 Mandagery Creek at U/S Eugowra, 412043 Goobang Creek at Darbys Dam, 412050 Crookwell River at Narrawa North, 412065 Lachlan River at Narrawa, 412072 Back Creek at Koorawatha, 412077 Belubula River at Carcoar, 412080 Flyers Creek at Beneree, 412083 Tuena Creek at Tuena, 412092 Coombin Creek near Neville

**Table A5:** Macquarie summary of contextual data (421018 to 421066)

| | **421018** | **421026** | **421035** | **421041** | **421042** | **421048** | **421052** | **421053** | **421055** | **421058** | **421059** | **421066** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area (km$^2$) | 1629 | 880 | 593 | 349 | 2963 | 577 | 618 | 203 | 563 | 841 | 701 | 115 |
| Average annual rainfall (mm) | 709 | 782 | 984 | 732 | 641 | 629 | 825 | 740 | 542 | 665 | 626 | 731 |
| Winter surplus | Yes | Yes | Yes | Yes | No | Yes | Yes | Yes | No | Yes | Yes | Yes |
| Flow (ML) | 111188 | 85731 | 89067 | 25338 | 52154 | 38681 | 72148 | 14646 | 21090 | 24344 | 24264 | 14647 |
| Saltload (t) | 29916 | 11052 | 4369 | 4135 | 8956 | 3218 | 9243 | 2026 | 663 | 3936 | 7512 | 4826 |
| Salt export (t km$^{-2}$) | 18 | 13 | 7 | 12 | 3 | 6 | 15 | 10 | 1 | 5 | 11 | 42 |
| Deep alluvial loams ('000 ha) | 2 | | | | | | | 1 | | <1 | | |
| Deep black cracking clays ('000 ha) | | | | | 99 | | | | | | | |
| Deep structured red clay loams ('000 ha) | 34 | 5 | 2 | <1 | 27 | | 12 | | | 8 | | |
| Massive red and yellow earths ('000 ha) | 46 | 31 | 44 | | 41 | | 21 | 19 | 41 | 6 | | |
| Red brown earths ('000 ha) | 21 | | | | 27 | 22 | | | 15 | <1 | 61 | |
| Shallow black self-mulching clay ('000 ha) | 1 | 22 | | 5 | 60 | | 3 | | | | | 2 |
| Shallow loams ('000 ha) | 3 | 5 | 5 | | 3 | 12 | | | | | 1 | |
| Yellow & red texture contrast soils ('000 ha) | 57 | 25 | 8 | 30 | 39 | 24 | 26 | | | 69 | 9 | 10 |
| Lower slopes ('000 ha) | 13 | 6 | 3 | 2 | 21 | 2 | 4 | 1 | 5 | 7 | 4 | 1 |
| Mid slopes ('000 ha) | 63 | 36 | 23 | 13 | 100 | 22 | 28 | 9 | 18 | 38 | 28 | 3 |
| Upper slopes ('000 ha) | 63 | 34 | 27 | 15 | 138 | 27 | 24 | 9 | 18 | 32 | 31 | 5 |
| Crests ('000 ha) | 23 | 12 | 7 | 6 | 37 | 6 | 6 | 2 | 15 | 7 | 8 | 3 |
| Alluvial area (%) | 3 | 1 | 2 | 3 | 13 | 13 | 4 | 2 | 65 | 19 | 0 | 0 |
| Cropping ('000 ha) | 21 | <1 | <1 | <1 | 29 | 6 | 4 | <1 | 9 | 5 | 26 | <1 |
| Pasture ('000 ha) | 128 | 42 | 37 | 29 | 214 | 37 | 47 | 18 | 30 | 64 | 43 | 10 |
| Trees ('000 ha) | 10 | 45 | 21 | 5 | 53 | 15 | 7 | 2 | 17 | 15 | 1 | 2 |
| Other ('000 ha) | 3 | 1 | 1 | <1 | <1 | <1 | 4 | <1 | <1 | <1 | <1 | <1 |
| Intermediate & local flow in fractured rock ('000 ha) | 60 | 7 | 10 | 3 | 20 | 8 | 19 | 6 | | 10 | 29 | 2 |
| Local systems in aeolian sands ('000 ha) | 1 | <1 | 1 | | | | | | | <1 | | |
| Local systems in colluvial fans ('000 ha) | | 1 | 14 | 2 | 15 | 19 | <1 | 1 | | 31 | 16 | |
| Local systems in fractured basalts ('000 ha) | 11 | 1 | 2 | 1 | 58 | | 9 | <1 | | <1 | <1 | <1 |
| Local systems in fractured rock aquifers ('000 ha) | 88 | 80 | 31 | 29 | 141 | 19 | 33 | 13 | 52 | 19 | 20 | 9 |
| Local systems in upland alluvium ('000 ha) | 4 | | 1 | <1 | 62 | 11 | <1 | 1 | <1 | 22 | 5 | <1 |
| Regional systems in alluvial aquifers ('000 ha) | | | | | | | | | 4 | | | |
| Water ('000 ha) | | | <1 | | | | | | | | | |

*continued/*

**Table A5 (cont.):** Macquarie summary of contextual data (421018 to 421066)

| | 421018 | 421026 | 421035 | 421041 | 421042 | 421048 | 421052 | 421053 | 421055 | 421058 | 421059 | 421066 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mesozoic sedimentary rocks ('000 ha) | 2 | 3 | | 1 | 111 | 1 | | | 52 | 5 | 2 | |
| Cainozoic alluvium ('000 ha) | 4 | | 2 | <1 | 42 | 4 | <1 | 1 | 4 | 21 | 5 | <1 |
| Cainozoic volcanics ('000 ha) | 12 | 1 | 2 | 1 | 60 | | 16 | <1 | <1 | <1 | <1 | <1 |
| Cainozoic residual and aeolian sands ('000 ha) | 1 | <1 | 1 | | | | | | | <1 | | |
| Late Palaeozoic metasedimentary rocks ('000 ha) | | 20 | 1 | 9 | 19 | | | | | 6 | | |
| Cainozoic duricrusts ('000 ha) | <1 | | | | | | | | | <1 | | |
| Cainozoic colluvium ('000 ha) | | | | | 20 | 7 | | | | 1 | | |
| Limestones ('000 ha) | 9 | | | <1 | <1 | | | <1 | | <1 | 4 | |
| Granitoids ('000 ha) | <1 | 1 | 13 | 2 | 15 | 19 | <1 | 1 | | 31 | 16 | |
| Water ('000 ha) | | | <1 | | | | | | | | | |
| Siluro-Devonian basic rocks ('000 ha) | 6 | <1 | | | <1 | 2 | | | | <1 | 1 | |
| Late Palaeozoic volcanics ('000 ha) | | | | | <1 | | | | | <1 | | |
| Siluro-Devonian sedimentary rocks ('000 ha) | 52 | 24 | 14 | 18 | 10 | 1 | 19 | 7 | | 7 | 16 | 11 |
| Early Palaeozoic metasedimentary rocks ('000 ha) | | 15 | 24 | | 12 | <1 | <1 | 2 | | 8 | 10 | |
| Mesozoic volcanics ('000 ha) | | | | | | | | | | <1 | 1 | |
| Early Palaeozoic volcanics ('000 ha) | 68 | 23 | 3 | 4 | <1 | | 17 | 2 | | 2 | | |
| Siluro-Devonian acid volcanics ('000 ha) | 8 | <1 | | | 7 | 23 | 10 | 7 | | 1 | 16 | |
| Depth to watertable <5 m ('000 ha) | 12 | | 2 | | 11 | | 11 | 2 | | 5 | 6 | |
| Depth to watertable 5–10 m ('000 ha) | 20 | <1 | 5 | 4 | 23 | 1 | 10 | 12 | | 13 | 15 | |
| Depth to watertable 10–15 m ('000 ha) | 40 | 20 | 11 | 7 | 32 | 11 | 6 | 2 | | 23 | 22 | |
| Depth to watertable 15–20 m ('000 ha) | 45 | 23 | 10 | 8 | 50 | 5 | 3 | 1 | <1 | 13 | 16 | <1 |
| Depth to watertable >20 m ('000 ha) | 45 | 45 | 31 | 17 | 180 | 41 | 31 | 2 | 56 | 30 | 11 | 11 |
| Number of groundwater monitoring bores | 21 | | | | 58 | 1 | 21 | | 16 | 14 | 6 | |

421018 Bell River at Newrea, 421026 Turon River at Sofala, 421035 Fish River at Tarana, 421041 Crudine River at Turon River junction, 421042 Talbragar River at Elong Elong, 421048 Little River at Obley No. 2, 421052 Lewis Ponds Creek at Ophir, 421053 Queen Charlottes Creek at Georges Plains, 421055 Coolbaggie Creek at Rawsonville, 421058 Wyaldra Creek at Gulgong, 421059 Buckinbah Creek at Yeoval, 421066 Green Valley Creek at Hill End

**Table A6:** Macquarie summary of contextual data (421072 to 421101)

| | **421072** | **421073** | **421079** | **421101** |
|---|---|---|---|---|
| Area (km$^2$) | 720 | 729 | 1090 | 918 |
| Average annual rainfall (mm) | 744 | 735 | 744 | 831 |
| Winter surplus | Yes | Yes | Yes | Yes |
| Flow (ML) | 74472 | 84161 | 45625 | 79688 |
| Saltload (t) | 7715 | 9773 | 10532 | 12999 |
| Salt export (t km$^{-2}$) | 11 | 13 | 10 | 14 |
| Deep structured red clay loams ('000 ha) | | | <1 | 19 |
| Massive red and yellow earths ('000 ha) | 8 | | 26 | 61 |
| Shallow black self-mulching clay ('000 ha) | 13 | 20 | 14 | |
| Shallow loams ('000 ha) | | | | 7 |
| Stony sandy loams ('000 ha) | | | 8 | |
| Yellow & red texture contrast soils ('000 ha) | 51 | 53 | 61 | 5 |
| Lower slopes ('000 ha) | 4 | 4 | 7 | 7 |
| Mid slopes ('000 ha) | 28 | 19 | 49 | 36 |
| Upper slopes ('000 ha) | 31 | 34 | 33 | 36 |
| Crests ('000 ha) | 9 | 16 | 20 | 13 |
| Alluvial area (%) | 1 | 1 | 5 | 1 |
| Cropping ('000 ha) | 1 | <1 | 2 | <1 |
| Pasture ('000 ha) | 46 | 56 | 59 | 78 |
| Trees ('000 ha) | 25 | 16 | 47 | 13 |
| Other ('000 ha) | <1 | <1 | 2 | <1 |
| Intermediate & local flow in fractured rock ('000 ha) | 8 | 9 | 5 | 25 |
| Local systems in aeolian sands ('000 ha) | 1 | | | 1 |
| Local systems in colluvial fans ('000 ha) | 8 | 1 | 2 | 4 |
| Local systems in fractured basalts ('000 ha) | | <1 | 1 | 6 |
| Local systems in fractured rock aquifers ('000 ha) | 54 | 63 | 97 | 52 |
| Local systems in upland alluvium ('000 ha) | 1 | | 3 | 3 |
| Mesozoic sedimentary rocks ('000 ha) | | | 32 | |
| Cainozoic alluvium ('000 ha) | 1 | | 3 | 4 |
| Cainozoic volcanics ('000 ha) | | <1 | 2 | 7 |
| Cainozoic residual and aeolian sands ('000 ha) | 1 | | | 1 |
| Late Palaeozoic metasedimentary rocks ('000 ha) | | 4 | 39 | |
| Limestones ('000 ha) | <1 | | 1 | 1 |
| Granitoids ('000 ha) | 8 | 1 | 2 | 4 |
| Water ('000 ha) | | | | <1 |
| Siluro-Devonian basic rocks ('000 ha) | <1 | | 1 | |
| Late Palaeozoic volcanics ('000 ha) | | | 4 | |
| Siluro-Devonian sedimentary rocks ('000 ha) | 56 | 67 | 19 | 23 |
| Early Palaeozoic metasedimentary rocks ('000 ha) | | | 1 | 31 |
| Mesozoic volcanics ('000 ha) | | | <1 | |
| Early Palaeozoic volcanics ('000 ha) | <1 | | 2 | 17 |
| Siluro-Devonian acid volcanics ('000 ha) | 6 | 1 | 4 | 5 |
| Depth to watertable <5 m ('000 ha) | 1 | 1 | 18 | 6 |
| Depth to watertable 5–10 m ('000 ha) | 6 | 6 | 13 | 14 |
| Depth to watertable 10–15 m ('000 ha) | 12 | 10 | 10 | 18 |
| Depth to watertable 15–20 m ('000 ha) | 16 | 8 | 11 | 12 |
| Depth to watertable >20 m ('000 ha) | 38 | 48 | 58 | 41 |
| Number of groundwater monitoring bores | 3 | | 3 | 5 |

421072 Winburndale Rivulet Howards Bridge, 421073 Meroo Creek at Yarrabin 2, 421079 Cudgegong River at Windamere Dam, 421101 Campbells River U/S Ben Chifley Dam

**Table A7:** Murrumbidgee summary of contextual data

| | 410008 | 410025 | 410038 | 410043 | 410044 | 410045 | 410047 | 410048 | 410057 | 410059 | 410061 | 410071 | 410073 | 410103 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area (km$^2$) | 13110 | 2141 | 386 | 563 | 1059 | 842 | 1639 | 547 | 665 | 276 | 146 | 116 | 1633 | 1136 |
| Average annual rainfall (mm) | 794 | 682 | 1075 | 932 | 658 | 628 | 841 | 689 | 1312 | 1131 | 1138 | 867 | 1332 | 577 |
| Winter surplus | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Flow (ML) | 1377632 | 99087 | 81799 | 108742 | 51393 | 14371 | 179140 | 40614 | 273092 | 84796 | 37970 | 19268 | 1629150 | 2369 |
| Saltload (t) | 124421 | 53391 | 5259 | 14058 | 25828 | 1845 | 23015 | 8716 | 7997 | 3536 | 2310 | 3063 | 35841 | 0 |
| Salt export (t km$^{-2}$) | 9 | 25 | 14 | 25 | 24 | 2 | 14 | 16 | 12 | 13 | 16 | 26 | 22 | 0 |
| Deep alluvial loams ('000 ha) | | | <1 | | | | <1 | | | | | | | |
| Deep black cracking clays ('000 ha) | 61 | | | | | | | | | | | | | |
| Deep friable red and brown clays ('000 ha) | | 11 | | | | | | | | | | | | |
| Deep structured red clay loams ('000 ha) | 3 | 3 | | | 16 | | | | | | | | 9 | |
| Massive red and yellow earths ('000 ha) | 388 | 23 | | | 21 | 42 | 19 | | | | | | | 71 |
| Red brown earths ('000 ha) | | | | | | | | | | | | | | 18 |
| Shallow loams ('000 ha) | 546 | 6 | 2 | | 8 | 1 | | | 59 | 2 | | 4 | 135 | |
| Stony sandy loams ('000 ha) | 1 | 4 | | | | | | | | | | | | |
| Yellow & red texture contrast soils ('000 ha) | 311 | 167 | 37 | 56 | 62 | 41 | 145 | 55 | 8 | 26 | 15 | 8 | 19 | 24 |
| Lower slopes ('000 ha) | 72 | 9 | 1 | 2 | 9 | 11 | 7 | 3 | 2 | 1 | <1 | <1 | 11 | 8 |
| Mid slopes ('000 ha) | 498 | 85 | 17 | 24 | 42 | 28 | 68 | 22 | 30 | 13 | 7 | 5 | 72 | 47 |
| Upper slopes ('000 ha) | 604 | 88 | 17 | 26 | 46 | 38 | 75 | 25 | 31 | 13 | 6 | 5 | 66 | 46 |
| Crests ('000 ha) | 136 | 31 | 3 | 4 | 9 | 7 | 15 | 4 | 4 | 1 | 1 | 1 | 14 | 12 |
| Alluvial area (%) | 3 | 3 | 1 | 1 | 6 | 24 | 4 | 14 | 0 | 2 | 0 | 0 | 2 | 31 |
| Cropping ('000 ha) | 8 | 37 | <1 | <1 | 12 | 23 | 2 | 2 | <1 | <1 | <1 | | | 72 |
| Pasture ('000 ha) | 512 | 173 | 18 | 37 | 87 | 55 | 107 | 49 | 3 | 14 | 8 | 9 | 7 | 41 |
| Trees ('000 ha) | 773 | 2 | 20 | 19 | 7 | 6 | 55 | 4 | 63 | 12 | 6 | 3 | 142 | 1 |
| Other ('000 ha) | 18 | 2 | <1 | <1 | 1 | <1 | <1 | <1 | <1 | 1 | 1 | <1 | 15 | <1 |
| Intermediate & local flow in fractured rock ('000 ha) | 218 | 38 | <1 | 3 | 28 | 21 | 39 | 11 | 1 | 1 | 1 | 1 | 5 | 24 |
| Local systems in aeolian sands ('000 ha) | 21 | <1 | | | | | | | <1 | | | | 1 | |
| Local systems in colluvial fans ('000 ha) | 312 | 111 | 31 | 33 | 6 | 16 | 30 | 16 | 39 | 17 | 7 | 3 | 59 | 63 |
| Local systems in fractured basalts ('000 ha) | 48 | <1 | <1 | | | | 1 | | <1 | <1 | | <1 | 6 | |
| Local systems in fractured rock aquifers ('000 ha) | 681 | 56 | 6 | 18 | 59 | 17 | 77 | 13 | 26 | 9 | 7 | 7 | 86 | 4 |
| Local systems in upland alluvium ('000 ha) | 17 | 8 | <1 | 2 | 9 | 12 | 5 | 6 | <1 | 1 | | 1 | <1 | 23 |
| Regional systems in alluvial aquifers ('000 ha) | | | | 1 | 3 | 18 | 12 | 10 | | | | | | <1 |
| Water ('000 ha) | 9 | | | | | | | | | | | | 6 | |

| | 410008 | 410025 | 410038 | 410043 | 410044 | 410045 | 410047 | 410048 | 410057 | 410059 | 410061 | 410071 | 410073 | 410103 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mesozoic sedimentary rocks ('000 ha) | | | | | | | | | | | | | | |
| Cainozoic alluvium ('000 ha) | 14 | 8 | <1 | 3 | 12 | 30 | 17 | 16 | <1 | 1 | | 1 | <1 | 23 |
| Cainozoic volcanics ('000 ha) | 54 | <1 | <1 | | | | 1 | | <1 | <1 | | <1 | 6 | |
| Cainozoic residual and aeolian sands ('000 ha) | 21 | <1 | | | <1 | | | | <1 | | | | 1 | |
| Cainozoic duricrusts ('000 ha) | <1 | <1 | | | <1 | | | | | | | | | |
| Cainozoic colluvium ('000 ha) | 4 | | | | | <1 | | | | | | | | <1 |
| Limestones ('000 ha) | 11 | | | | | | | | | | | | 2 | |
| Granitoids ('000 ha) | 312 | 111 | 31 | 32 | 6 | 16 | 30 | 16 | 39 | 17 | 7 | 3 | 59 | 64 |
| Water ('000 ha) | 11 | | | | | | | | | | | | 6 | |
| Siluro-Devonian basic rocks ('000 ha) | 4 | <1 | 3 | <1 | <1 | 2 | | | 8 | | 1 | 1 | <1 | 1 |
| Siluro-Devonian sedimentary rocks ('000 ha) | 108 | 4 | | | 20 | 5 | | | | 4 | | 1 | 27 | 4 |
| Ultramafics ('000 ha) | | 1 | 2 | | 4 | <1 | | | <1 | | | 2 | 1 | |
| Early Palaeozoic metasedimentary rocks ('000 ha) | 414 | | | 17 | | 2 | 116 | 24 | | | | | 6 | 19 |
| Mesozoic volcanics ('000 ha) | <1 | | | | | | | | | | | | | |
| Early Palaeozoic volcanics ('000 ha) | 12 | 6 | | 3 | 17 | | | | | 5 | 7 | 1 | 18 | <1 |
| Siluro-Devonian acid volcanics ('000 ha) | 342 | 84 | 2 | | 46 | 28 | | | 19 | | | 2 | 37 | 4 |
| Depth to watertable <5 m ('000 ha) | 178 | 59 | | | 12 | 2 | 24 | 11 | <1 | <1 | | 1 | | 1 |
| Depth to watertable 5–10 m ('000 ha) | 335 | 79 | 1 | 2 | 35 | 9 | 17 | 10 | 3 | 2 | 1 | 3 | 14 | 7 |
| Depth to watertable 10–15 m ('000 ha) | 314 | 55 | 3 | 14 | 34 | 24 | 21 | 12 | 4 | 5 | 2 | 3 | 17 | 8 |
| Depth to watertable 15–20 m ('000 ha) | 482 | 20 | 34 | 40 | 25 | 50 | 102 | 22 | 59 | 21 | 11 | 5 | 132 | 97 |
| Depth to watertable >20 m ('000 ha) | 1 | 1 | | | <1 | <1 | <1 | | | <1 | | | <1 | 1 |
| Number of groundwater monitoring bores | 42 | 107 | | | 61 | 15 | 6 | 12 | | | | | | 21 |

410008 Murrumbidgee River at Burrinjuck Dam, 410025 Jugiong Creek at Jugiong, 410038 Adjungbilly Creek at Darbalara, 410043 Hillas Creek at Mount Adrah, 410044 Muttama Creek at Coolac, 410045 Billabung Creek at Sunnyside, 410047 Tarcutta Creek at Old Borambola, 410048 Kyeamba Creek at Ladysmith, 410057 Goobarragandra River at Lacmalac, 410059 Gilmore Creek at Gilmore, 410061 Adelong Creek at Batlow Road, 410071 Brungle Creek at Red Hill, 410073 Tumut River at Oddys Bridge, 410103 Houligans Creek at Downside

**Table A8:** Murray summary of contextual data

| | Lake Hume | 410091 | 410097 | 410098 | 410099 |
|---|---|---|---|---|---|
| Area ($km^2$) | 5208 | 1976 | 346 | 102 | 232 |
| Average annual rainfall (mm) | 1121 | 686 | 807 | 952 | 918 |
| Winter surplus | Yes | Yes | Yes | Yes | Yes |
| Flow (ML) | n/a | n/a | n/a | n/a | n/a |
| Saltload (t) | n/a | n/a | n/a | n/a | n/a |
| Salt export ($t\ km^{-2}$) | n/a | n/a | n/a | n/a | n/a |
| Coarsely cracking grey and brown clays ('000 ha) | 14 | | | | |
| Deep structured red clay loams ('000 ha) | 10 | | | | |
| Massive red and yellow earths ('000 ha) | 132 | 8 | | 5 | 8 |
| Red brown earths ('000 ha) | | 30 | | | |
| Scalded red texture contrast soils ('000 ha) | | 23 | | | |
| Shallow loams ('000 ha) | 169 | | | | |
| Yellow and red texture contrast soils ('000 ha) | 188 | 136 | 35 | 6 | 15 |
| Lower slopes ('000 ha) | n/a | n/a | n/a | n/a | n/a |
| Mid slopes ('000 ha) | n/a | n/a | n/a | n/a | n/a |
| Upper slopes ('000 ha) | n/a | n/a | n/a | n/a | n/a |
| Crests ('000 ha) | n/a | n/a | n/a | n/a | n/a |
| Alluvial area (%) | 3 | 36 | 8 | 11 | 11 |
| Cropping ('000 ha) | 4 | 25 | 1 | <1 | <1 |
| Pasture ('000 ha) | 200 | 159 | 28 | 7 | 16 |
| Trees ('000 ha) | 284 | 11 | 6 | 3 | 6 |
| Other ('000 ha) | 9 | 1 | <1 | <1 | <1 |
| Regional flow systems in alluvial aquifers ('000 ha) | 10 | 79 | 1 | | |
| Local flow systems in fractured rock aquifers ('000 ha) | 159 | 25 | 18 | 1 | 6 |
| Local flow systems in upland alluvium ('000 ha) | 23 | 19 | 4 | 2 | 5 |
| Local flow systems in colluvial fans ('000 ha) | 275 | 47 | 2 | 7 | 9 |
| Intermediate and local flow systems in fractured rock aquifers ('000 ha) | 36 | 29 | 9 | | 3 |
| Local flow systems in aeolian sands ('000 ha) | <1 | | | | |
| Local flow systems in fractured basalts ('000 ha) | 9 | | | | |
| Water ('000 ha) | 6 | | | | |

| | Lake Hume | 410091 | 410097 | 410098 | 410099 |
|---|---|---|---|---|---|
| Late Palaeozoic metasedimentary rocks ('000 ha) | 0 | 0 | 0 | 0 | 0 |
| Cainozoic residual and aeolian sands ('000 ha) | 0 | 0 | 0 | 0 | 0 |
| Cainozoic alluvium ('000 ha) | 24 | 90 | 5 | 2 | 5 |
| Granitoids ('000 ha) | 275 | 47 | 2 | 7 | 9 |
| Cainozoic volcanics ('000 ha) | 10 | 0 | 0 | 0 | 0 |
| Limestones ('000 ha) | 0 | 0 | 0 | 0 | 0 |
| Siluro-Devonian sedimentary rocks ('000 ha) | 13 | 4 | 0 | 0 | 0 |
| Early Palaeozoic metasedimentary rocks ('000 ha) | 160 | 43 | 28 | 1 | 9 |
| Siluro-Devonian acid volcanics ('000 ha) | 9 | 7 | 0 | 0 | 0 |
| Cainozoic colluvium ('000 ha) | 10 | 8 | 0 | 0 | 0 |
| Early Palaeozoic volcanics ('000 ha) | 13 | 0 | 0 | 0 | 0 |
| Water ('000 ha) | 6 | 0 | 0 | 0 | 0 |
| Depth to watertable <5 m ('000 ha) | 25 | 8 | 4 | 0 | 2 |
| Depth to watertable 5–10 m ('000 ha) | 44 | 37 | 6 | <1 | 3 |
| Depth to watertable 10–15 m ('000 ha) | 44 | 35 | 7 | 2 | 3 |
| Depth to watertable 15–20 m ('000 ha) | 43 | 118 | 17 | 8 | 14 |
| Depth to watertable >20 m ('000 ha) | 365 | <1 | <1 | <1 | <1 |
| Number of groundwater monitoring bores | 13 | 24 | 9 | 1 | 4 |

410091 Billabong Creek at Walbundrie, 410097 Billabong Creek at Aberfeldy, 410098 Ten Mile Creek at Holbrook No 2, 410099 Yarra Yarra Creek at Yarra Yarra

# Appendix B: Sub-catchment summaries of analysis themes

Analyses and information presented in Chapter 3 is summarised on a sub-catchment basis (defined by gauging station). Results from the land salinisation and modelling components are presented in one set of tables while the stream EC trend analyses are presented in separate tables. This separation is due to the fact that additional sub-catchments were used for the stream EC trend analyses.

**Table B1:** Border Rivers summary of interpreted data

| | **416003** | **416008** | **416010** | **416020** | **416021** | **416026** | **416032** | **416036** | **416039** |
|---|---|---|---|---|---|---|---|---|---|
| Area (km$^2$) | 531 | 903 | 2136 | 374 | 821 | 284 | 1583 | 319 | 1746 |
| Average annual rainfall (mm) | 819 | 739 | 761 | 718 | 727 | 735 | 839 | 629 | 850 |
| Winter surplus | No | No | No | No | No | No | No | No | Yes |
| Stream flow (ML) | 45168 | 65674 | 130176 | 14086 | 66801 | 23659 | 121968 | 8935 | 151318 |
| Salt load (t) | 4142 | 4694 | 18507 | 3631 | 8103 | 1884 | 8946 | 1599 | 13079 |
| Current salt outbreaks (ha) | 12 | | 95 | | | | 16 | | 35 |
| Predicted minimum extent (ha) | 6 | | | | | | 6 | | 3 |
| Predicted maximum extent (ha) | 12 | | 95 | | | | 16 | | 35 |
| Surface runoff (% of total stream flow) | 70.6 | 91.6 | 53.1 | 98.9 | 73.4 | 90.8 | 62.8 | 99.0 | 64.4 |
| Sub-surface lateral flow (% of total stream flow) | 15.7 | 5.2 | 30.5 | 0.7 | 16.8 | 8.6 | 12.8 | 1.0 | 11.9 |
| Surface discharge of ground water (% of total stream flow) | 13.8 | 3.2 | 15.9 | 0.3 | 8.4 | 0.5 | 23.6 | 0.0 | 23.2 |
| Groundwater discharge to stream (% of total stream flow) | 0.0 | 0.0 | 0.5 | 0.1 | 1.4 | 0.1 | 0.8 | 0.0 | 0.4 |
| Flow from hillslope areas (% of total stream flow) | 95.0 | 95.2 | 90.3 | 96.5 | 89.3 | 98.2 | 94.1 | 31.2 | 89.6 |
| Flow from alluvial areas (% of total stream flow) | 5.0 | 4.8 | 9.7 | 3.5 | 10.7 | 1.8 | 5.9 | 68.8 | 10.4 |
| Salt washoff (% of total salt load) | 94.1 | 97.6 | 45.8 | 75.5 | 95.1 | 99.0 | 93.2 | 83.6 | 92.3 |
| Salt in sub-surface lateral flow (% of total salt load) | 3.4 | 1.5 | 36.7 | 15.0 | 3.2 | 0.9 | 2.7 | 16.4 | 3.2 |
| Salt from surface discharge (% of total salt load) | 2.4 | 0.8 | 16.9 | 5.8 | 1.4 | 0.0 | 3.9 | 0.0 | 4.4 |
| Salt from discharge to stream (% of total salt load) | 0.0 | 0.0 | 0.6 | 3.8 | 0.2 | 0.0 | 0.2 | 0.0 | 0.1 |
| Salt from hillslope areas (% of total salt load) | 95.1 | 96.4 | 91.6 | 90.3 | 91.9 | 98.7 | 96.6 | 54.3 | 90.3 |
| Salt from alluvial areas (% of total salt load) | 4.9 | 3.6 | 8.4 | 9.7 | 8.1 | 1.3 | 3.4 | 45.7 | 9.7 |
| Change in stream flow for 2100 (%) | 1 | 1 | 1 | 0 | 2 | 0 | 3 | 0 | 1 |
| Change in salt load for 2100 (%) | 0 | 0 | 2 | 18 | 0 | 0 | 1 | 0 | 0 |
| Salt load for baseline conditions (t) | 2611 | 3894 | 19493 | 2379 | 3678 | 1178 | 7378 | 1403 | 8454 |
| Salt load for year 2100 (t) | 2619 | 3906 | 19977 | 2799 | 3696 | 1178 | 7424 | 1402 | 8466 |

416003 Tenterfield Creek at Clifton, 416008 Beardy River at Haystack ,416010 Macintyre River at Wallangra, 416020 Ottleys Creek at Coolatai, 416021 Frazers Creek at Westholme, 416026 Reedy Creek at Dumaresq, 416032 Mole River at Donaldson, 416036 Campbells Creek at Deebo, 416039 Severn River at Strathbogie

**Table B2:** Border Rivers summary of stream EC trend analyses

| Station | Name | Trend | Linear Coefficient | Standard Error | Probability Slope=0 | Cycle ratio | Percent of cycle | Recovery factor | Mean EC | $R^2$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 416003 | Tenterfield Ck at Clifton | No trend | -0.0007 | 0.0015 | Nil | 1.02 | 9.7 | 0.97 | 332 | 0.63 |
| 416008 | Beardy R. at Haystack | Falling | -0.0098 | 0.0021 | 0.01 | 1.09 | 32.3 | 1.13 | 233 | 0.37 |
| 416010 | Macintyre R. at Wallangra | No trend | -0.0033 | 0.0023 | Nil | 1.03 | 17.5 | 1.04 | 515 | 0.37 |
| 416016 | Macintyre R. at Inverell | No trend | -0.0027 | 0.0029 | Nil | 1.04 | 23.4 | 1.00 | 493 | 0.25 |
| 416020 | Ottleys Ck at Coolatai | No trend | 0.0014 | 0.0027 | Nil | 1.03 | 21.8 | 0.89 | 724 | 0.22 |
| 416021 | Frazers Ck at Ashford | Rising | 0.0081 | 0.0024 | 0.01 | 1.08 | 45.2 | 0.72 | 433 | 0.45 |
| 416023 | Deepwater Ck at Bolivia | No trend | -0.0007 | 0.0025 | Nil | 1.03 | 15.5 | 0.96 | 159 | 0.46 |
| 416027 | Gil Gil Ck at Weemelah | No trend | 0.0027 | 0.0033 | Nil | 1.03 | 14.7 | 0.90 | 420 | 0.54 |
| 416032 | Mole R. at Donaldson | Falling | -0.0022 | 0.0012 | 0.10 | 1.01 | 6.6 | 1.03 | 204 | 0.69 |
| 416039 | Severn R. at Strathbogie | Rising | 0.0058 | 0.0023 | 0.05 | 1.04 | 20.5 | 0.72 | 298 | 0.29 |

**Table B3:** Gwydir summary of interpreted data

| | **418005** | **418015** | **418016** | **418017** | **418018** | **418021** | **418022** | **418023** | **418025** | **418029** | **418032** | **418033** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area (km$^2$) | 235 | 1954 | 535 | 871 | 556 | 344 | 525 | 668 | 171 | 1986 | 837 | 186 |
| Average annual rainfall (mm) | 875 | 770 | 737 | 750 | 760 | 866 | 861 | 871 | 748 | 792 | 709 | 806 |
| Winter surplus | No | No | No | No | No | Yes | Yes | Yes | No | Yes | No | No |
| Stream flow (ML) | 23621 | 189036 | 23950 | 34581 | 32376 | 34165 | 48288 | 83623 | 7596 | 143522 | 31148 | 12323 |
| Salt load (t) | 1380 | 38712 | 4482 | 12207 | 5648 | 2387 | 3157 | 6136 | 4296 | 15101 | 5936 | 633 |
| Current salt outbreaks (ha) | | 136 | 36 | 301 | 2 | | | | | | 231 | |
| Predicted minimum extent (ha) | | 57 | 22 | 182 | 1 | | | | | | 89 | |
| Predicted maximum extent (ha) | | 136 | 36 | 301 | 2 | | | | | | 231 | |
| Surface runoff (% of total stream flow) | 10.7 | 63.5 | 69.8 | 68.8 | 77.4 | 46.1 | 31.2 | 42.8 | 88.2 | 27.5 | 81.9 | 18.8 |
| Sub-surface lateral flow (% of total stream flow) | 86.8 | 10.5 | 5.4 | 7.7 | 8.1 | 27.5 | 24.6 | 22.5 | 7.1 | 56.5 | 8.8 | 80.5 |
| Surface discharge of ground water (% of stream flow) | 2.5 | 23.6 | 24.6 | 23.4 | 13.1 | 24.3 | 42.6 | 34.1 | 4.2 | 14.9 | 9.0 | 0.6 |
| Groundwater discharge to stream (% of stream flow) | 0.0 | 2.4 | 0.2 | 0.2 | 1.4 | 2.0 | 1.6 | 0.6 | 0.5 | 1.1 | 0.2 | 0.1 |
| Flow from hillslope areas (% of total stream flow) | 92.8 | 91.8 | 96.5 | 93.7 | 92.8 | 85.8 | 88.9 | 93.3 | 95.8 | 93.0 | 90.7 | 94.4 |
| Flow from alluvial areas (% of total stream flow) | 7.2 | 8.2 | 3.5 | 6.3 | 7.2 | 14.2 | 11.1 | 6.7 | 4.2 | 7.0 | 9.3 | 5.6 |
| Salt washoff (% of total salt load) | 61.5 | 35.5 | 31.8 | 20.7 | 91.2 | 92.2 | 86.4 | 90.1 | 27.8 | 80.1 | 73.9 | 78.2 |
| Salt in sub-surface lateral flow (% of total salt load) | 37.5 | 17.6 | 11.8 | 18.6 | 2.8 | 4.3 | 5.4 | 5.1 | 36.3 | 15.6 | 13.5 | 21.6 |
| Salt from surface discharge (% of total salt load) | 1.0 | 43.6 | 56.0 | 60.6 | 5.2 | 3.3 | 7.8 | 4.7 | 29.2 | 4.1 | 12.3 | 0.2 |
| Salt from discharge to stream (% of total salt load) | 0.0 | 3.3 | 0.4 | 0.1 | 0.8 | 0.3 | 0.4 | 0.1 | 6.8 | 0.3 | 0.3 | 0.0 |
| Salt from hillslope areas (% of total salt load) | 93.2 | 93.9 | 97.2 | 98.2 | 95.9 | 94.9 | 93.1 | 93.5 | 77.8 | 93.6 | 86.5 | 96.2 |
| Salt from alluvial areas (% of total salt load) | 6.8 | 6.1 | 2.8 | 1.8 | 4.1 | 5.1 | 6.9 | 6.5 | 22.2 | 6.4 | 13.5 | 3.8 |
| Change in stream flow for 2100 (%) | 2 | 0 | 0 | 1 | 1 | 1 | 1 | 2 | 3 | 3 | 0 | 1 |
| Change in salt load for 2100 (%) | 1 | 5 | 2 | 6 | 1 | 1 | 1 | 1 | 24 | 1 | 1 | 0 |
| Salt load for baseline conditions (t) | 1558 | 23735 | 6580 | 17159 | 2562 | 1635 | 2539 | 3171 | 4171 | 10262 | 4384 | 873 |
| Salt load for year 2100 (t) | 1570 | 25007 | 6692 | 18264 | 2595 | 1647 | 2555 | 3188 | 5170 | 10358 | 4439 | 877 |

418005 Copes Creek at Kimberley, 418015 Horton River at Rider, 418016 Warialda Creek at Warialda No.3, 418017 Myall Creek at Molroy, 418018 Keera Creek at Keera, 418021 Laura Creek at Laura, 418022 Georges Creek at Clerkness, 418023 Moredun Creek at Bundarra, 418025 Halls Creek at Bingara, 418029 Gwydir River at Stoneybatter, 418032 Tycannah Creek at Horseshoe Lagoon, 418033 Bakers Creek at Bundarra

**Table B4:** Gwydir summary of stream EC trend analyses

| Station | Name | Trend | Linear coefficient | Standard error | Probability slope=0 | Cycle ratio | Percentage of cycle | Recovery factor | Mean EC | $R^2$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 418005 | Copes Ck at Kimberley | Falling | -0.0066 | 0.0021 | 0.01 | 1.03 | 15.2 | 1.17 | 178 | 0.51 |
| 418008 | Gwydir R. at Bundarra | Rising | 0.0028 | 0.0012 | 0.05 | 1.02 | 8.8 | 0.93 | 284 | 0.58 |
| 418014 | Gwydir at Yarrowych | Falling | -0.0044 | 0.0017 | 0.01 | 1.02 | 12.0 | 1.12 | 357 | 0.63 |
| 418015 | Horton R. at Killara | No trend | -0.0010 | 0.0011 | Nil | 1.03 | 19.4 | 1.00 | 622 | 0.48 |
| 418016 | Warialda Ck at Warialda | No trend | -0.0008 | 0.0021 | Nil | 1.01 | 6.2 | 0.92 | 833 | 0.54 |
| 418017 | Myall Ck At Molroy | No trend | -0.0018 | 0.0019 | Nil | 1.04 | 24.7 | 0.98 | 1046 | 0.36 |
| 418018 | Keera Ck at Keera | No trend | -0.0069 | 0.0060 | Nil | 1.06 | 35.8 |  | 611 | 0.31 |
| 418021 | Laura Ck at Laura | No trend | 0.0007 | 0.0020 | Nil | 1.01 | 4.5 | 0.97 | 266 | 0.79 |
| 418023 | Moredun Ck at Bundarra | No trend | 0.0034 | 0.0053 | Nil | 1.04 | 22.3 |  | 238 | 0.48 |
| 418025 | Halls Ck at Bingara | Falling | -0.0045 | 0.0013 | 0.01 | 1.02 | 16.9 | 1.10 | 1039 | 0.02 |
| 418027 | Horton R. at DamSite | Falling | -0.0183 | 0.0030 | 0.01 | 1.10 | 53.7 | 1.69 | 506 | 0.64 |
| 418029 | Gwydir R. at Stoneybatter | No trend | 0.0009 | 0.0038 | Nil | 1.07 | 38.6 |  | 301 | 0.60 |
| 418032 | Tycannah Ck at Horseshoe Lagoon | No trend | -0.0010 | 0.0023 | Nil | 1.04 | 22.6 | 0.97 | 749 | 0.52 |
| 418052 | Carole Ck at Nr. Garah | No trend | -0.0055 | 0.0048 | Nil | 1.05 | 30.6 | 1.05 | 400 | 0.30 |

**Table B5:** Namoi/Peel summary of interpreted data

| | **419005** | **419027** | **419029** | **419032** | **419043** | **419051** | **419072** | **Goran** | **419016** | **419035** | **419036** | **419045** | **419077** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area (km$^2$) | 2525 | 3106 | 358 | 3796 | 1636 | 658 | 959 | 1842 | 893 | 459 | 92 | 409 | 95 |
| Average annual rainfall (mm) | 828 | 709 | 797 | 614 | 766 | 772 | 627 | 595 | 828 | 832 | 959 | 965 | 1079 |
| Winter surplus | Yes | No | Yes | No | No | No | No | No | Yes | Yes | Yes | Yes | Yes |
| Stream flow (ML) | 248474 | 136574 | 23385 | 95349 | 72669 | 23949 | 12714 | | 79283 | 29866 | 12974 | 47861 | 13534 |
| Salt load (t) | 23148 | 32203 | 4991 | 9595 | 15552 | 3306 | 2136 | | 11413 | 9012 | 2393 | 9802 | 2597 |
| Current salt outbreaks (ha) | | | | 900 | 361 | | 59 | 6 | | | | | |
| Predicted minimum extent (ha) | | | | 446 | | | 24 | 1 | | | | | |
| Predicted maximum extent (ha) | | | | 900 | 361 | | 59 | 6 | | | | | |
| Surface runoff (% of total stream flow) | 36.5 | 92.1 | 76.5 | 98.0 | 75.1 | 60.4 | 93.2 | | 54.2 | 70.6 | 38.5 | 44.5 | 41.3 |
| Sub-surface lateral flow (% of total stream flow) | 33.9 | 2.0 | 13.4 | 1.4 | 6.1 | 14.2 | 2.8 | | 15.9 | 6.0 | 10.4 | 9.7 | 13.7 |
| Surface discharge of ground water (% of stream flow) | 28.7 | 5.2 | 10.1 | 0.6 | 16.1 | 20.4 | 4.1 | | 29.1 | 23.0 | 41.8 | 44.6 | 41.2 |
| Groundwater discharge to stream (% of stream flow) | 0.9 | 0.6 | 0.1 | 0.0 | 2.7 | 4.9 | 0.0 | | 0.7 | 0.4 | 9.3 | 1.1 | 3.8 |
| Flow from hillslope areas (% of total stream flow) | 96.0 | 61.3 | 97.9 | 66.4 | 90.5 | 88.1 | 79.3 | | 92.3 | 94.8 | 94.2 | 92.4 | 98.4 |
| Flow from alluvial areas (% of total stream flow) | 4.0 | 38.7 | 2.1 | 33.6 | 9.5 | 11.9 | 20.7 | | 7.7 | 5.2 | 5.8 | 7.6 | 1.6 |
| Salt washoff (% of total salt load) | 83.0 | 30.9 | 88.8 | 90.3 | 65.4 | 70.1 | 65.7 | | 63.8 | 27.3 | 20.8 | 30.3 | 18.2 |
| Salt in sub-surface lateral flow (% of total salt load) | 9.6 | 15.6 | 6.3 | 7.7 | 7.9 | 11.5 | 16.2 | | 12.4 | 14.6 | 13.7 | 11.8 | 19.8 |
| Salt from surface discharge (% of total salt load) | 6.9 | 46.7 | 4.8 | 2.0 | 22.9 | 14.9 | 18.1 | | 23.1 | 57.6 | 53.7 | 56.2 | 56.2 |
| Salt from discharge to stream (% of total salt load) | 0.6 | 6.7 | 0.1 | 0.0 | 3.8 | 3.5 | 0.0 | | 0.8 | 0.6 | 11.8 | 1.7 | 5.8 |
| Salt from hillslope areas (% of total salt load) | 96.2 | 74.8 | 98.7 | 68.8 | 89.1 | 93.2 | 85.7 | | 92.6 | 96.4 | 92.8 | 89.3 | 96.9 |
| Salt from alluvial areas (% of total salt load) | 3.8 | 25.2 | 1.3 | 31.2 | 10.9 | 6.8 | 14.3 | | 7.4 | 3.6 | 7.2 | 10.7 | 3.1 |
| Change in stream flow for 2100 (%) | 5 | 0 | 6 | 1 | 1 | 3 | 2 | -100 | 3 | 0 | 0 | 0 | 0 |
| Change in salt load for 2100 (%) | 1 | 5 | 4 | 3 | 5 | 4 | 11 | -100 | 3 | 6 | 1 | 3 | 0 |
| Salt load for baseline conditions (t) | 12481 | 51060 | 1762 | 15567 | 10235 | 3920 | 6146 | | 6168 | 6770 | 1842 | 5673 | 2655 |
| Salt load for year 2100 (t) | 12611 | 53736 | 1832 | 16040 | 10796 | 4082 | 6850 | | 6360 | 7151 | 1853 | 5850 | 2655 |

419005 Namoi River at North Cuerindi, 419016 Cockburn River at Mulla Crossing, 419027 Mooki River at Breeza, 419029 Halls Creek at Ukolan, 419032 Coxs Creek at Boggabri, 419035 Goonoo Goonoo Creek at Timbumburi, 419036 Duncans Creek at Woolomin, 419043 Manilla River at Split Rock Dam, 419045 Peel River Chaffey Dam, 419051 Maules Creek at Avoca East, 419072 Baradine Creek at Kienbri, 419077 Dungowan Creek at Dungowan Dam

**Table B6:** Namoi/Peel summary of stream EC trend analyses

| Station | Name | Trend | Linear coefficient | Standard error | Probability slope=0 | Cycle ratio | Percentage of cycle | Recovery factor | Mean EC | $R^2$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 419005 | Namoi R. at Nth Cuerindi | Falling | -0.0116 | 0.0038 | 0.01 | 1.07 | 33.1 | 1.44 | 278 | 0.55 |
| 419016 | Cockburn R. at Mulla Xing | Falling | -0.0100 | 0.0021 | 0.01 | 1.03 | 16.8 | 1.34 | 434 | 0.27 |
| 419027 | Mooki R. at Breeza | Rising | 0.0127 | 0.0023 | 0.01 | 1.08 | 52.7 | 0.70 | 975 | 0.23 |
| 419029 | Halls Ck at Ukalon | Falling | -0.0065 | 0.0025 | 0.05 | 1.04 | 25.5 | 1.08 | 669 | 0.58 |
| 419032 | Coxs Ck at Boggabri | No trend | -0.0071 | 0.0059 | Nil | 1.09 | 52.3 | 1.33 | 660 | 0.14 |
| 419033 | Coxs Ck at Tambar Springs | No trend | -0.0017 | 0.0022 | Nil | 1.02 | 13.6 | 1.05 | 1092 | 0.48 |
| 419035 | Goonoo Ck at Timbumburi | No trend | -0.0023 | 0.0037 | Nil | 1.03 | 17.5 | 0.97 | 1040 | 0.38 |
| 419051 | Maules Ck At Avoca | No trend | -0.0011 | 0.0016 | Nil | 1.04 | 22.2 | 1.10 | 363 | 0.29 |
| 419054 | Swamp Oak Ck at Limbri | No trend | -0.0048 | 0.0038 | Nil | 1.03 | 19.8 | 0.71 | 519 | 0.42 |
| 419072 | Baradine Ck at Kienbri | No trend | 0.0056 | 0.0049 | Nil | 1.06 | 33.5 | 0.78 | 289 | 0.60 |

**Table B7:** Macquarie summary of interpreted data (421018 to 421059)

| | **421018** | **421026** | **421035** | **421041** | **421042** | **421048** | **421052** | **421053** | **421055** | **421058** | **421059** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Area (km$^2$) | 1629 | 880 | 593 | 349 | 2963 | 577 | 618 | 203 | 563 | 841 | 701 |
| Average annual rainfall (mm) | 709 | 782 | 984 | 732 | 641 | 629 | 825 | 740 | 542 | 665 | 626 |
| Winter surplus | Yes | Yes | Yes | Yes | No | Yes | Yes | Yes | No | Yes | Yes |
| Stream flow (ML) | 111188 | 85731 | 89067 | 25338 | 52154 | 38681 | 72148 | 14646 | 21090 | 24344 | 24264 |
| Salt load (t) | 29916 | 11052 | 4369 | 4135 | 8956 | 3218 | 9243 | 2026 | 663 | 3936 | 7512 |
| Current salt outbreaks (ha) | 1802 | 24 | 28 | 275 | 2325 | 915 | 182 | 54 | | 981 | 1651 |
| Predicted minimum extent (ha) | 1025 | 13 | 12 | 153 | 1538 | 546 | 56 | 23 | | 808 | 1037 |
| Predicted maximum extent (ha) | 1802 | 24 | 28 | 275 | 2325 | 915 | 182 | 54 | | 981 | 1651 |
| Surface runoff (% of total stream flow) | 90.4 | 51.7 | 22.3 | 53.8 | 83.2 | 59.3 | 28.6 | 58.9 | 98.1 | 72.6 | 48.0 |
| Sub-surface lateral flow (% of total stream flow) | 5.0 | 11.3 | 10.4 | 10.8 | 5.2 | 11.1 | 10.5 | 15.0 | 1.9 | 7.7 | 7.8 |
| Surface discharge of ground water (% of total stream flow) | 4.6 | 34.1 | 66.1 | 34.2 | 10.4 | 29.5 | 59.3 | 23.2 | 0.0 | 19.7 | 43.0 |
| Groundwater discharge to stream (% of total stream flow) | 0.0 | 2.9 | 1.2 | 1.2 | 1.2 | 0.1 | 1.6 | 2.9 | 0.0 | 0.0 | 1.3 |
| Flow from hillslope areas (% of total stream flow) | 32.6 | 94.8 | 95.6 | 96.2 | 86.4 | 91.7 | 92.4 | 92.0 | 28.5 | 80.3 | 92.4 |
| Flow from alluvial areas (% of total stream flow) | 67.4 | 5.2 | 4.4 | 3.8 | 13.6 | 8.3 | 7.6 | 8.0 | 71.5 | 19.7 | 7.6 |
| Salt washoff (% of total salt load) | 96.7 | 50.2 | 56.8 | 52.9 | 75.3 | 93.5 | 34.9 | 56.6 | 99.4 | 97.2 | 25.7 |
| Salt in sub-surface lateral flow (% of total salt load) | 2.8 | 11.9 | 6.7 | 11.2 | 8.2 | 2.1 | 9.5 | 16.3 | 0.6 | 0.6 | 11.4 |
| Salt from surface discharge (% of total salt load) | 0.4 | 34.9 | 35.1 | 34.7 | 15.3 | 4.4 | 53.2 | 23.8 | 0.0 | 2.2 | 61.8 |
| Salt from discharge to stream (% of total salt load) | 0.0 | 3.0 | 1.3 | 1.3 | 1.2 | 0.0 | 2.4 | 3.4 | 0.0 | 0.0 | 1.2 |
| Salt from hillslope areas (% of total salt load) | 5.1 | 93.8 | 94.7 | 96.0 | 89.7 | 88.2 | 89.7 | 91.3 | 32.3 | 80.5 | 94.4 |
| Salt from alluvial areas (% of total salt load) | 94.9 | 6.2 | 5.3 | 4.0 | 10.3 | 11.8 | 10.3 | 8.7 | 67.7 | 19.5 | 5.6 |
| Change in stream flow for 2100 (%) | 5 | 0 | 0 | 0 | 3 | 2 | 0 | 0 | 4 | 7 | 0 |
| Change in salt load for 2100 (%) | 0 | 1 | 0 | 3 | 7 | 0 | 2 | 2 | 0 | 1 | 4 |
| Salt load for baseline conditions (t) | 47985 | 6800 | 4171 | 2370 | 15062 | 2223 | 7195 | 1386 | 1664 | 3069 | 9345 |
| Salt load for year 2100 (t) | 47933 | 6854 | 4174 | 2430 | 16092 | 2230 | 7358 | 1420 | 1669 | 3100 | 9743 |

421018 Bell River at Newrea, 421026 Turon River at Sofala, 421035 Fish River at Tarana, 421041 Crudine River at Turon River junction, 421042 Talbragar River at Elong Elong, 421048 Little River at Obley No. 2, 421052 Lewis Ponds Creek at Ophir, 421053 Queen Charlottes Creek at Georges Plains, 421055 Coolbaggie Creek at Rawsonville, 421058 Wyaldra Creek at Gulgong, 421059 Buckinbah Creek at Yeoval

**Table B8:** Macquarie summary of interpreted data (421066 to 421101)

| | **421066** | **421072** | **421073** | **421079** | **421101** |
|---|---|---|---|---|---|
| Area (km$^2$) | 115 | 720 | 729 | 1090 | 918 |
| Average annual rainfall (mm) | 731 | 744 | 735 | 744 | 831 |
| Winter surplus | Yes | Yes | Yes | Yes | Yes |
| Stream flow (ML) | 14647 | 74472 | 84161 | 45625 | 79688 |
| Salt load (t) | 4826 | 7715 | 9773 | 10532 | 12999 |
| Current salt outbreaks (ha) | 57 | 60 | 468 | 626 | 52 |
| Predicted minimum extent (ha) | 13 | 29 | 113 | 422 | 37 |
| Predicted maximum extent (ha) | 57 | 60 | 468 | 626 | 52 |
| Surface runoff (% of total stream flow) | 62.0 | 49.0 | 44.4 | 49.5 | 27.1 |
| Sub-surface lateral flow (% of total stream flow) | 14.9 | 12.2 | 14.4 | 9.3 | 12.9 |
| Surface discharge of ground water (% of total stream flow) | 21.9 | 37.4 | 40.0 | 40.8 | 57.0 |
| Groundwater discharge to stream (% of total stream flow) | 1.2 | 1.4 | 1.2 | 0.4 | 3.0 |
| Flow from hillslope areas (% of total stream flow) | 95.7 | 94.8 | 93.1 | 95.0 | 85.6 |
| Flow from alluvial areas (% of total stream flow) | 4.3 | 5.2 | 6.9 | 5.0 | 14.4 |
| Salt washoff (% of total salt load) | 31.2 | 67.8 | 55.8 | 56.1 | 24.6 |
| Salt in sub-surface lateral flow (% of total salt load) | 26.9 | 8.1 | 11.5 | 8.1 | 13.3 |
| Salt from surface discharge (% of total salt load) | 39.6 | 23.2 | 31.5 | 35.4 | 58.4 |
| Salt from discharge to stream (% of total salt load) | 2.2 | 1.0 | 1.2 | 0.4 | 3.7 |
| Salt from hillslope areas (% of total salt load) | 92.6 | 95.8 | 92.8 | 95.1 | 83.1 |
| Salt from alluvial areas (% of total salt load) | 7.4 | 4.2 | 7.2 | 4.9 | 16.9 |
| Change in stream flow for 2100 (%) | 0 | 0 | 0 | 0 | 0 |
| Change in salt load for 2100 (%) | 4 | 1 | 1 | 1 | 1 |
| Salt load for baseline conditions (t) | 1590 | 4025 | 5189 | 7033 | 14971 |
| Salt load for year 2100 (t) | 1648 | 4062 | 5259 | 7132 | 15140 |

421066 Green Valley Creek at Hill End, 421072 Winburndale Rivulet Howards Bridge, 421073 Meroo Creek at Yarrabin 2, 421079 Cudgegong River at Windamere Dam, 421101 Campbells River U/S Ben Chifley Dam

**Table B9:** Macquarie summary of stream EC trend analyses

| Station | Name | Trend | Linear coefficient | Standard error | Probability slope=0 | Cycle ratio | Percentage of cycle | Recovery factor | Mean EC | $R^2$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 421018 | Bell R. at Newrea | Rising | 0.0027 | 0.0012 | 0.05 | 1.01 | 9.2 | 0.92 | 651 | 0.65 |
| 421023 | Bogan R. at Gongolgon | No trend | 0.0033 | 0.0025 | Nil | 1.05 | 30.7 | 0.82 | 347 | 0.32 |
| 421025 | Macquarie R. at Bruinbuin | No trend | 0.0024 | 0.0015 | Nil | 1.03 | 15.5 | 0.90 | 318 | 0.53 |
| 421026 | Turon R. at Sofala | No trend | -0.0025 | 0.0021 | Nil | 1.03 | 19.1 | 0.94 | 378 | 0.66 |
| 421035 | Fish R. at Tarana | No trend | 0.0012 | 0.0087 | Nil | 1.05 | 21.9 | 0.88 | 124 | 0.21 |
| 421039 | Bogan R. at Neurie Plains | No trend | 0.0014 | 0.0052 | Nil | 1.04 | 19.8 | 1.01 | 131 | 0.09 |
| 421042 | Talbragar R. at Elong Elong | Rising | 0.0083 | 0.0031 | 0.01 | 1.08 | 51.0 | 0.73 | 1052 | 0.34 |
| 421048 | Little R. at Obley | Rising | 0.0223 | 0.0026 | 0.01 | 1.12 | 66.3 | 0.50 | 609 | 0.65 |
| 421055 | Coolbaggie Ck at Rawsonville | No trend | 0.0025 | 0.0060 | Nil | 1.13 | 56.7 | 1.05 | 153 | 0.10 |
| 421056 | Coolaburragundy Ck at Coolah | No trend | 0.0005 | 0.0025 | Nil | 1.01 | 8.7 | 0.95 | 834 | 0.32 |
| 421059 | Buckinbar Ck at Yeoval | No trend | 0.0018 | 0.0022 | Nil | 1.04 | 27.0 | 0.90 | 1392 | 0.53 |
| 421072 | Winburndale Rivlt at Howards Bdge | No trend | 0.0119 | 0.0101 | Nil | 1.04 | 23.0 |  | 297 | 0.67 |
| 421073 | Meroo Ck at Yarrabin 2 | No trend | -0.0008 | 0.0083 | Nil | 1.00 | 1.9 | 1.02 | 392 | 0.59 |
| 421076 | Bogan R. at Peak Hill 2 | No trend | 0.0045 | 0.0071 | Nil | 1.06 | 28.2 | 0.84 | 136 | 0.14 |
| 421084 | Burrill Ck at Mickibri | No trend | 0.0076 | 0.0114 | Nil | 1.08 | 39.4 |  | 209 | 0.32 |
| 421101 | Campbells R. U/S Ben Chifley Dam | No trend | 0.0027 | 0.0025 | Nil | 1.01 | 8.3 | 0.94 | 440 | 0.78 |

**Table B10:** Lachlan summary of interpreted data

| | **412028** | **412029** | **412030** | **412043** | **412050** | **412065** | **412072** | **412077** | **412080** | **412083** | **412092** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Area (km$^2$) | 2624 | 1547 | 1689 | 4115 | 756 | 2239 | 797 | 233 | 86 | 320 | 132 |
| Average annual rainfall (mm) | 837 | 702 | 679 | 506 | 809 | 702 | 661 | 774 | 973 | 802 | 804 |
| Winter surplus | Yes | Yes | Yes | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Stream flow (ML) | 294417 | 93847 | 77799 | 73556 | 90333 | 174122 | 23249 | 19078 | 13070 | 34655 | 19314 |
| Salt load (t) | 27179 | 24880 | 21563 | 7665 | 11181 | 41844 | 9807 | 3923 | 2834 | 4783 | 3754 |
| Current salt outbreaks (ha) | 503 | 3693 | 1541 | 638 | 2071 | 4647 | 2049 | 45 | 7 | 148 | 14 |
| Predicted minimum extent (ha) | 207 | | | | | | | 45 | 6 | 92 | 6 |
| Predicted maximum extent (ha) | 503 | 3693 | 1541 | 638 | 2071 | 4647 | 2049 | 87 | 9 | 148 | 14 |
| Surface runoff (% of total stream flow) | 34.2 | 25.2 | 53.3 | 94.0 | 33.0 | 53.1 | 39.9 | 24.8 | 18.5 | 40.6 | 21.1 |
| Sub-surface lateral flow (% of total stream flow) | 14.1 | 10.6 | 8.9 | 4.0 | 12.1 | 10.3 | 10.7 | 10.8 | 7.5 | 15.3 | 11.2 |
| Surface discharge of ground water (% of total stream flow) | 49.6 | 62.0 | 35.9 | 1.9 | 52.0 | 32.6 | 46.3 | 64.3 | 72.9 | 43.0 | 67.3 |
| Groundwater discharge to stream (% of total stream flow) | 2.1 | 2.2 | 1.8 | 0.1 | 2.9 | 3.9 | 3.2 | 0.2 | 1.1 | 1.2 | 0.4 |
| Flow from hillslope areas (% of total stream flow) | 89.5 | 91.5 | 92.8 | 44.9 | 91.6 | 87.2 | 89.0 | 97.3 | 89.0 | 84.6 | 96.5 |
| Flow from alluvial areas (% of total stream flow) | 10.5 | 8.5 | 7.2 | 55.1 | 8.4 | 12.8 | 11.0 | 2.7 | 11.0 | 15.4 | 3.5 |
| Salt washoff (% of total salt load) | 64.0 | 24.7 | 26.4 | 99.3 | 56.2 | 53.4 | 16.3 | 28.5 | 8.7 | 55.3 | 25.8 |
| Salt in sub-surface lateral flow (% of total salt load) | 7.9 | 10.9 | 14.4 | 0.6 | 8.2 | 10.9 | 15.4 | 9.9 | 8.3 | 11.1 | 10.9 |
| Salt from surface discharge (% of total salt load) | 26.7 | 62.2 | 56.7 | 0.1 | 33.7 | 31.6 | 63.6 | 61.5 | 81.4 | 32.3 | 62.7 |
| Salt from discharge to stream (% of total salt load) | 1.4 | 2.2 | 2.5 | 0.0 | 1.9 | 4.1 | 4.7 | 0.2 | 1.5 | 1.2 | 0.5 |
| Salt from hillslope areas (% of total salt load) | 92.5 | 91.4 | 92.3 | 15.6 | 93.5 | 87.8 | 88.1 | 97.0 | 84.8 | 85.9 | 96.0 |
| Salt from alluvial areas (% of total salt load) | 7.5 | 8.6 | 7.7 | 84.4 | 6.5 | 12.2 | 11.9 | 3.0 | 15.2 | 14.1 | 4.0 |
| Change in stream flow for 2100 (%) | 0 | 0 | 0 | 3 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Change in salt load for 2100 (%) | 1 | 3 | 3 | 0 | 1 | 6 | 6 | 1 | 1 | 0 | 1 |
| Salt load for baseline conditions (t) | 16575 | 20731 | 24455 | 36461 | 5295 | 16542 | 15727 | 3220 | 3844 | 2343 | 1999 |
| Salt load for year 2100 (t) | 16690 | 21455 | 25310 | 36477 | 5335 | 17534 | 16606 | 3242 | 3881 | 2348 | 2024 |

412028 Abercrombie River at Abercrombie, 412029 Boorowa River at Prossers Crossing, 412030 Mandagery Creek at U/S Eugowra, 412043 Goobang Creek at Darbys Dam, 412050 Crookwell River at Narrawa North, 412065 Lachlan River at Narrawa, 412072 Back Creek at Koorawatha, 412077 Belubula River at Carcoar, 412080 Flyers Creek at Beneree, 412083 Tuena Creek at Tuena, 412092 Coombin Creek near Neville

**Table B11:** Lachlan summary of stream EC trend analyses

| Station | Name | Trend | Linear coefficient | Standard error | Probability slope=0 | Cycle ratio | Percentage of cycle | Recovery factor | Mean EC | $R^2$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 412009 | Belubula R. at Canowindra | Rising | 0.0045 | 0.0018 | 0.05 | 1.02 | 13.5 | 0.86 | 643 | 0.48 |
| 412028 | Abercrombie R. at Abercrombie | No trend | -0.0023 | 0.0017 | Nil | 1.01 | 4.0 | 1.08 | 280 | 0.58 |
| 412030 | Mandagery Ck at U/S Eugowra | Rising | 0.0138 | 0.0032 | 0.01 | 1.04 | 30.1 | 0.61 | 987 | 0.42 |
| 412043 | Goobang Ck at Darbys Dam | Rising | 0.0284 | 0.0092 | 0.01 | 1.04 | 21.9 | 0.69 | 364 | 0.43 |
| 412050 | Crookwell R. at Narrawa North | No trend | -0.0008 | 0.0021 | Nil | 1.01 | 5.5 | 1.11 | 418 | 0.66 |
| 412055 | Belubula R. at Bangaroo Bdge | No trend | 0.0056 | 0.0040 | Nil | 1.03 | 18.1 | 0.76 | 624 | 0.40 |
| 412065 | Lachlan R. at Narrawa | Rising | 0.0044 | 0.0022 | 0.05 | 1.03 | 17.3 | 0.87 | 855 | 0.56 |
| 412072 | Back Ck at Koorawatha | Rising | 0.0162 | 0.0079 | 0.05 | 1.02 | 15.9 | 0.74 | 1665 | 0.38 |
| 412083 | Tuena Ck at Tuena | No trend | -0.0100 | 0.0027 | Nil | 1.01 | 9.1 | 1.03 | 483 | 0.68 |
| 412086 | Goobang Ck at Parkes | Falling | -0.0146 | 0.0064 | 0.05 | 1.06 | 32.7 | 1.15 | 573 | 0.60 |
| 412096 | Pudmans Ck at Kennys Rd | No trend | 0.0028 | 0.0038 | Nil | 1.02 | 10.8 | 0.84 | 1294 | 0.71 |
| 412099 | Manna Ck Nr Lake Cowal | Rising | 0.0223 | 0.0069 | 0.01 | 1.12 | 64.5 | 0.67 | 451 | 0.29 |
| 412103 | Bland Ck at Mongarell | Rising | 0.0871 | 0.0176 | 0.01 | 1.23 | 106.0 | 0.35 | 326 | 0.26 |

**Table B12:** Murrumbidgee summary of interpreted data

| | **410008** | **410025** | **410038** | **410043** | **410044** | **410045** | **410047** | **410048** | **410057** | **410059** | **410061** | **410071** | **410073** | **410103** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area (km$^2$) | 13110 | 2141 | 386 | 563 | 1059 | 842 | 1639 | 547 | 665 | 276 | 146 | 116 | 1633 | 1136 |
| Average annual rainfall (mm) | 794 | 682 | 1075 | 932 | 658 | 628 | 841 | 689 | 1312 | 1131 | 1138 | 867 | 1332 | 577 |
| Winter surplus | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Stream flow (ML) | 1377632 | 99087 | 81799 | 108742 | 51393 | 14371 | 179140 | 40614 | 273092 | 84796 | 37970 | 19268 | 1629150 | 2369 |
| Salt load (t) | 124421 | 53391 | 5259 | 14058 | 25828 | 1845 | 23015 | 8716 | 7997 | 3536 | 2310 | 3063 | 35841 | 0 |
| Current salt outbreaks (ha) | 4949 | 6756 | | 8 | 2156 | 507 | 448 | 78 | | 4 | | | | 917 |
| Predicted minimum extent (ha) | 4136 | 6227 | | 8 | 2156 | 507 | 30 | 78 | | 4 | | | | 491 |
| Predicted maximum extent (ha) | 4949 | 7943 | | 44 | 3345 | 1170 | 448 | 320 | | 29 | | | | 917 |
| Surface runoff (% of total stream flow) | 24.0 | 26.9 | 11.6 | 31.3 | 43.0 | 57.5 | 27.8 | 32.9 | 12.0 | 21.0 | 21.2 | 17.3 | 11.4 | 39.5 |
| Sub-surface lateral flow (% of total stream flow) | 17.2 | 10.5 | 11.4 | 12.0 | 14.4 | 27.1 | 13.4 | 24.9 | 21.6 | 14.2 | 19.4 | 17.1 | 15.8 | 15.7 |
| Surface discharge of ground water (% of stream flow) | 58.8 | 62.2 | 76.1 | 54.9 | 35.7 | 15.1 | 55.7 | 37.3 | 65.5 | 64.4 | 59.2 | 61.0 | 70.8 | 44.8 |
| Groundwater discharge to stream (% of stream flow) | 0.0 | 0.4 | 0.8 | 1.8 | 7.0 | 0.4 | 3.0 | 5.0 | 0.9 | 0.3 | 0.2 | 4.6 | 2.0 | 0.0 |
| Flow from hillslope areas (% of total stream flow) | 99.1 | 98.1 | 97.1 | 94.3 | 88.7 | 82.1 | 92.2 | 85.9 | 95.7 | 96.3 | 94.0 | 94.6 | 96.6 | 84.7 |
| Flow from alluvial areas (% of total stream flow) | 0.9 | 1.9 | 2.9 | 5.7 | 11.3 | 17.9 | 7.8 | 14.1 | 4.3 | 3.7 | 6.0 | 5.4 | 3.4 | 15.3 |
| Salt washoff (% of total salt load) | 29.3 | 10.5 | 18.7 | 13.5 | 16.6 | 84.3 | 29.4 | 37.7 | 31.8 | 27.8 | 17.5 | 11.2 | 28.7 | 27.2 |
| Salt in sub-surface lateral flow (% of total salt load) | 16.4 | 12.6 | 11.3 | 15.4 | 21.8 | 11.7 | 14.9 | 26.4 | 19.7 | 14.2 | 21.4 | 19.0 | 15.2 | 16.3 |
| Salt from surface discharge (% of total salt load) | 54.2 | 76.4 | 69.4 | 68.0 | 51.2 | 3.6 | 50.0 | 27.2 | 47.8 | 57.7 | 60.8 | 65.1 | 54.5 | 56.4 |
| Salt from discharge to stream (% of total salt load) | 0.0 | 0.5 | 0.6 | 3.0 | 10.4 | 0.4 | 5.7 | 8.7 | 0.7 | 0.3 | 0.3 | 4.7 | 1.5 | 0.0 |
| Salt from hillslope areas (% of total salt load) | 98.7 | 98.8 | 97.6 | 91.2 | 87.0 | 75.9 | 87.3 | 75.5 | 96.8 | 96.3 | 93.6 | 95.2 | 97.5 | 90.4 |
| Salt from alluvial areas (% of total salt load) | 1.3 | 1.2 | 2.4 | 8.8 | 13.0 | 24.1 | 12.7 | 24.5 | 3.2 | 3.7 | 6.4 | 4.8 | 2.5 | 9.6 |
| Change in stream flow for 2100 (%) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Change in salt load for 2100 (%) | 0 | 1 | 0 | 0 | 7 | 0 | 1 | -1 | 0 | 0 | 0 | 1 | 0 | 1 |
| Salt load for baseline conditions (t) | 166808 | 67919 | 8578 | 17092 | 21183 | 3003 | 20843 | 4667 | 9256 | 4095 | 3366 | 4180 | 24109 | 14000 |
| Salt load for year 2100 (t) | 166975 | 68805 | 8619 | 17173 | 22565 | 3008 | 20963 | 4640 | 9257 | 4099 | 3366 | 4219 | 24135 | 14104 |

410008 Murrumbidgee River at Burrinjuck Dam, 410025 Jugiong Creek at Jugiong, 410038 Adjungbilly Creek at Darbalara, 410043 Hillas Creek at Mount Adrah, 410044 Muttama Creek at Coolac, 410045 Billabung Creek at Sunnyside, 410047 Tarcutta Creek at Old Borambola, 410048 Kyeamba Creek at Ladysmith, 410057 Goobarragandra River at Lacmalac, 410059 Gilmore Creek at Gilmore, 410061 Adelong Creek at Batlow Road, 410071 Brungle Creek at Red Hill, 410073 Tumut River at Oddys Bridge, 410103 Houligans Creek at Downside

**Table B13:** Murrumbidgee summary of stream EC trend analyses

| Station | Name | Trend | Linear coefficient | Standard error | Probability slope=0 | Cycle ratio | Percentage of cycle | Recovery factor | Mean EC | $R^2$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 410024 | Goodradidgbee R. at Wee Jasper | Falling | -0.0043 | 0.0013 | 0.01 | 1.06 | 25.8 | 1.12 | 86 | 0.63 |
| 410025 | Jugiong Ck at Jugiong | Rising | 0.0195 | 0.0016 | 0.01 | 1.08 | 55.0 | 0.57 | 1184 | 0.52 |
| 410026 | Yass R. at Yass | Rising | 0.0080 | 0.0036 | 0.05 | 1.04 | 25.6 | 0.83 | 688 | 0.36 |
| 410033 | Murrumbidgee R. at Mittagang X'ing | Falling | -0.0100 | 0.0025 | 0.01 | 1.10 | 37.8 | 1.79 | 76 | 0.08 |
| 410038 | Adjungbilly Ck at Darbalara | No trend | -0.0015 | 0.0026 | Nil | 1.04 | 21.3 | 1.11 | 160 | 0.46 |
| 410044 | Muttama Ck at Coolac | Rising | 0.0112 | 0.0023 | 0.01 | 1.06 | 42.0 | 0.90 | 1294 | 0.59 |
| 410045 | Billabung Ck at Sunnyside | Rising | 0.0269 | 0.0133 | 0.10 | 1.09 | 46.3 | 0.62 | 257 | 0.13 |
| 410047 | Tarcutta Ck at Old Borambola | Rising | 0.0127 | 0.0013 | 0.01 | 1.08 | 41.3 | 0.79 | 254 | 0.42 |
| 410048 | Kyeamba Ck at Ladysmith | Rising | 0.0213 | 0.0027 | 0.01 | 1.12 | 70.5 | 0.55 | 836 | 0.54 |
| 410050 | Murrumbidgee R. at Billingra | Falling | -0.0087 | 0.0019 | 0.01 | 1.08 | 35.1 | 1.29 | 100 | 0.09 |
| 410057 | Goobaragandra R. at Lacmalac | No trend | 0.0015 | 0.0020 | Nil | 1.04 | 16.7 | 1.00 | 59 | 0.22 |
| 410061 | Adelong Ck at Batlow Rd. | No trend | -0.0008 | 0.0015 | Nil | 1.03 | 16.3 | 1.10 | 125 | 0.46 |
| 410062 | Numeralla R. at Numeralla Sch. | Falling | -0.0074 | 0.0017 | 0.01 | 1.07 | 34.2 | 1.24 | 144 | 0.56 |
| 410088 | Goodradigbee R. at Brindabella | No trend | 0.0007 | 0.0018 | Nil | 1.04 | 17.6 | 1.00 | 100 | 0.66 |
| 410091 | Billabong Ck at Wallabundrie | Rising | 0.0195 | 0.0026 | 0.01 | 1.11 | 65.5 | 0.52 | 1324 | 0.73 |
| 410097 | Billabong Ck at Aberfeldy | Rising | 0.0109 | 0.0019 | 0.01 | 1.06 | 37.4 | 0.72 | 507 | 0.55 |
| 410103 | Houligans Ck at Downside | Rising | 0.1852 | 0.0115 | 0.01 | 1.90 | 195.0 | 0.01 | 4707 | 0.59 |
| 410107 | Mountain Ck at Mountain Ck | Rising | 0.0101 | 0.0026 | 0.01 | 1.09 | 43.6 | 0.70 | 164 | 0.69 |

**Table B14:** Murray summary of interpreted data

| | Lake Hume | 410091 | 410097 | 410098 | 410099 |
|---|---|---|---|---|---|
| Area (km$^2$) | 5208 | 1976 | 346 | 102 | 232 |
| Average annual rainfall (mm) | 1121 | 686 | 807 | 952 | 918 |
| Winter surplus | Yes | Yes | Yes | Yes | Yes |
| Stream flow (ML) | n/a | n/a | n/a | n/a | n/a |
| Salt load (t) | n/a | n/a | n/a | n/a | n/a |
| Current salt outbreaks (ha) | 164 | 76 | 115 | 12 | 7 |
| Predicted minimum extent (ha) | 18 | 43 | 37 | 12 | 7 |
| Predicted maximum extent (ha) | 164 | 76 | 115 | 190 | 66 |
| Surface runoff (% of total stream flow) | 13.1 | 47.8 | 47.0 | 65.8 | 51.4 |
| Sub-surface lateral flow (% of total stream flow) | 12.8 | 46.0 | 23.7 | 22.0 | 19.4 |
| Surface discharge of ground water (% of stream flow) | 73.0 | 4.7 | 16.5 | 6.4 | 20.0 |
| Groundwater discharge to stream (% of stream flow) | 1.1 | 1.5 | 12.8 | 5.8 | 9.2 |
| Flow from hillslope areas (% of total stream flow) | 98.9 | 65.3 | 96.0 | 92.2 | 95.9 |
| Flow from alluvial areas (% of total stream flow) | 1.1 | 34.7 | 4.0 | 7.8 | 4.1 |
| Salt washoff (% of total salt load) | 2.4 | 39.2 | 29.0 | 44.3 | 24.7 |
| Salt in sub-surface lateral flow (% of total salt load) | 13.6 | 51.5 | 22.5 | 22.3 | 19.1 |
| Salt from surface discharge (% of total salt load) | 82.7 | 7.4 | 26.1 | 17.6 | 36.7 |
| Salt from discharge to stream (% of total salt load) | 1.3 | 2.0 | 22.4 | 15.8 | 19.5 |
| Salt from hillslope areas (% of total salt load) | 99.6 | 52.1 | 97.4 | 93.6 | 97.4 |
| Salt from alluvial areas (% of total salt load) | 0.4 | 47.9 | 2.6 | 6.4 | 2.6 |
| Change in stream flow for 2100 (%) | n/a | n/a | n/a | n/a | n/a |
| Change in salt load for 2100 (%) | n/a | n/a | n/a | n/a | n/a |
| Salt load for baseline conditions (t) | n/a | n/a | n/a | n/a | n/a |
| Salt load for year 2100 (t) | n/a | n/a | n/a | n/a | n/a |

410091 Billabong Creek at Walbundrie, 410097 Billabong Creek at Aberfeldy, 410098 Ten Mile Creek at Holbrook No 2, 410099 Yarra Yarra Creek at Yarra Yarra

**Table B15:** Murray summary of stream EC trend analyses

| Station | Name | Trend | Linear coefficient | Standard error | Probability slope=0 | Cycle ratio | Percentage of cycle | Recovery factor | Mean EC | $R^2$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 410091 | Billabong Ck at Wallabundrie | Rising | 0.0195 | 0.0026 | 0.01 | 1.11 | 65.5 | 0.52 | 1324 | 0.73 |
| 410097 | Billabong Ck at Aberfeldy | Rising | 0.0109 | 0.0019 | 0.01 | 1.06 | 37.4 | 0.72 | 507 | 0.55 |

*ANUCLIM is a software package that enables the user to obtain estimates of monthly mean climate variables, bioclimatic parameters and indices relating to crop growth.

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