Hydrogeological Landscapes for the Murray Catchment Management Authority

Eastern Murray Catchment

UNIVERSITY OF CANBERRA
AUSTRALIA'S CAPITAL UNIVERSITY

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Cover: Upper Murray valley. Photo: OEH/R Muller.

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1. Salinity Basics

1.1 What is salinity?

Salinity refers to the accumulation of salts in the landscape. It is also a term that can be used in reference to salinity entering streams via base flow from groundwater and runoff from the adjacent land. Land salinity can occur naturally, however, it typically occurs as a result of a change to the hydrologic balance within a catchment.

Salinity occurs when salts present in the landscape are mobilised by surface water or groundwater. It is the result of changes in water use by vegetation. When the landscape water balance is altered, salinity can result.

Salt is naturally present in the Australian landscape and is stored within the landscape in soils, regolith materials, groundwater and rocks. The salts which mobilise through changes in water balance and are present in salinity processes are mainly derived from:

- cyclic salt – deposited as sea spray/atmospheric salt (i.e. rainfall)
- aeolian salt – deposited with dust
- rock weathering – mineral weathering within rocks
- connate salts – salt from sedimentary rocks where the salt stayed within the rock matrix at the time of deposition.

The dynamics of groundwater processes are important to the salt story. There are a variety of systems/scenarios of how water and salt move through the landscape. These systems need to be understood to best target remediation and to understand the risk and impacts of salinity occurring in the landscape.

Pre-European settlement, landscapes were characterised by:

- native vegetation communities which had a high perennial plant component (trees and grasses)
- native vegetation communities which had a high diversity of species
- soils which had organic matter layers (A0 horizons).

Post-European settlement land use has led to significant changes. The landscape has been ‘annualised’ by farming and grazing systems of the past and present, meaning that most farming systems are now based on annual plants. This has resulted in simplification of the biodiversity of the landscape. Diverse woodlands and grasslands have been replaced by monocultures of crops or simple mixtures of pasture species. This limits the timing and amount of water used by the vegetation in the landscape over the year and across climate cycles and events.

In rural areas where a land use change (e.g. clearing of vegetation) has occurred, the water balance is altered and must adjust to find a new balance. This can result in salinity at various points in the landscape. In urban situations where the landscape is altered further by activities which impede water movement and/or increase water use (e.g. road construction and building), salinity symptoms may emerge.

The process of capillary rise often causes salts to be transported to the land surface where they can have an adverse effect on plant growth, infrastructure and dwellings.

Some plants or construction materials are more resistant to salts than others. In plants, this is referred to as ‘salt tolerance’ – such plants occurring naturally may indicate a salinity problem in the landscape. Some of the common landscape indications of salinity include:

- the presence of indicator plant species
- bare ground
- puffy soil
- salt crystals at the surface
- discharge of water
- dieback of vegetation that is less salt tolerant
- yellowing of crops or grassed areas
- stock congregating and licking a particular area of ground
- damage to infrastructure such as roads and houses
- dry scalds which occur when topsoils are lost through wind and water erosion, and saline and sodic subsoils are exposed to the surface.

Discharge refers to groundwater that is seeping into streams or to the land surface. On the land, it is often expressed as areas of waterlogging. Salt sites may occur as a result of evaporation.

1.1.1 Concentration of salt

High watertables and the process of capillary rise and evaporation lead to salts concentrating in the surface layers of the soil. This process can be intensified when vegetation and soil cover are lost and any impediments to drainage occur due to salt and waterlogging impacts. This means that quite high levels of salt can be expressed at discharge sites in the landscape even though the background levels of salt in groundwater and soils can be quite low. The amount of salt expressed in the surface soils at discharge sites can vary dramatically over time. Seasonal and longer-term climatic influences will either dilute or concentrate salt over time. Plants have various levels of tolerance or ability to cope with salt concentration in the root zone.

1.1.2 Soil chemistry

The chemistry and behaviour of soils is modified by the addition of cations and anions present in the landscape, which are often concentrated and mobilised in groundwater. There can be considerable variation in the type of salt present at salt sites. The dominant cations are generally sodium and/or calcium which have combined with the anions bicarbonate, chloride, sulfate and/or carbonate in varying ratios.

1.1.3 Waterlogging

Waterlogging leads to low levels of oxygen being available in the soil. This has an impact on plant growth, health and survival. Plants have various levels of tolerance or ability to cope with waterlogging.

1.1.4 Vegetation impacts

The levels and combined effects of waterlogging and salinity will impact on a range of plants. Some plants can cope with high levels of salt, some with high levels of waterlogging. Few plants can cope with both salt concentration and waterlogging. Common effects on-site include loss of production of agricultural species, decline of exotic pastures and native grasses, tree death and change in pasture health and composition.

Vegetation is a victim and an indication of salinity processes. Some plants can cope with the conditions on a salt site. These plants commonly fill the vacuum left by original vegetation as it dies. Salt tolerant plants commonly colonise and dominate salt sites. These plants can be very useful to recognise as indicators of saline conditions.

1.1.5 Erosion

Salinity impacts on, and is impacted by, gully and sheet erosion in sloping landscapes. It causes loss of groundcover and amplifies erosion processes.

Soils frequently exhibit ‘puffiness’ as a result of salts concentrated close to the soil surface. This results in the soils becoming more susceptible to erosion.

When gullies develop they may intersect the watertable. If the groundwater is saline, the discharge of this water in the gullies makes it difficult to revegetate naturally or with outside remedial action. This results in further erosion and more saline groundwater input to the gully for longer periods. Accordingly, the gully degrades further.

1.1.6 Impacts on infrastructure

Salinity processes impact on a range of infrastructure through waterlogging, salt concentration and the growth of salt crystals in porous material.

Much infrastructure is designed and constructed to allow for short-term inundation or is waterproof from the top down. However, salinity impacts are more likely to result from long periods of waterlogging, upward pressure from groundwater systems or intermittent wetting and drying.

Salinity compromises the strength and resilience of many metals used in infrastructure, predominantly through enhancement of the rusting process.

Salt can enter porous media (bricks and pavers) through capillary rise, with subsequent evaporation of the salt-bearing solution precipitating salt crystals. As the crystals grow they exert physical pressure on the media and cause it to fail from within.

1.1.7 Off-site impacts

The effects of changes in vegetation and land use are not always felt where the changes occur. Off-site impacts include:

- sub-catchment impacts where cause and effect are separated by distance and time
- water quality of streams, rivers and water bodies
- catchment impact of redistribution of load, and the issues of water quality versus water quantity.

It is common for discharge areas to be impacted by recharge occurring over considerable areas distant to the site. Recharge refers to water that percolates through to groundwater. Increased recharge can lead to rising watertables and mobilise salt stored in the soil. These changes also take time to be expressed. Increased recharge will impact on a catchment in line with the:

- groundwater storage capacity of the catchment
- porosity of the regolith material and the related rate of groundwater flow within the catchment.

1.2 Salinity expression

Aside from land salinity (also referred to as dryland salinity or salt land), salt is mobilised within catchments and impacts the water quality of streams and rivers. Changes in salt concentration relate to the total amount of salt mobilised, groundwater salinity levels, flow rates in the river and dilution effects from rainfall. These changes are commonly expressed in two ways:

- as ‘pulses’ of water with a high(er) salt concentration moving down-stream over a comparatively short time (hours or days)
- as streams with consistently high concentrations which do not vary significantly with variation in stream flow.

Management of salinity needs an understanding of the dynamics of land salinity, salt concentration (EC – see 1.2.3) and salt load.

1.2.1 Land salinity

Land salinity results from high watertables and the concentration of salt due to evaporation at the soil surface. This process impacts on land assets by damaging infrastructure, ecosystems, vegetation, soil health and agricultural production. In most areas land salinity is often expressed as scalds (bare soil surfaces), usually low in the landscape and often actively eroding. In the Eastern Murray area it is often related to waterlogging.

1.2.2 Salt load

Salt loads are a measure of the dissolved load of salt in a stream, and are expressed as a mass per unit time (e.g. tonnes per day). High salt loads can result from low volumes of water with high concentrations of salt or high volumes of water with low concentrations of salt. Salt loads vary as a result of salt distribution and redistribution in the landscape. Diffuse salt sources in upland and slopes areas are moved by streams and rivers to areas further downstream in catchments. Extraction of water from rivers and streams for irrigation redistributes some of this salt load into the soil. Salt loads are also redistributed across wetlands and flood plain areas during floods, particularly in non-regulated streams. Floods also act as flushing events for the near-surface, leaching salts further into the regolith.

1.2.3 Electrical conductivity – EC (water quality)

Stream salinity integrates landscape processes within a catchment and is a primary water quality indicator. In a salinity context, water quality primarily relates to the concentration of dissolved salts in the water and is measured in terms of the electrical conductivity (EC) of the water, which is a function of the total concentration of dissolved salts. EC is measured in units of microsiemens per centimetre (µS/cm) at 25ºC and is easily measured in-stream with a conductivity meter. High salinity levels in inland water systems can be detrimental to the ecological function of riverine environments and wetland systems. They also limit domestic, recreational, industrial and agricultural uses.

1.2.4 Managing salinity processes

Accurate tailoring of appropriate land use for salinity management should be a core objective for natural resource and land managers. It is a technique of matching appropriate land use to the best locations for management results.

The magnitude of variation in recharge which occurs due to land management practices is a critical factor in the management of salinity. Salinity processes are driven by the climate, the water use characteristics of the vegetation, and hydrogeological characteristics of the landscape. Actions which impact on the way water is used by vegetation or stored in the soil will have impacts on how recharge and runoff occurs.

Salinity processes are usually diffuse within a landscape. Action is needed over a large proportion of a catchment to have impacts. The design of management actions must allow for both continual and episodic recharge patterns. Like many environmental issues, salinity processes are not always linear. Annual and decadal climatic cycles (e.g. droughts) are related to patterns of salinity occurrence and intensity. Design of land management actions should consider extreme events affecting recharge and discharge.

Catchment-scale salinity management also must consider the surface hydrology of the landscape. Catchment management should consider sources and sizes of both saline inputs and fresh inputs to the catchment hydrologic system.

2. Introduction to the Eastern Murray Catchment

2.1 Background

This document and the accompanying maps deal with the nature and consequences of salinity in the Eastern Murray catchment. They have been produced for the Murray Catchment Management Authority (Murray CMA) by the NSW Office of Environment and Heritage (OEH) and NSW Department of Primary Industries (DPI). The maps and document result from a series of salinity projects OEH is undertaking to better understand how dryland salinity manifests in the landscape and how salinity may be best managed.

The Natural Heritage Trust (NHT 2001) estimates that the threat from salinity will increase across Australia from ~5.7 million hectares in 2000 to ~17 million hectares by 2050. The targeting of beneficial land use activity to control dryland salinity at specific locations is paramount if salinity is to be appropriately managed. Variation in climate, soil characteristics, hydrology and salt storage occur down to the property scale. Accordingly, a landscape assessment system that enables land use recommendations to be developed at this scale is required.

Hydrogeological landscapes (HGL) have been developed to characterise and manage the quality and distribution of water on the surface and in the shallow sub-surface of the landscape. HGLs build on the existing Groundwater Flow System (GFS) framework which was developed largely for salinity management (Coram 1998, Coram *et al.* 2000, Walker *et al.* 2003). The GFS framework was largely developed using existing geological data, supplemented by hydrological and topographic data. GFS map units subdivided the landscape into areas with similar groundwater flow and salinity characteristics.

The hydrogeological landscape concept further develops and enhances GFS by including information regarding landforms, regolith (including soils) and elements of structural geology (Wilford *et al.* 2008; Wilford *et al.* 2010). The 'Hydrogeological' term highlights the important components of water, geology and regolith whereas 'Landscape' highlights the influence of landforms and regolith on the hydrological regime. Similar frameworks in North America have used a landscape approach to delineate hydrological systems for managing groundwater and surface water resources (Winter 2001). Hydrological landscape units accordingly integrate information on lithology, bedrock structure, regolith (including soils), landforms and contained hydrologic systems. The HGL unit (or area) therefore represents a landscape component that captures many hydrological parameters including water flow (surface, shallow lateral and groundwater flow), storage and quality that can be used to support a range of natural resource management (NRM) applications including assessment and management of land salinisation.

The HGL concept provides a structure for understanding how differences in salinity are expressed across the landscape. A HGL spatially differentiates areas with similar salt stores and pathways for salt mobilisation. The process of delineating a HGL relies on the integration of a number of causative factors: geology, soils, slope, regolith thickness, and climate; an understanding of the different modes of salinity development; and the impacts of salinity within landscapes (land salinity, salt load and salt concentration in streams due to salt contributions from base flow and runoff). Information sources such as soil landscape maps, site characterisation, salinity occurrence maps, hydrogeological data, surface water and groundwater data are incorporated into standardised unit descriptions.

The HGL unit descriptions provide a framework which spatially defines salinity management areas and recommends how best to manage and prioritise these landscapes. In this project undertaken for the Murray CMA, 33 different HGLs have been defined, each with unique salinity situations (salinity management areas) which require tailored management solutions involving specific management actions.

The project relied upon a number of different disciplines and skill sets in order to develop an integrated understanding of the landscape. The following groups were involved in the project:

- OEH/DPI Staff
  - Landscape Management Technical Group – HGL conceptualisation, land management
  - Spatial Products Unit – geographical information system (GIS) support
  - Soil Science Unit – site characterisation, mapping, HGL unit definition
- University of Canberra – regolith understanding, HGL conceptualisation, geology
- Murray CMA staff – local information.

Over the course of the project, a number of discussions and meetings were held with Murray CMA staff. This enabled incorporation of local knowledge into the HGL unit descriptions and in return gave the Murray CMA staff an understanding of how the HGL product functions.

Terminology specific to soil, regolith and geology is used extensively throughout this document. The following glossaries are recommended for further information on the terms used:

- soil – Houghton and Charman (1986); Isbell (2002); Morse *et al.* (1982); NCST (2009); Northcote (1979) and Stace *et al.* 1968
- regolith – Eggleton (2001)
- geology – Neuendorf *et al*. (2011).

A map showing the distribution of the 33 Eastern Murray HGLs and a summary table of their attributes are contained in Appendix A.

The detailed unit descriptions for the 33 HGLs are contained in Appendix B.

Data sources are described in Appendix C and an overview of the attribute table attached to the HGL dataset is given in Appendix D.

2.2 Regional setting

2.2.1 Location

The Murray CMA is in south New South Wales and encompasses an area of over 77 000 km^2. The Eastern Murray Catchment (Figure 1) lies in the upstream portion of the Murray CMA and covers approximately 9300 km^2. It is broadly defined by the catchment area on the NSW side of the Murray River extending from the western slopes of the Great Dividing Range to the eastern edge of the Riverine Plain at Corowa. The mapped area includes the city of Albury and the towns of Corowa, Culcairn, Holbrook, Tumbarumba and Khancoban.

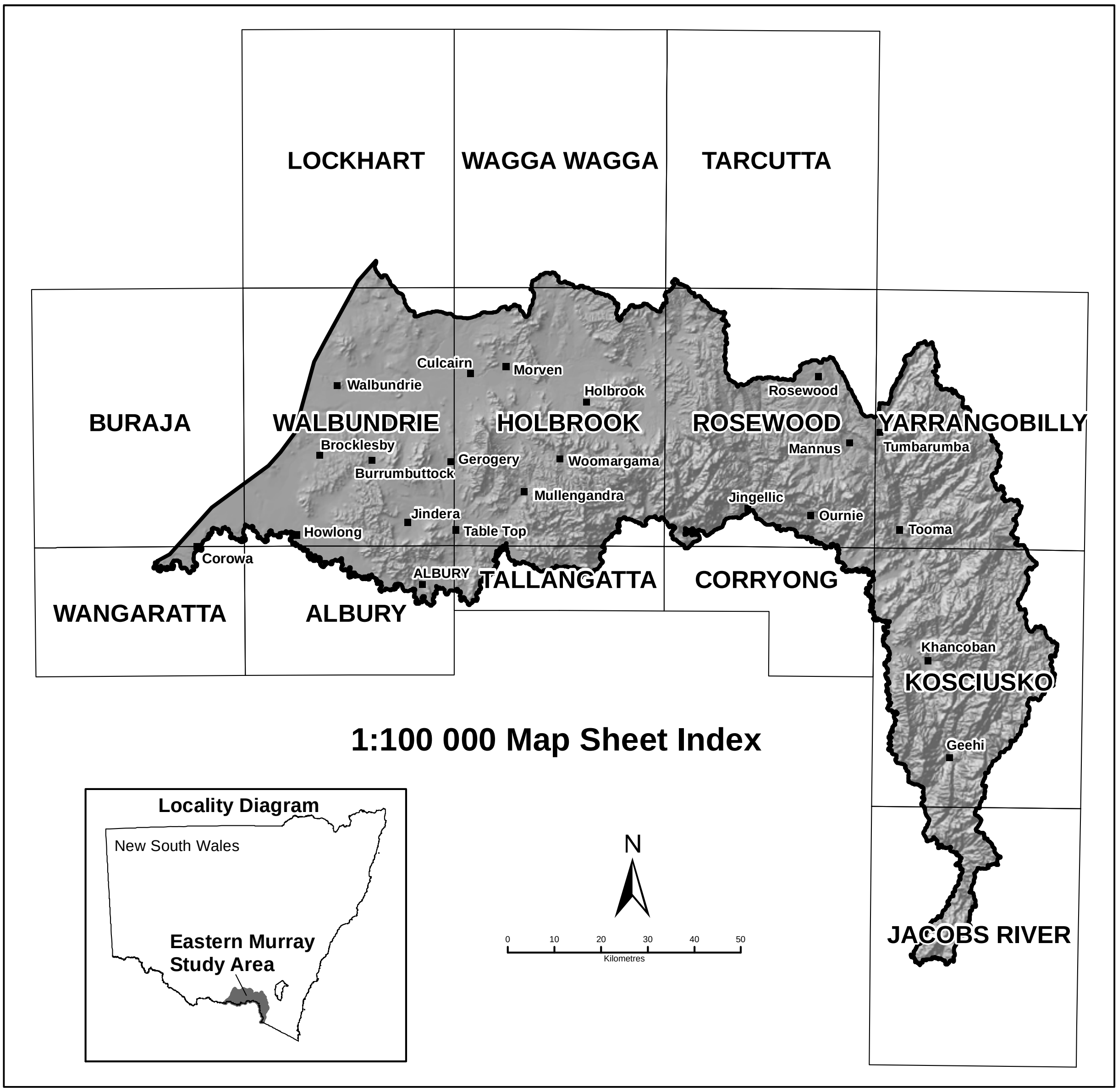

Figure 1: Location map of the Eastern Murray study area showing 1:100 000 map sheet coverage.

2.2.2 Physiography

The terrain of the Eastern Murray is highly variable. It can be broadly described by four physiographic regions as set out by Pain *et al.* (2011) in the Physiographic Regions of Australia (Figure 2). Each region is a geomorphic subdivision with internally consistent landform morphology and inferred landscape process origins as determined from the Shuttle Radar Terrain Mission digital elevation model (SRTM DEM).

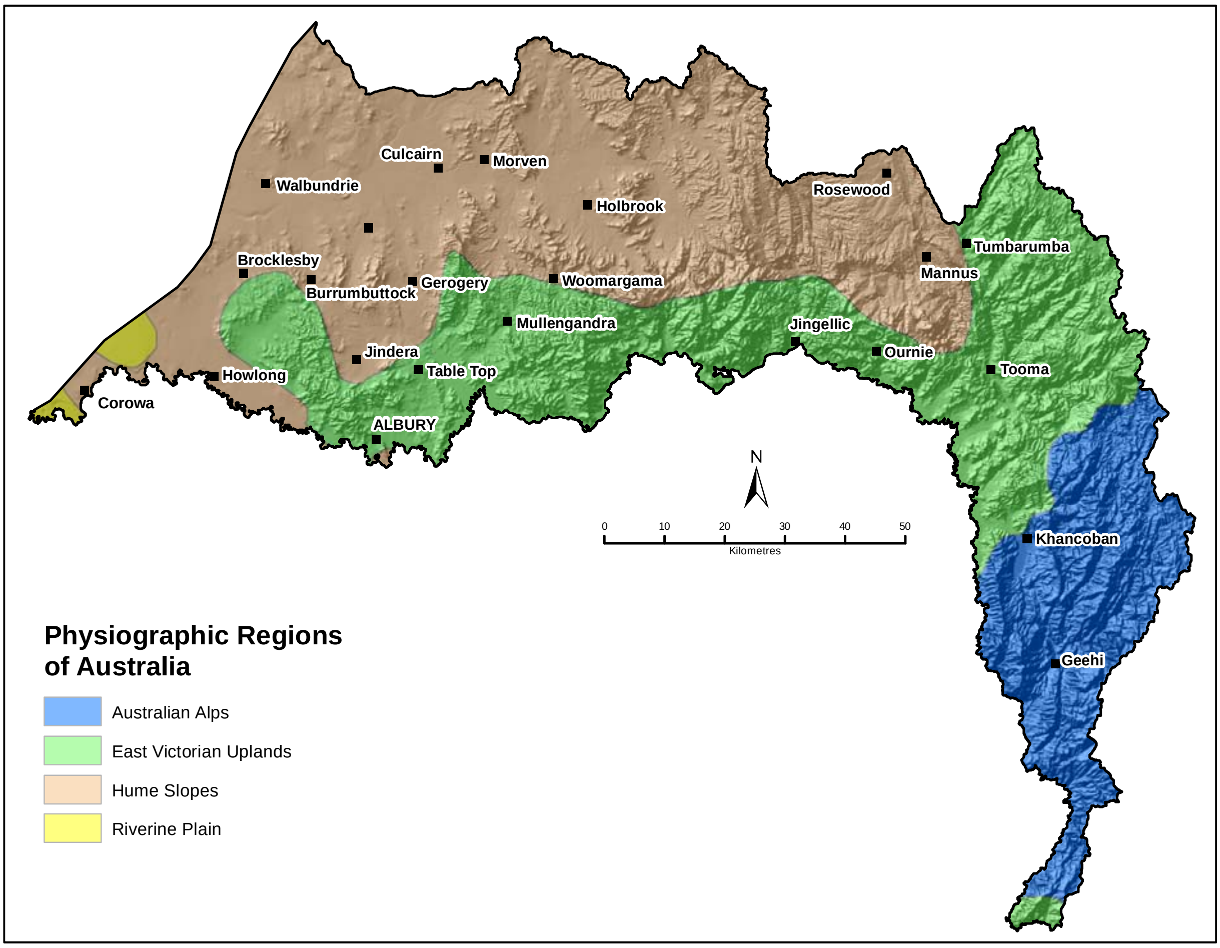

Figure 2: Distribution of Australian physiographic regions across the Eastern Murray study area (Source: Pain *et al.* 2011).

The south-eastern extent of the Eastern Murray study area is dominated by the Australian Alps. These are dissected high uplands that display some periglacial features. The uplifted blocks are surrounded by highly dissected high relief hill country. Moderately weathered bedrock is dominant.

The East Victorian Uplands are west of the Alps and along the northern side of the Murray River, extending approximately as far west as Albury. They are characterised by dissected high plateaus on various rock types, with isolated high plains. Weathering of bedrock is moderate.

The Hume Slopes make up the northern and western portions of the Eastern Murray. These comprise ridges and minor tablelands stepping down westwards and breaking into detached hills with intervening alluvial valley floors. Landforms are typically structurally controlled. Bedrock is moderately to highly weathered.

Small areas of the alluvial Riverine Plain occur in the far south-west of the area near Corowa. This physiographic region is much more extensive to the west of the study area.

Elevation within the Eastern Murray ranges from 125 m above seal level at Corowa to 2228 m at Mount Kosciuszko. The area is predominantly drained by the Murray River and the Billabong Creek which drains into the Edward River at Moulamein. The complex nature of the terrain has implications for the manner in which salt is stored and mobilised in the landscape.

2.2.3 Climate

Climate in the Eastern Murray varies, ranging from alpine conditions in the east to semi-arid conditions in the west (Table 1). Summers are typically warm to hot and winters are cool to cold. Temperatures decrease with altitude and frost increases. Rainfall is winter dominant when east-moving low pressure cells and associated frontal systems along the southern margins of Australia give rise to widespread protracted rainfall. In the summer months, rainfall is mostly from showers and thunderstorms associated with convectional lifting of moist air during the hottest parts of the day. These storms can be of short duration, high intensity and are localised (Johnston 1978).

Extended drought conditions that occurred during the first decade of the 21st century (the Millennium Drought) have been followed by a number of extreme weather events that have had significant land and water degradation and social impacts on the Eastern Murray area.

Table 1: Mean annual climate statistics for selected locations in the Eastern Murray study area (Bureau of Meteorology).

Statistic	Bureau of Meteorology Sites				
	Corowa Airport (074034)	Albury Airport (072146)	Khancoban (072060)	Tumbarumba Post Office (072043)	Charlotte Pass (071003)
Maximum temperature (°C)	22.6	22.1	20.5	19.5	9.7
Minimum temperature (°C)	8.9	8.7	7	5.5	-0.5
Rainfall (mm)	541.2	709.9	961.5	978.9	2040.7
Number of rain days	88.4	115.1	135.9	110.1	137.7
Period of Record	1890–2013	1973–2013	1961–2011	1885–2013	1930–2013

2.2.4 Geology

The rocks found in the Eastern Murray study area are diverse and reflect its long geological evolution. Figure 3 broadly illustrates the geological distribution of major rock types across the study area. The summary below is derived predominantly from Brown & Stephenson (1991), Scheibner (1999) and Branagan & Packham (2000).

Quartz-rich, intermediate- to deep-water marine sediments (turbidites) were deposited in a back arc basin (Wagga Marginal Basin) during the Ordovician. These underwent deformation and metamorphism during Late Ordovician-Early Silurian orogenic activity to form the schist, slate and shale that comprises the Wagga Group. This group is common throughout the central and western parts of the Eastern Murray. Magmatism associated with this orogenic activity saw the widespread emplacement of granitic and felsic volcanic rocks across the region during the Silurian and Early Devonian. Further folding, faulting and metamorphism related to orogenic activity occurred during the Devonian. During this time, deeper water marine sedimentation gave way to shallow marine and freshwater deposition of siltstones, sandstones and conglomerates. Today the remnants of these rocks are represented by the Great Yambla Ridge east of Gerogery. A final phase of orogenic activity in the Late Devonian-Early Carboniferous saw the open folding and faulting of the older Devonian rocks.

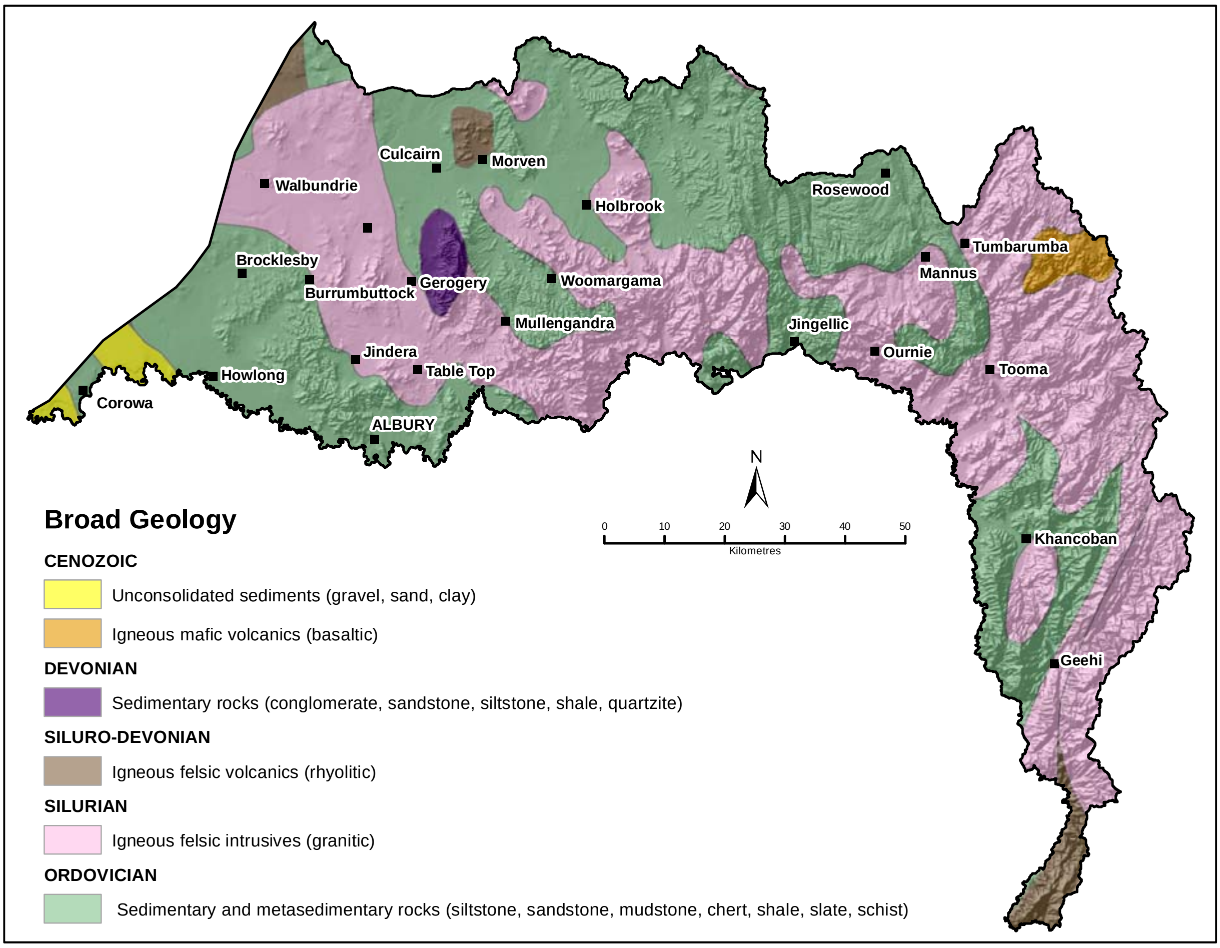

Figure 3: Geological groupings across the Eastern Murray study area.

The western side of the Eastern Murray study area coincides with the eastern edge of the Murray Basin. Three major sequences were deposited in the Basin during the Palaeocene (from ~66 to 23 million years ago). Non-marine sand, silt, clay, and carbonaceous sediments are predominant in the east and north. In the centre and the south-west parts of the Basin, smaller amounts of marine sedimentary rocks are present. In the west of the Basin, the sediments are overlain by Quaternary aeolian sand with some fluvial and lacustrine sediments; while in the east, the Quaternary is dominated by fluvio-lacustrine sediments, with lesser aeolian sand. During the Miocene Epoch (from ~23 to 5 million years ago), the Australian Plate moved across a hot spot in the mantle which provided the source of volcanic material that was extruded as basalt lava, remnants of which are seen in highland areas near Tumbarumba.

Earth movement during the Cenozoic saw the uplift of parts of the Australian alpine region. This saw the rejuvenation of river systems and led to the deposition of coarse sands and gravels in the Murray Basin. Broad valleys were cut and filled with thick deposits of alluvium comprising interbedded sands and clays.

2.2.5 Soil

Soils in the Eastern Murray reflect variations in climate, parent material and relief from east to west. Great Soil Groups (Stace *et al.* 1969) are used throughout this report as they are available for the entire study area. Where available, the Australian Soil Classifications (ASC)

(Isbell 2002) are also provided. Soil descriptions specific to the Murray CMA area are further described in DECCW (2010). (For further information on documents, see References page.)

Alpine Humus Soils have developed in elevated areas, generally above 1600 m elevation. These soils are characterised by thick (>20 cm) topsoils that are black, organic, friable and acid.

Soils are generally shallow (<60 cm deep) on the steep slopes of Alps and the Eastern Victorian Uplands physiographic regions. Soils range from: sandy Yellow Earths on granitic rocks; Chocolate Soils on basalt in areas with a relatively dry and cold climate; Krasnozems on basalt in wetter climates; Red and Yellow Podzolic Soils on most other rock types. On gentler lower slopes soils are deeper (80–120 cm). Red and Yellow Podzolic Soils are more prevalent in these landscape positions. In non-perennial drainage lines Soloths and Solodic Soils are common. These soils have a sodic subsoil (exchangeable sodium percentage (ESP) greater than 6%).

The Hume Slopes physiographic region is characterised by deeper (>100 cm), gradational soils – typically Red and Yellow Earths. Siliceous and Earthy Sands are found in association with palaeo-channels, sand dunes and some granites. Red Podzolic Soils occur on wetter hillslopes. Yellow Solodic Soils are also common, generally on back plain areas where there is a mix of older alluvium and modern alluvium from infrequent flooding. Grey Clays, Brown Clays, solodised Red-Brown Earths and heavy Alluvial Soils are dominant on the lower slopes and riverine plains where a semi-arid climate dominates (Crouch 1978).

Soil type can influence the presence or absence of salinity. The Podzolic Soils are texture contrast i.e. they have a sharp boundary between the lighter textured (sandy and loamy) topsoils and the clay subsoils. A preferential pathway for lateral water movement is at the boundary between the relatively permeable topsoils and the less permeable subsoil. Wet areas and saline scalding commonly occur on Podzolic Soils where the slope flattens out from the steeper upper- and mid-slopes to the more gently inclined lower slopes, i.e. at the break of slope.

Solodic Soils and Soloths are texture contrast soils with a sodic subsoil. The dispersible nature of sodic materials make them prone to soil degradation such as gully erosion, scalding and waterlogging. Sodic scalds can develop into saline scalds and it is not uncommon for scalds to wax between sodic and saline depending on rainfall.

Soil material can act as a salt store. The amount of salt depends on factors such as climate, soil type and depth of soil material. In the Hume and Riverine Plain, physiographic regions soil materials are much deeper and often have a higher clay content than soils in the east of the study area. The potential salt store is accordingly much greater in these materials. On granite rocks the sandy soils often hold little salt and are highly permeable. Landscapes characterised by these soils may be net dilution areas, providing relatively fresh water to the hydrogeological system. However, some granite areas are conducive to salinity due to factors such as the development of thick clay subsoils, deep weathering of the substrate, and jointing patterns in the granite.

2.2.6 Land use

Land use within the Eastern Murray study area is strongly influenced by climate, landform and soils. In the western part, extensive dryland cropping of cereals, canola and pulses is dominant. Mixed farming (wheat-sheep-pasture) occurs on the undulating south-west slopes and on plateau areas around Tumbarumba. Sheep and cattle grazing on improved and semi-improved pasture is prevalent in the central and eastern portions of the study area.

Intensive farming enterprises typically include orchard, vegetable crops and viticulture around Tumbarumba and Albury, and dairying along the upper Murray River and Tooma River flood plains. In the higher eastern part of the catchment, significant land uses are plantation forestry for timber and paper, conservation in national parks, and electricity generation and water supply through the Snowy Mountain Hydro-Electric Scheme and the Hume Weir.

Urbanisation is an increasingly important land use, particularly in Albury and the larger rural towns. Peri-urban developments such as lifestyle blocks and hobby farms are significant around Albury and along the Murray River.

2.2.7 Vegetation

The transition in elevation and rainfall across the Eastern Murray study area is reflected by changes in vegetation communities. As a rule, the tree canopy structure becomes taller and less open from west to east. The vegetation communities can be described in terms of four Australian biogeographic regions (Figure 4). They are the Australian Alps, the South Eastern Highlands, the NSW South West Slopes and the Riverina.

These bio-regions are large, geographically distinct areas based on common climate, geology, landform, native vegetation and species information. They have been generated under the Interim Biogeographic Regionalisation for Australia (IBRA) (Department of the Environment 2012). IBRA is updated as improved spatial mapping and information on vegetation communities and ecosystems becomes available from state and territory agencies.

According to Sheahan (1998), the bio-regions found in the Eastern Murray study area contain the following vegetation communities:

- Australian Alps – eucalypt open forests, eucalypt open woodlands, tussock grassland and heath
- South Eastern Highlands – tall forests, moist open forest and riparian vegetation
- NSW South West Slopes – dry open forest, dry ridges, box woodlands, yellow box woodlands, yellow box/Blakely’s red gum associations, white box woodlands, grey box woodlands and riparian vegetation
- Riverina – grey box woodlands, yellow box/cypress pine/bulloak woodlands, lignum communities and native grasslands.

Vegetation communities and individual species are discussed in more detail in Stelling (1998).

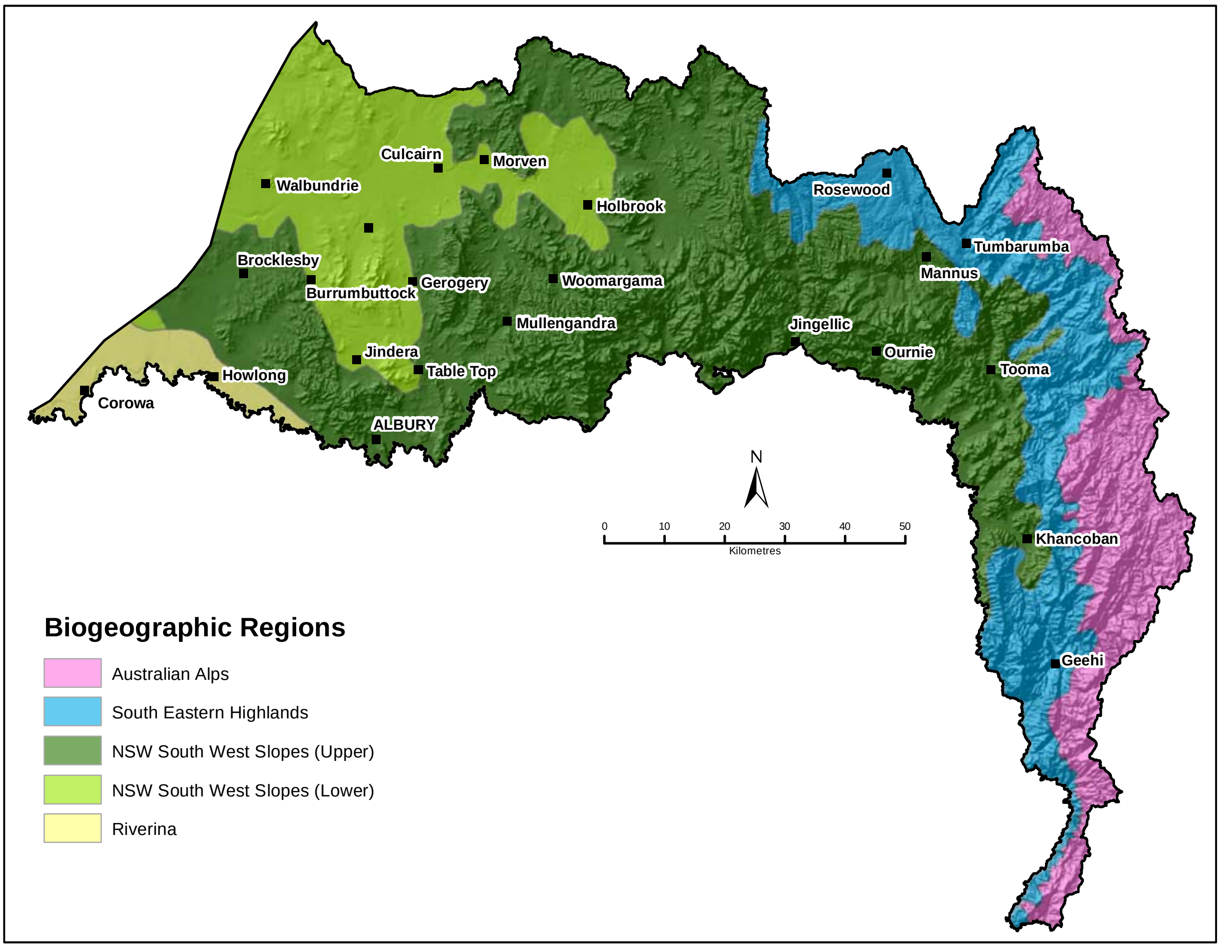

Figure 4: IBRA Regions covering the Eastern Murray study area (Department of the Environment 2012).

2.3 HGL unit descriptions

A HGL characterises a discrete unit of land within which salinity manifests in a similar or consistent way, and accordingly can be managed with a relatively specific combination of land use practices. However, the salinity response and salinity management options will differ from one HGL to the next.

For ease of comparison and consistency, descriptions of HGLs use the following standard structure:

- how salinity manifests itself in the landscape. Salinity is described in terms of its dryland occurrence, salt export from the HGL and the impact on water quality
- the amount of salt stored in the landscape and how available it is for export (i.e. mobility)
- the relative hazard, as defined by the impact of salinity, and its likelihood of occurrence
- lithology, dominant geologies, landforms
- soil landscapes, land and soil capability, land use, land degradation
- vegetation
- hydrogeology, by quantifying a range of groundwater and catchment characteristics including aquifer type, catchment size and residence time
- function of the HGL in terms of catchment salinity context (landscape function)
- management strategies to improve or maintain function

- specific management actions to implement appropriate strategies.

In addition, each HGL unit description includes:

- conceptual cross-sections
- management diagrams
- landscape photos
- references.

A map showing the distribution of the 33 Eastern Murray Hydrogeological Landscapes and a summary table of their attributes are contained in Appendix A.

The detailed unit descriptions for the 33 HGLs derived for the Eastern Murray catchment are contained in Appendix B.

3. Utilisation of HGL framework for managing salinity in the landscape

The HGL concept provides a structure to understand how salinity manifests itself in the landscape and how differences in salinity are expressed across the landscape.

A standardised reporting format is used to describe the differences in salinity development and impacts in hydrogeological landscapes. Each management unit in a HGL encompasses a unique combination of landscape factors, such as soil, groundwater, geology, slope and climate which show the source, transportation and expression of salt in the landscape. A land manager is then able to identify where action should be taken to obtain the most efficient and effective result. The format of this document, with maps, cross-sections and graphs, allows information to be easily communicated to landholders, CMA staff and the community to affect landscape change.

The 33 HGL unit descriptions defined for the Eastern Murray study area provide a framework that spatially defines management areas, each with unique salinity situations requiring tailored management solutions through specifically assigned management actions. This framework facilitates an ‘understanding of landscapes’ and the application of technically sound methods to target and prioritise limited funds to address natural resource management issues. This landscape understanding process assists CMAs, communities, landholders and organisations in placing ‘the right activities in the right locations’ within sub-catchments.

The HGL framework is not limited to NRM investment in salinity. Recent project activity has demonstrated that HGLs are useful tools in understanding, targeting and setting priorities for investment in multiple NRM issues, such as:

- sodicity, acid sulfate soils, erosion
- wetland classification and definition
- surface and groundwater interaction in the landscape
- vegetation boundaries and biodiversity management units within landscapes
- design of monitoring, evaluation and reporting (MER) data collection and analysis at local, catchment and state scales.

The simple process diagram in Figure 5 indicates the basic steps in the development of Hydrogeological Landscapes.

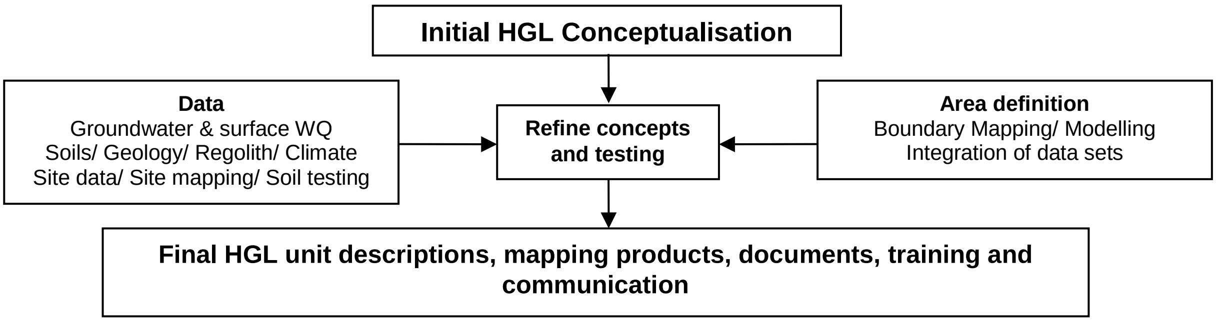

Figure 5: Steps involved in the generation of Hydrogeological Landscapes.

HGL frameworks for salinity management are specifically useful for:

- strategic decisions (Section 3.1)
- salinity risk determination and priority setting (Section 3.2)
- on-ground spatial attribution and communication (Section 3.3).

3.1 Strategic use

The structure of the HGL management framework with a cascading approach can inform attribution of ‘the right action in the right place’. At the local catchment scale, the appropriate landscape functions and management strategy objectives can be identified. The location and specific nature of the appropriate management actions can be then be defined and applied at the small scale using the management area concept. The following sequential structure is used in each of the HGL templates: **landscape function > management strategy > management action**. These key components are discussed in detail in Wooldridge *et al.* (2015).

Application of this workflow allows different management strategies to be applied to different landscapes, and different actions within each landscape (management area). Management is guided by broad landscape management strategies, and then directed towards management actions that are most appropriate to specific situations. Combinations of management actions can be tailored to address a wide range of salinity management issues. These management actions can then be applied to differing management areas within a structured landform analysis to specifically guide actions to address landscape salinity. Figure 6 illustrates how the HGL management framework parallels the Catchment Action Plan (CAP) process and target setting workflow.

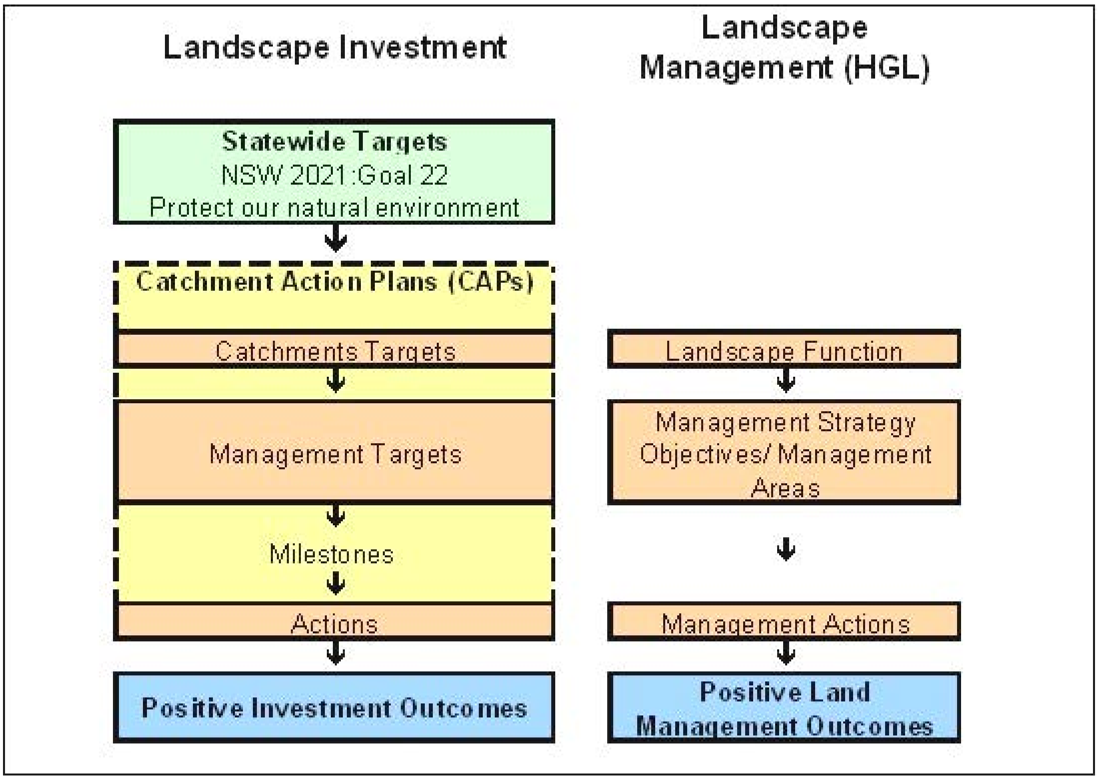

Figure 6: HGL management framework from Landscape Function to Management Actions.

Note: The cascading workflow is in line with the CAP process.

3.1.1 Catchment Action Plans

Landscape Function (see Section 5.2.1) refers to the high level salinity function provided by a particular landscape; e.g. provision of freshwater runoff, or generation of salt load which enters streams. These landscape functions will vary within each HGL. Once the landscape function is recognised, management is guided according to broad management strategy objectives.

Targets

As part of the development of their blueprints and CAPs, CMAs developed within-valley targets. To ensure a focus on important assets within the catchment:

- most CMAs had specific land salinity targets
- these targets inform and direct CAPs
- catchment targets addressing soil condition usually try to improve soil condition by reducing erosion and salinity
- management targets addressing land salinity usually aim to remediate saline discharge and recharge sites in priority areas.

The HGL framework will specifically inform the following local landscape priority in the Murray CMA 2013-2023 CAP:

> ***4. Support innovative, productive and** sustainable **farming systems** – support healthy and well-managed soils, including minimising off-site impacts, researching sustainable land management practices, and delivering efficient on-farm and broad-scale irrigation networks supported by appropriate water-sharing arrangements.*

Program logic relationship

The HGL framework is consistent with program logic models. It provides background information about a program's action, the assumptions on which the success of the program is predicated and the specific activities involved. The framework also attributes the 'right action to the right location', and identifies the risks involved.

NRC standards and targets

The HGL framework is useful for implementing the standards and targets set by the NSW Natural Resource Commission (NRC). The HGL framework provides:

- a mechanism to collect and use knowledge to facilitate an understanding of landscapes
- scale-specific information and landscape-specific management actions
- a framework for training and communication
- defined risk framework of land salinity, salt load, salt concentration and salinity hazard
- a basis for the design of data collection and analysis programs to support monitoring, evaluation and reporting (MER) activities at local, catchment and state scales
- a management framework that allows information to be used specifically in a structured format, as well as an open-ended system to incorporate innovation.

3.1.2 Monitoring

The attribution of spatially relevant actions to sub-catchments assists in development of MER programs. The HGL framework has been used:

- as a basis for the design of MER data collection
- in State-wide MER program analysis at local and catchment scales
- to inform location of monitoring equipment and monitoring programs
- for generation of baseline landscape data.

3.2 Salinity risk and priority determination

The risk analysis component of the HGL framework is specifically designed to allow the landscape impacts and hazards of a particular HGL area to be determined. At the start of each HGL unit description (see Appendix B) the factors determining salinity risk – land salinity, in-stream salt load, and in-stream EC – are each rated high, moderate or low and diagrammatically represented using a pie chart (Figure 7).

X. Example Hydrogeological Landscape

LOCALITIES	**Jonestown, Smithsville**	
MAP SHEET	**Jerilderie 1:250 000** **Tallangatta 1:250 000** **Wagga Wagga 1:250 000**	
CONFIDENCE LEVEL	**Low**	

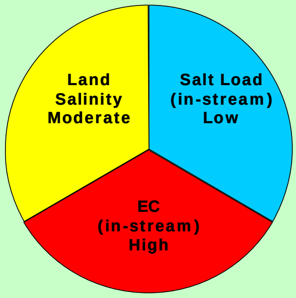

Figure 7: Example HGL unit description, with pie chart illustrating the impacts of land salinity, in-stream salt load and EC.

Impacts ratings for the Eastern Murray HGL project are assigned based on the conditions listed in Table 2.

Table 2: Conditions used to assign impact rating to Eastern Murray HGL pie charts.

	Land Salinity	Salt Load	EC
Low	No land salinity observed or mapped.	No stream flow or mostly dry; EC below 400 µS/cm.	Streams dry or typically below 400 µS/cm.
Moderate	Minor areas of land salinity observed or mapped.	Streams flowing intermittently; EC above 400 µS/cm.	Streams flowing often or always; EC above 400 µS/cm.
High	Significant areas of land salinity observed or mapped.	Streams always flowing; EC above 400 µS/cm.	Streams flowing often or always; EC above 800 µS/cm.

3.2.1 Mobility and overall salinity hazard

Salt mobility is also used to distinguish salinity behaviour. Salt in a landscape can be available to varying degrees and in different salt stores. The basic ‘rule of thumb’ is that sand constitutes a low salt store with a high availability, while clay has a low availability but is a high salt store. The relationship between salt availability and salt store is tabulated in each HGL unit description as illustrated in Table 3.

Table 3: Relationship between salt availability and salt store used to describe the mobility of salt in a landscape. The mobility is described using three classes ranging from low to high.

SALT MOBILITY			
	Low availability	**Moderate** availability	**High** availability
High salt store	**Moderate**	**High**	**High**
Moderate salt store	**Low**	**Moderate**	**High**
Low salt store	**Low**	**Low**	**Moderate**

The overall salinity hazard and the resultant priority for action can be inferred from the interaction of land / load / EC factors. Salinity assessment of a landscape can be made by determining salinity hazard using a standard risk format. The matrix of 'potential impact' and 'likelihood of occurrence' can determine the overall salinity hazard for each HGL.

This hazard integrates the salinity impacts in a landscape. The overall salinity hazard of a landscape is influenced by regolith thickness, the salt storage, the landscape shape and the underlying geology. Salinity hazard within a catchment is also variable. The relationship between potential impact, likelihood of occurrence and overall salinity impact is tabulated in each HGL description, as illustrated in Table 4.

Table 4: Relationship between potential impact of salinity and the likelihood of salinity occurring as used to assign overall salinity hazard.

OVERALL SALINITY HAZARD			
	Limited potential impact	**Significant** potential impact	**Severe** potential impact
High likelihood of occurrence	**Moderate**	**High**	**Very High**
Moderate likelihood of occurrence	**Low**	**Moderate**	**High**
Low likelihood of occurrence	**Very Low**	**Low**	**Moderate**

Note: The overall hazard uses five classes ranging from very low to very high.

For interpretation purposes the salinity impacts for each HGL are summarised in Table 5.

Table 5: Summary of salinity impacts for each HGL for Eastern Murray catchment.

HGL	Land Salinity Impact	Salt Load Impact	EC Impact on Water Quality	Overall Salinity Hazard
Lower Billabong	Low	High	High	Very High
Walla Walla	Moderate	Low	Low	Low
Upper Billabong	Moderate	Moderate	Moderate	Moderate
Murray Alluvium	Low	Low	Low	Very Low
Long Plain	Moderate	Low	Low	Low
Swampy Plains	Low	Low	Low	Very Low
Simmons Creek	High	Moderate	High	High
Ryan	Moderate	Moderate	Moderate	Moderate
Burrumbuttock	Moderate	Moderate	Low	Low
Brocklesby	High	Moderate	Moderate	Moderate
Nail Can-Bungowannah	High	Moderate	Moderate	Moderate
Yambla	Moderate	Moderate	Moderate	Moderate
Table Top	Moderate	Moderate	Moderate	High
Thurgoona	Moderate	Moderate	Low	Low
Hume	High	Moderate	Moderate	Moderate
Soldiers Hill	Moderate	Low	Low	Low
Boorook	Moderate	Moderate	Moderate	Low
Morgan's Range-Black Rock	Moderate	Low	Low	Moderate
Sweetwater	Moderate	Moderate	Moderate	High
Woomargama	Moderate	Moderate	Low	Low
Wymah-Jergyle	Moderate	Low	Low	Low
Cookardinia	Low	Moderate	Low	Moderate
Stonehaven	Moderate	Moderate	Moderate	Moderate
Bald Hill	Moderate	High	Moderate	High
Lankeys	Moderate	Moderate	Low	Moderate
Rosewood	Low	Low	Low	Moderate
Mannus	Moderate	Moderate	Low	Moderate
Ournie	Moderate	Low	Moderate	Moderate
Welaregang	Moderate	Moderate	Moderate	Moderate
Tumbarumba	Low	Low	Low	Low
Nine Mile	Low	Low	Low	Low
Khancoban	Low	Low	Low	Very Low
Kosciuszko-Welumba	Low	Low	Low	Very Low

4. Hydrogeological Landscape (HGL) Features

A HGL characterises a discrete unit of land within which salinity manifests in a similar or consistent way, and can be managed with a relatively specific combination of land use practices. The salinity response and salinity management options will differ from one HGL to the next. For consistency and ease of comparison, the unit description for each HGL follows a similar format. Each unit description describes a number of features that are typical for that HGL.

4.1 Lithology

Lithology refers to the nature of rocks at the macroscopic level in terms of their colour, texture, and composition. In fractured rock landscapes such as those in the Eastern Murray catchment, the lithology of the underlying rocks is important as it influences many of the other landscape features such as regolith, landform and soils. Lithological characteristics are one of the key datasets for determining HGL boundaries.

Lithological descriptions for the Eastern Murray HGL project come from Raymond *et al.* (2007) and Geoscience Australia (2011).

4.2 Rainfall

The Eastern Murray catchment covers a range of rainfall zones, due largely to the diverse landscape which ranges from mountains down to riverine plains. For the HGL unit descriptions, a range of mean annual rainfall figures are given. These values are based on the annual precipitation bioclimatic parameter from BIOCLIM climatic modelling (DECCW 2009).

4.3 Regolith and landforms

Regolith is typically defined as all the material between fresh bedrock and the land surface (Scott & Pain 2008). It includes all soil horizons, alluvial, colluvial and aeolian material as well as weathered bedrock and any indurated or hardened layers in the landscape.

The nature and distribution of regolith materials is strongly influenced by the following (Scott & Pain 2008; Taylor & Eggleton 2001):

- Parent material – the chemistry of the parent material influences the chemistry of the regolith materials. The weathering pathways and products derived from parent material can be predicted if the mineralogical make-up of the parent material is known.
- Climate – temperature and rainfall both have a major impact on regolith development, however, rainfall is of particular importance in the formation of regolith materials. Water is the primary agent in the weathering process, therefore, as rainfall increases, so to do weathering rates. Generally, areas with higher temperatures experience higher weathering rates than those with the same rainfall and lower temperatures.
- Topography – this influences erosion across the landscape. Areas with a lower gradient commonly have lower erosion rates than those with a higher gradient.
- Biota – biological activity in the regolith can consist of anything from termite to marsupial activity. This type of activity can influence the structure of regolith materials and the rate at which they develop. A higher occurrence of biological activity may result in an increased rate of regolith development.

- Time – materials that have been subjected to weathering process for longer periods are typically more weathered than those that have been subjected to weathering for a shorter period.

Landforms have been on described on the basis of their morphology (size and shape). The terminology used generally relates back to the Australian Soil and Land Survey Field Handbook compiled by the National Committee on Soil and Terrain (NCST 2009).

4.4 Soil landscapes

Soil landscapes provide knowledge of the distribution and attributes of soil and land resources. The relevant soil landscape map and document is an invaluable resource to build robust HGL models. Using the relevant 1:100 000 Soil landscape map sheets, some soil landscapes broadly correlate with HGL boundaries. For other HGLs, soil landscapes are either wholly or partially merged, and others are split.

Soil landscapes are areas of land that "*have recognisable and specifiable topographies and soils, that are capable of presentation on maps, and can be described by concise statements*" (Northcote 1979). The soil landscape concept integrates both soil and topographical constraints into one unit for the purpose of land management (Hazelton 1992).

They are comparable to land systems (Christian & Stewart 1953; Walker 1991) in that landform and geology are important factors in determining unit boundaries but soil landscapes usually place greater emphasis on the soils and less on the vegetation. Soil landscapes differ from soil associations (where recurring soil patterns are mapped) in that greater significance is assigned to geomorphic processes. The main difference from HGL mapping is that more emphasis is placed on the top 2 m of the regolith profile and less on water movement.

Soils are described in terms of soil layers in addition to the more traditional soil profile. These layers are termed soil materials and are defined by Atkinson *et al.* (1985) as *"... three dimensional soil entities which have a degree of homogeneity and lateral continuity*". Each soil material is defined and described in terms of its readily recognised and characteristic morphological properties. The definitive attributes may vary from one soil material to another, depending on what is recognisably characteristic of the material. In most cases each soil material has a consistent set of properties and limitations.

Soils can be classified using traditional soil taxonomic systems such as Great Soil Groups (Stace *et al*. 1968), Principal Profile Forms (Northcote 1979) or the Classification System for Australian Soils – ASC (Isbell 2002). Great Soil Groups are used throughout this report as they are available for the entire study area. Where available, the ASC is also provided.

Soils have been examined and described in detail at key sites and inspected at many other sites. At each described site, soil morphological data and site information has been recorded on Soil Data Cards (Milford *et al.* 2001). Landscape boundaries and descriptions are checked at each site inspection. Soils from road batters, building sites, trenches, backhoe pits and hand-augered holes are described. Sufficient field sampling is undertaken within each soil landscape to identify and describe the range of soil materials present to enable individual descriptions of their occurrence and relationships. At least one sample is collected of each soil material for laboratory analysis.

Soil landscape descriptions for the Eastern Murray HGL project come from DECCW (2010).

4.5 Land and soil capability

Land capability is the inherent physical capacity of the land to sustain a range of land uses and management practices in the long term without degradation to soil, land, air and water resources. Failure to manage land in accordance with its capability risks degradation of resources both on- and off-site leading to a decline in natural ecosystem values, agricultural productivity and infrastructure functionality.

The Land and Soil Capability (LSC) scheme builds on the Rural Land Capability (RLC) system developed in 1986 for NSW (Emery 1986). It retains the eight classes of the earlier system but places additional emphasis on specific soil limitations and their management. It is described fully in OEH (2012).

The LSC assessment scheme uses the biophysical features of the land and soil including landform position, slope gradient, drainage, climate, soil type and soil characteristics to derive detailed rating tables for a range of land and soil hazards. These hazards include water erosion, wind erosion, soil structure decline, soil acidification, salinity, waterlogging, shallow soils and mass movement. Each hazard is given a rating between 1 (best, highest capability land) and 8 (worst, lowest capability land). The final LSC class of the land is based on the most limiting hazard. The LSC classes are briefly described in Table 6.

The LSC class gives an indication of the land management practices that can be applied to a parcel of land without causing degradation to the land and soil at the site and to the off-site environment. High impact practices require good quality, high capability land, such as LSC classes 1 to 3, while low impact practices can be sustainable on poorer quality, lower capability land, such as LSC classes 5 to 8. As land capability decreases, the management of hazards requires an increase in knowledge, expertise and investment. In lands with lower capability, the hazards cannot be managed effectively for some land uses. Knowledge of LSC throughout NSW, together with the principles of land management within capability, provide valuable tools for the sustainable use and management of the State's land and soil resources.

The LSC assessment scheme is most suitable for broad-scale assessment of land capability, particularly for assessment of lower intensity, dryland agricultural land use. It is less applicable for high intensity land use or for irrigation.

For the Eastern Murray study area, most HGL units contain several LSC classes. A typical class is given in each HGL description. However it is likely that both higher and lower classes will also be present in localised areas of each HGL.

Table 6: Land andsoil capability classes – general definitions (OEH 2012).

LSC Class	General definition
Land capable of a wide variety of land uses (cropping, grazing, horticulture, forestry, nature conservation)	
1	**Extremely high capability land:** Land has no limitations. No special land management practices required. Land capable of all rural land uses and land management practices.
2	**Very high capability land:** Land has slight limitations. These can be managed by readily available, easily implemented management practices. Land is capable of most land uses and land management practices, including intensive cropping with cultivation.
3	**High capability land:** Land has moderate limitations and is capable of sustaining high-impact land uses, such as cropping with cultivation, using more intensive, readily available and widely accepted management practices. However, careful management of limitations is required for cropping and intensive grazing to avoid land and environmental degradation.
Land capable of a variety of land uses (cropping with restricted cultivation, pasture cropping, grazing, some horticulture, forestry, nature conservation)	
4	**Moderate capability land:** Land has moderate to high limitations for high-impact land uses. Will restrict land management options for regular high-impact land uses such as cropping, high-intensity grazing and horticulture. These limitations can only be managed by specialised management practices with a high level of knowledge, expertise, inputs, investment and technology.
5	**Moderate–low capability land:** Land has high limitations for high-impact land uses. Will largely restrict land use to grazing, some horticulture (orchards), forestry and nature conservation. The limitations need to be carefully managed to prevent long-term degradation.
Land capable for a limited set of land uses (grazing, forestry and nature conservation, some horticulture)	
6	**Low capability land:** Land has very high limitations for high-impact land uses. Land use restricted to low-impact land uses such as grazing, forestry and nature conservation. Careful management of limitations is required to prevent severe land and environmental degradation.
Land generally incapable of agricultural land use (selective forestry and nature conservation)	
7	**Very low capability land:** Land has severe limitations that restrict most land uses and generally cannot be overcome. On-site and off-site impacts of land management practices can be extremely severe if limitations not managed. There should be minimal disturbance of native vegetation.
8	**Extremely low capability land:** Limitations are so severe that the land is incapable of sustaining any land use apart from nature conservation. There should be no disturbance of native vegetation.

4.6 Land use

Agricultural land uses are dominant in the Eastern Murray catchment. The list of land uses given in the HGL unit descriptions is based on those given in soil-landscape descriptions that are present in each HGL.

Land use descriptions for the Eastern Murray HGL project come from DECCW (2010).

4.7 Land degradation

The list of land degradation issues given in the HGL unit descriptions is based on those in soil landscape descriptions relevant to each HGL. These issues have been observed and are currently occurring.

Land degradation descriptions for the Eastern Murray HGL project come from DECCW (2010).

4.8 Native vegetation

Native vegetation is influenced by geology and landscape morphology and can actually represent underlying landscape variability. Vegetation may indicate the presence of specific landscapes and landscape elements. Specific native vegetation ‘signatures’ of a suite of communities or a single native vegetation community can indicate particular geophysical or geological characteristics. Where preserved, native vegetation is therefore a very useful key to recognise differences between and within landscapes such as HGLs.

Native vegetation assemblages are described in the HGL unit descriptions. Details are given of community structure and distribution within HGLs. The descriptions include species lists of plants observed in the area. The detail is taken from Stelling (1998), personal observations or from soil landscape reports.

4.9 Hydrogeology

Hydrogeology is the study of the relationships between geological materials, processes and water. Surficial geology, soil, physiography and topography all influence the relationship between precipitation across the landscape and the water draining from it (Fetter 1994).

Following snow or rain, water flows overland and enters streams as runoff, or infiltrates into underlying soil and rocks. This infiltration provides soil moisture for plant growth, replenishes groundwater systems and provides interflow and base flow into streams (Freeze & Cherry 1979).

Geological complexity and a paucity of hydrogeological investigations in many areas of New South Wales, especially where fractured rock is dominant, make it difficult to provide definitive values for a hydrogeological parameter. However, it is possible to give typical values based on studies in similar rock types around the world (van Dijk *et al.* 2004; Domenico & Schwartz 1998; Driscoll 1989; Fetter 1994; Freeze & Cherry 1979).

When describing HGLs, a number of hydrogeological parameters are considered important:

- Aquifer type – describes whether groundwater within an aquifer is confined by an overlying less permeable layer, or unconfined if there are no confining layers. Consideration is also given to the nature of the aquifer material. Unconsolidated aquifers are loose and groundwater is able to flow through connected pore spaces and voids in the aquifer material. Fractured rock aquifers are made up of consolidated rock, groundwater flow is mainly through fractures in the rock. In porous rocks, additional flow may also occur through pore spaces (dual porosity).

- Hydraulic Conductivity – describes the capacity of a permeable material to transmit water. It depends on porosity, the degree of connection between pores, grain size and how well sorted those grains are.
- Transmissivity – describes the capability of an aquifer to transmit water across its saturated thickness. This parameter is generally used for groundwater modelling.
- Specific Yield – is a measure of the capacity of a saturated material to drain by gravity. Due to molecular attraction and capillarity, only a percentage of the total volume of water stored in pores will be released. Generally speaking, the greater the grain size of the material making up the aquifer, the greater the percentage of water released. This parameter only applies to unconfined aquifers.
- Hydraulic Gradient – describes the change in hydraulic head over distance along a flow-path.
- Groundwater Salinity – describes the electrical conductivity of groundwater. This parameter uses saline water classes defined by the Australian Water Resources Council (1976).
- Depth to Watertable – is a measure of the depth from the land surface to the water saturated zone in the underlying soil and rock.
- Typical Catchment Size – a general indication of the areal extent across which catchment groundwater processes are occurring.
- Scale – indicates whether local, intermediate or regional scale groundwater flow is predominant (NLWRA 2001). This parameter also considers typical flow length of streams within the HGL.
- Recharge Estimate – an estimate of the rate of recharge occurring across the HGL.
- Residence Time – describes the time it takes for a molecule of water to travel through the groundwater system entry until exit. Longer residence times mean the groundwater has more time to chemically react with the surrounding soil and rock.
- Responsiveness to Change – indicates the time it takes before land use change (and the associated change to the water balance) can be seen to impact on salinity expressions in the landscape.

4.10 Management options

In order to guide the design of targeted management plans and actions within a HGL, a Management Options overview is provided for each HGL. This provides a summary of the Landscape Function, Management Strategy Objectives, Specific Land Management Opportunities and Constraints, and a summary of appropriate Management Actions for different parts of the HGL, as illustrated in a management cross-section (Figure 8).

Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Landscape functions and management strategies and actions are discussed further in Section 5, and in detail in *Guidelines for managing salinity in rural areas* (Wooldridge *et al.* 2015).

5. Landscape Management

This section discusses the broad concepts and terminology used in the *Management Options* section of each HGL description. More detailed explanation is found in Wooldridge *et al.* (2015).

Accurate tailoring of appropriate land use for salinity management should be a core objective for natural resource and land managers. It is a technique of matching appropriate land use to the best locations for management results that this document and the complementary management guidelines aim to achieve.

At the local scale the HGL mapping hierarchy identifies landscape facets (e.g. hill crest, mid slope and lower slopes) which can be linked to specific land management actions. Where the HGL concept is applied to salinity management the mapping units show differences in salinity and hydrological characteristics which invariably reflect an integration of geology, regolith, landform, climate and native vegetation.

5.1 Management areas

Management areas are defined as areas of land within a HGL that can be managed in a uniform manner. They enable the link between landscape and targeted management and they operate at the scale of landform facets (crest, upper slopes, footslopes, floodplains etc.) (NCST 2009). For ease of comparison, management areas have been standardised (Table 7).

Table 7: Management Areas.

Management Area	Description
MA 1	Crest or ridge
MA2	Upper slope – erosional
MA3	Upper slope – colluvial
MA4	Mid slope
MA5	Lower slope – colluvial
MA6	Rises
MA 7	Saline site
MA 8	Structurally controlled saline sites
MA 9	Alluvial plains
MA 10	Alluvial channels

The management area concept allows a complex suite of management actions to be directed to the appropriate part of a landscape. Management areas can be represented spatially on a map, or on the conceptual cross-section for the individual HGL (Figure 8). The management areas are based in part on the terminology used in the Australian Soil and Land Survey Field Handbook (NCST 2009).

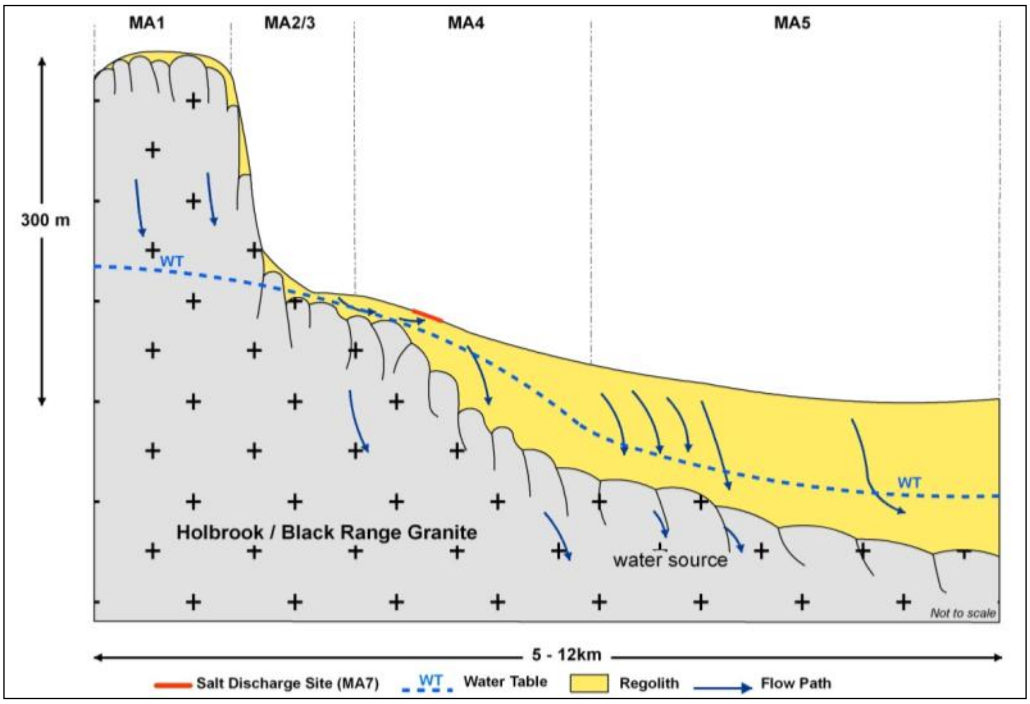

Figure 8: An example of a HGL conceptual cross-section showing the shape of the landscape and key landscape features such as soils, vegetation, salt outbreaks and water flow paths. Management areas are assigned to specific landform elements.

5.2 Management framework

The management framework provides a way to help assign optimal management actions to discrete parts of the landscape. The framework identifies the relevant landscape function and appropriate management strategy. The location and specific nature of the management actions are then defined at the local scale using management area concepts. The management framework can be applied to most landscape mapping systems.

The following sequential structure is used in each HGL unit:

landscape function > management strategy > management action

Each of these is discussed below.

Different management actions are applied to different parts of the landscape (management areas). Typically, the landscape function level corresponds with the catchment (greater than or equal to 1:250 000 scale); management strategy corresponds with the landscape (approximately 1:100 000 scale) and management area to the facet (1:10 000 scale or less). Once biophysical characteristics are recognised and organised using this structure the management actions for each management area can be selected (Figure 9).

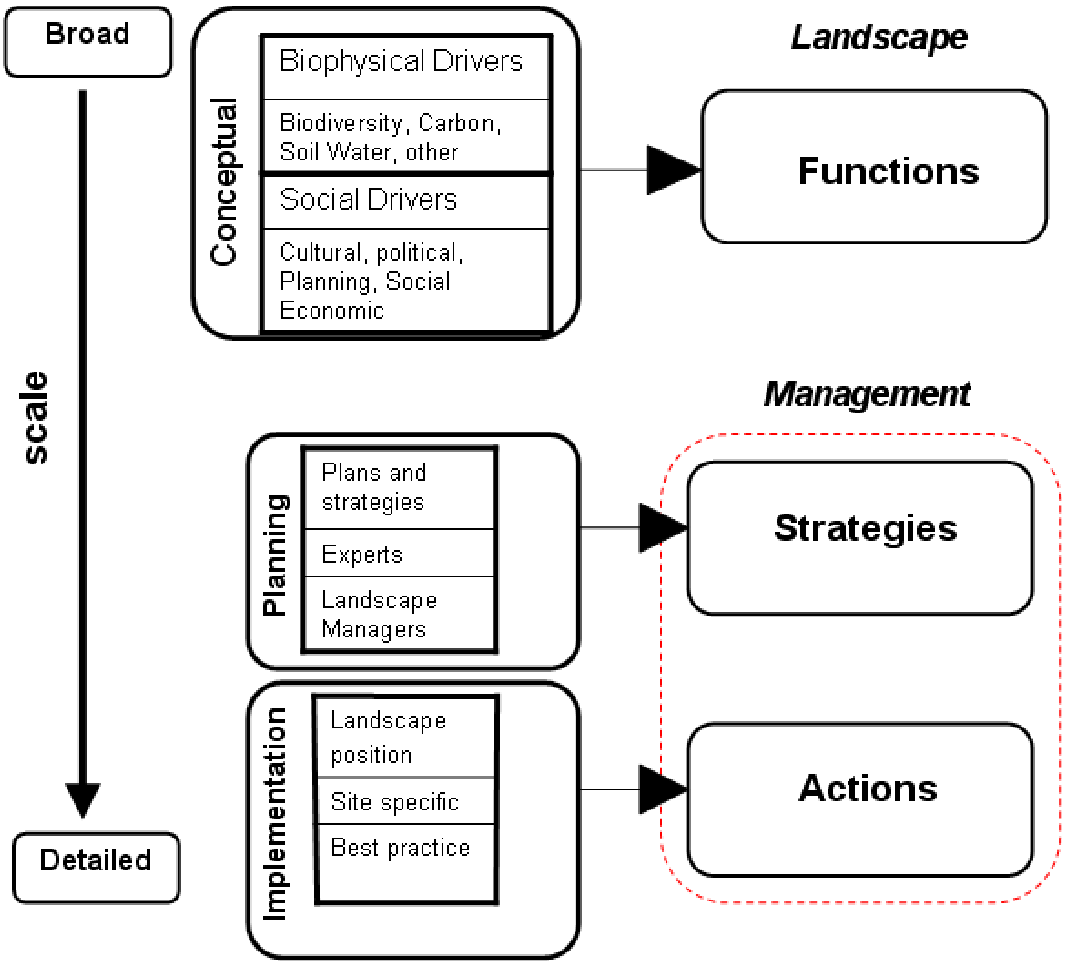

Figure 9: Scale and level of landscape functions and management strategies and actions as used in HGL.

5.2.1 Landscape function

Landscape function is the highest order within the hierarchical HGL structure. Functions are inherent biophysical characteristics of a landscape which impact upon catchments (Table 8). They will have impacts beyond the HGL. Effective salinity management involves understanding how landscape functions are maintained, improved or degraded. A HGL may provide one or more functions in a catchment.

Landscape function can also be used to define the priority of a landscape in a risk determination process.

For example, a landscape may have a priority as fresh water supply, and hence from Table 8 landscape functions A, B and C are relevant and can be mapped.

Similarly, a landscape can have a priority based on soil-related hazards for which landscape functions H and I are important.

Refer to Wooldridge *et al.* (2015) for further information on landscape function.

Table 8: Landscape functions

Function	Description
A	The landscape provides fresh water runoff as an important water source
B	The landscape provides fresh water runoff as an important dilution flow source
C	The landscape provides important base flows to local streams
D	The landscape generates salt loads which enter the streams and are redistributed in the catchment
E	The landscape receives and stores salt load through irrigation or surface flow
F	The landscape generates high salinity water that doesn't enter local streams
G	The landscape contains important land assets (including infrastructure and high value agricultural land) on which salinity processes impact
H	The landscape contains high hazard for generating sodic and saline sediments
I	The landscape contains high hazard for acid sulfate processes

It is important to understand that application of inappropriate management strategies and actions can negatively impact on landscape function and overall landscape resilience.

5.2.2 Management strategies

Management strategies are aimed at maintaining or improving landscape functions. One or more strategies may be applicable to any landscape. The 11 salinity management strategies are outlined in Table 9. As previously mentioned, recharge refers to water that percolates through to groundwater. Increased recharge can lead to rising watertables and mobilise salt stored in the soil. Discharge refers to groundwater that is seeping into streams or to the land surface. On the land, it is often expressed as areas of waterlogging. Salt sites may occur as a result of evaporation.

Management strategies are used to guide activities in a particular HGL. The actions associated with them recognise the need for diffuse and/or specific activities within the landscape in order to address salinity issues. The priority of management strategies will vary between HGLs.

Refer to Wooldridge *et al.* (2015) for further information on management strategies.

Table 9: Management strategies

Strategy	Description
Strategy 1	Buffer the salt store – keep it dry and immobile
Strategy 2	Intercept shallow lateral flow and shallow groundwater
Strategy 3	Stop discrete landscape recharge
Strategy 4	Discharge rehabilitation and management
Strategy 5	Increase agricultural production to dry out the landscape and reduce recharge
Strategy 6	Dry out the landscape with diffuse actions over most of the landscape
Strategy 7	Access and use groundwater to change the water balance
Strategy 8	Maximise recharge to dilute watertables and minimise runoff to streams
Strategy 9	Minimise recharge in lower parts of the landscape and maximise runoff to streams
Strategy 10	Maintain or maximise runoff
Strategy 11	Manage and avoid acid sulfate hazards

5.2.3 Management actions

Management actions deliver management outcomes. Detailed specific management actions are assigned to appropriate management areas, ensuring that the management options are applicable to any given part of the landscape.

The dynamics of a management action may vary. Sometimes the action is very suitable for delivering on a strategy, but unsuitable to deliver on a different strategy. Management actions are assessed for suitability and priority for salinity management within the landscape. A management action which is suitable for salinity management in one landscape may be unsuitable or ineffective in another. Combinations of management actions are tailored in accordance with the management strategy objectives. There are more than 50 defined management actions. The list is not exhaustive and new management actions or land management techniques are added as required. New techniques, technologies or discoveries offer new management options. New localities offer new challenges that may require management actions that have not yet been identified.

Refer to Wooldridge *et al.* (2015) for further information on management actions.

The management actions shown in Table 10 have been grouped as follows:

- VE Vegetation for ecosystem service
- VP Vegetation for production
- FS Farming systems
- SA Soil ameliorants
- E Engineering
- IS Irrigation systems
- SR Salt land rehabilitation
- AS Acid sulfate hazards.

Table 10: Groups of management actions

Management Action Group	Code	Management Action
Vegetation for ecosystem service	VE1	Establish and manage blocks of trees to reduce recharge
	VE2	Establish and manage trees to intercept lateral groundwater flow
	VE3	Maintain and improve existing native woody vegetation to reduce discharge
	VE4	Maintain and improve riparian native vegetation to reduce discharge to streams
	VE5	Establish and manage trees that are integrated into farming logistics to reduce recharge
	VE6	Revegetate non-agricultural land with native species to manage recharge
	VE7	Use targeted planting of trees to buffer salt stored in geological layers
Vegetation for production	VP1	Improve grazing management of existing perennial pastures to manage recharge
	VP2	Establish and manage perennial pastures to manage recharge
	VP3	Establish and manage perennial pastures to intercept shallow lateral groundwater flow
	VP4	Maximise agricultural production from pastures by input of additional ameliorants to manage recharge
	VP5	Improve grazing management to improve or maintain native pastures to manage recharge
	VP6	Establish and manage blocks of perennial forage shrubs to manage recharge
	VP7	Establish commercial forestry to manage recharge
	VP8	Establish and manage farm scale forestry integrated into farming logistics to reduce recharge
	VP9	Establish and manage perennial horticulture to manage recharge

Management Action Group	Code	Management Action
Farming systems	FS1	Implement pasture cropping with annual cereals in perennial pastures to manage recharge
	FS2	Maximise agricultural production by using ameliorants in annual cropping systems to manage recharge
	FS3	Implement rotational cropping with a perennial pasture component to manage recharge
	FS4	Implement opportunity cropping with annual crops and green manures to manage recharge
	FS5	Deep rip soil to improve soil structure and manage recharge
	FS6	Implement zero-till farming systems to increase soil water storage, soil water use and to reduce recharge
	FS7	Implement controlled traffic farming systems to increase soil water storage , soil water use and to reduce recharge
	FS8	Implement no-till farming systems to increase soil water storage, soil water use and to reduce recharge
	FS9	Implement reduced-till farming systems to increase soil water storage, soil water use and to reduce recharge
	FS10	Implement direct-drill farming systems to increase soil water storage, soil water use and to reduce recharge
	FS11	Use green manures and manure crops to increase soil water storage, soil water use and to reduce recharge
Soil ameliorants	SA1	Ameliorate soil sodicity by adding gypsum to increase plant water use and reduce recharge
	SA2	Ameliorate soil sodicity by adding lime to increase plant water use, reduce recharge and manage discharge sites
	SA3	Ameliorate soil acidity by adding lime to increase plant water use, reduce recharge and manage discharge sites
	SA4	Improve soil health by applying biological agents to the soil to increase plant water use, reduce recharge and manage discharge sites
	SA5	Improve soil health by applying compost to increase plant water use, reduce recharge and manage discharge sites

Management Action Group	Code	Management Action
Engineering	E1	Use groundwater to supplement or replace surface water for farm stock
	E2	Divert surface water to increase recharge in low lying areas and minimise runoff
	E3	Construct agricultural earthworks to maximise freshwater runoff and reduce recharge in low areas
	E4	Implement groundwater pumping and disposal
	E5	Manage stream flow to create dilution flows in regulated rivers
	E6	Manage flow cycles of rivers to periodically produce dry supply channels and streams
	E7	Install leaky weirs to slow streams and increase freshwater recharge
	E8	Construct diversion banks to connect streams with back plains to increase freshwater recharge
Irrigation systems	IS1	Manage on-farm irrigation to achieve best practice
	IS2	Manage irrigation supply systems to achieve best practice
	IS3	Establish effective effluent disposal systems specific to site conditions
Salt land rehabilitation	SR1	Fence and isolate salt land and discharge areas to promote revegetation
	SR2	Establish and manage salt land pasture systems to improve productivity
	SR3	Establish forestry systems on salt land to improve productivity
	SR4	Undertake rehabilitation to ameliorate land salinity processes and reduce land degradation
	SR5	Establish and manage salt land grazing systems based on forage shrubs to improve productivity
	SR6	Pond water on dry scalds to promote revegetation
	SR7	Reduce animal impact on scalds by providing mineral supplements to stock
	SR8	Mulch sites to reduce evaporation and promote pasture growth
	SR9	Mulch sites using tactical animal impact
Acid sulfate hazards	AS1	Improve or maintain the hydrological regime to keep acid sulfate soil saturated
	AS2	Isolate and improve acid sulfate soil sites

5.2.4 High hazard land use

Sixteen high hazard management actions are presented in this chapter. These have the potential to make salinity problems worse and may override positive salinity management actions. If a land use action is identified as high hazard it is actively discouraged.

High hazard management actions are assessed for their impact and their priority for salinity management within the landscape. A high hazard management action which may result in immediate and severe salinity impacts in one landscape may be less damaging in another. The dynamics of an action may vary. Sometimes the action is very suitable for delivering on a strategy, but may be unsuitable for a different strategy.

The list of high hazard land uses in Table 11 is not exhaustive and new management actions or land management techniques can be added after their efficacy has been assessed.

Refer to Wooldridge *et al.* (2015) for further information on high hazard land uses.

Table 11: Summary of high hazard land use actions

Code	Management Action
DLU1	Long fallows in farming systems
DLU2	Poor management of grazing pastures
DLU3	Annual cropping with annual plants
DLU4	Clearing and poor management of native vegetation
DLU5	Farm dams in flow lines
DLU6	Reducing runoff from fresh surface water catchments
DLU7	Locating infrastructure on discharge areas
DLU8	Poor soil management – tillage causing poor structure
DLU9	Poor soil management – chemical and biological
DLU10	Poor soil management – loss of surface soil layers
DLU11	Deep ripping of soils to maximise water infiltration to subsoil
DLU12	Flat contour banks
DLU13	Irrigation using inefficient on-farm water delivery practices
DLU14	Poor targeting of land suitable for irrigation
DLU15	Loading of soils with salt through irrigation and flow management
DLU16	Construction of drains to lower watertables

5.3 Land management for salinity in the Eastern Murray Catchment

This section provides information for salinity management in the Eastern Murray catchment. It complements the management strategies and actions discussed previously.

5.3.1 Key factors in land management for salinity

Salinity processes are influenced by a number of factors:

- water use characteristics of the vegetation
- climate and hydrogeological characteristics of the landscape
- volume of recharge that occurs and how this recharge responds to changes in land management practices.

Actions that impact on water use by vegetation or water stored in the soil will have impacts on how recharge occurs across the landscape:

- Salinity processes are usually diffuse across a landscape. Management actions will need to be applied over a large proportion of a catchment to have impacts.
- The design of management actions need to allow for both continual and episodic recharge patterns. Like many environmental issues, salinity processes are not always linear. Climatic cycles over years and decades are linked to patterns of salinity processes.
- Design of land management actions should consider extreme recharge and discharge events.
- Catchment scale salinity management needs to consider the surface hydrology of the landscape.

Specific management actions can be targeted when salinity processes are understood at the scale at which the management action is to be applied. It is important to recognise that targeting comparatively small areas of a catchment for management may not have a significant impact on salinity processes and outcomes for the broader catchment. Discharge management is an important part of sub-catchment salinity management. Table 12 outlines land salinity, salt load and water quality processes and related management for the Eastern Murray catchment.

Table 12: Management of catchment scale salinity processes in the Eastern Murray catchment.

	Land salinity	**Salt load export**	**Water quality – salt concentration (EC) in streams**
Process	• Land becoming degraded – saline and eroded • Slowly spreading areas of degrading land	• Large volume of salt moving down streams and rivers usually in high volumes of water at low concentration • Salt redistributed in landscape through water flow and irrigation	• High salt concentration water moving through rivers and streams
Impacts	• Loss of on-site agricultural productivity • Loss of vegetation and ecosystems function • Damage to infrastructure • Erosion and off-site water quality	• Wetlands, floodplains and riverine ecosystems • Irrigation land • Urban irrigated areas	• Point source water users: urban and industrial • Riverine and wetland ecosystems • Infrastructure
Management Aims	• Slow rate of spread • Remediate current sites • Minimise off site impacts	• Reduce load • Keep load where it is – diffuse in the landscape • Manage redistribution of salt load	• Reduce peaks in salt concentration. Smooth out the hydrograph • Dilute saline flows with fresh water flows where possible
Management Actions	• Rehabilitation of saline discharge sites. • Minimise recharge through vegetation and land use in recharge areas	• Minimise recharge through vegetation and land use in recharge areas of salt load generating landscapes • Manage redistribution of salt load to avoid negative impacts	• Minimise recharge through vegetation and land use in high salinity generating landscapes. • Use dilution flows in regulated catchments. • Manage high salinity flows to avoid negative impacts • Point source extractors can avoid high salinity flows. • Maintain and maximise runoff from fresh water generating areas

	Land salinity	Salt load export	Water quality – salt concentration (EC) in streams
Major areas	• Mid Catchment – e.g. Albury, Holbrook and Culcairn • Some irrigation areas	• Generated in mid and upper catchment from specific landscapes. • Generated in wetland environments • Redistributed in riverine ecosystems	• Time based: seen as events or spikes. These last hours or days • Area based: certain landscapes express consistently high salinity which is less affected by stream hydrographs
HGLs that exhibit high impacts	• Brocklesby, Nail Can-Bungowannah, Simmons Creek, Sweetwater, Hume	• Lower Billabong, Bald Hills	• Simmons Creek, Lower Billabong
HGLs that exhibit moderate impacts	• Walla Walla, Upper Billabong, Long Plain, Ryan, Burrumbuttock, Yambla, Tabletop, Thurgoona, Soldiers Hill, Boorook, Morgan's Range-Black Rock, Woomargama, Wymah-Jergyle, Stonehaven, Bald Hill, Lankeys, Mannus, Ournie, Welaregang	• Upper Billabong, Simmons Creek, Ryan, Burrumbuttock, Brocklesby, Nail Can-Bungowannah, Yambla, Tabletop, Thurgoona, Hume, Boorook, Sweetwater, Woomargama, Cookardinia, Stonehaven, Lankeys, Ournie,	• Upper Billabong, Ryan, Brocklesby, Nail Can-Bungowannah, Yambla, Tabletop, Hume, Boorook, Sweetwater, Stonehaven, Bald Hill

5.3.2 Key catchment salinity impacts

Changes in vegetation and land use impact on groundwater systems and salinity. The groundwater storage capacity of the catchment, the porosity and composition of the regolith material and the rate of groundwater flow within the catchment will influence rates of recharge and discharge.

The effects of these changes are not always observed where the changes occur. Changes also take varying lengths of time to be expressed.

Impact 1: Land salinity – land assets being affected by salinity processes

Salt is mobilised within the landscape impacting on land assets. In the Eastern Murray catchment comparatively small percentages of land are affected by land salinity. This land becomes degraded, liberating salt and sediment which is supplied to local streams.

Land salinity is commonly described on the basis of two factors:

- the amount of land being affected by land salinity, expressed as an area or as a percentage of the total landscape
- the intensity of effects being observed on the affected land, expressed as a relative rating of impacts (low, moderate, severe).

Land salinity processes impact on agricultural productivity, natural ecosystems, remnant vegetation, soil stability, access and damage to infrastructure. There is a high level of overlap between some active erosion areas and dryland salinity processes.

Impact 2: Water quality – salt load export and redistribution

Salt loads are a measure of the volume of salt. They are expressed in two ways:

- as a weight per time – when salt load is travelling in a stream (e.g. tonnes per day)
- as a weight per area – when salt load is being distributed on land through irrigation or stream flow pattern (e.g. tonnes per hectare).

High salt loads can be the result of low volumes of water with high concentrations of salt, or high volumes of water with low concentrations of salt. Salt loads are being redistributed through salinity processes.

Salt diffusely distributed in upland and slopes areas is transported by streams and rivers to the bottom of catchments. Salt is also relocated into the soils of irrigation districts via the water being pumped from rivers and streams. Salt loads are also redistributed to wetlands and flood plain areas during high flow events.

Impact 3: Water quality – salinity in streams and rivers

Salt mobilised within catchments impacts on the water quality of streams and rivers. Changes in salt concentration are related to the total amount of mobilised salt, flow regimes in streams and dilution through rainfall. Salt concentration is commonly expressed in two ways:

- as ‘pulses’ of water with a high(er) salt concentration moving down-stream over a comparatively short time (hours or days)
- as streams with consistently high concentrations which do not vary significantly with variation in stream flow.

High salinity levels in inland water systems can be detrimental to the ecological function of riverine environments and wetland systems. They also limit uses for domestic, recreational, industrial and agricultural purposes.

Table 13 summarises the impacts from land salinity, salt load and stream water quality for HGLs in the Eastern Murray catchment.

Table 13: Summary table of salinity impacts on Eastern Murray HGLs.

	Land salinity impacts	Salt load export	Impact on water quality – EC
High Impacts	• Simmons Creek • Brocklesby • Nail Can-Bungowannah • Hume	• Lower Billabong • Bald Hill	• Lower Billabong • Simmons Creek
Moderate Impacts	• Walla Walla • Upper Billabong • Long Plain • Ryan • Burrumbuttock • Yambla • Tabletop • Thurgoona • Soldiers Hill • Boorook • Morgan's Range-Black Rock • Sweetwater • Woomargama • Wymah-Jergyle • Stonehaven • Bald Hill • Lankeys • Mannus • Ournie • Welaregang	• Upper Billabong • Simmons Creek • Ryan • Burrumbuttock • Brocklesby • Nail Can-Bungowannah • Yambla • Tabletop • Thurgoona • Hume • Boorook • Sweetwater • Woomargama • Cookardinia • Stonehaven • Lankeys • Mannus • Welaregang	• Upper Billabong • Ryan • Brocklesby • Nail Can-Bungowannah • Yambla • Tabletop • Hume • Boorook • Sweetwater • Stonehaven • Bald Hill • Ournie • Welaregang
Low Impacts	• Lower Billabong • Murray Alluvium • Swampy Plain • Cookardinia • Rosewood • Tumbarumba • Nine Mile • Khancoban • Kosciuszko-Welumba	• Walla Walla • Murray Alluvium • Long Plain • Swampy Plain • Soldiers Hill • Morgan's Range-Black Rock • Wymah-Jergyle • Rosewood • Ournie • Tumbarumba • Nine Mile • Khancoban • Kosciuszko-Welumba	• Walla Walla • Murray Alluvium • Long Plain • Swampy Plain • Burrumbuttock • Thurgoona • Soldiers Hill • Morgans Range-Black Rock • Woomargama • Wymah-Jergyle • Cookardinia • Lankeys • Rosewood • Mannus • Tumbarumba • Nine Mile • Khancoban • Kosciuszko-Welumba

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