Hydrogeological Landscapes for the Murray Catchment Management Authority

Eastern Murray Catchment

UNIVERSITY OF CANBERRA
AUSTRALIA'S CAPITAL UNIVERSITY

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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 Diverse woodlands and grasslands have been replaced by monocultures of crops or simple mixtures of pasture species.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.

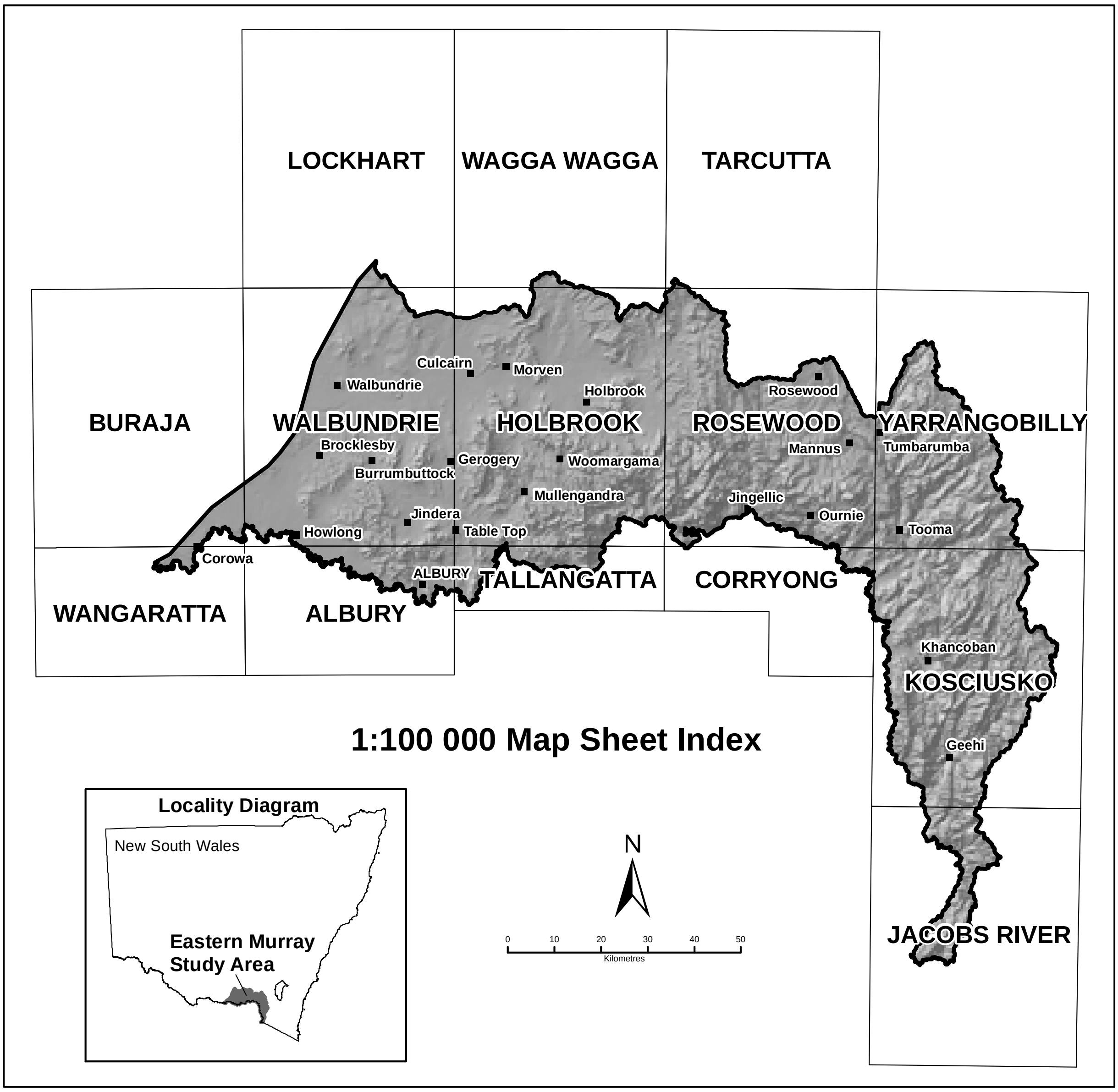


Figure 1: Location map of the Eastern Murray study area showing 1:100 000 map sheet coverage.

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).

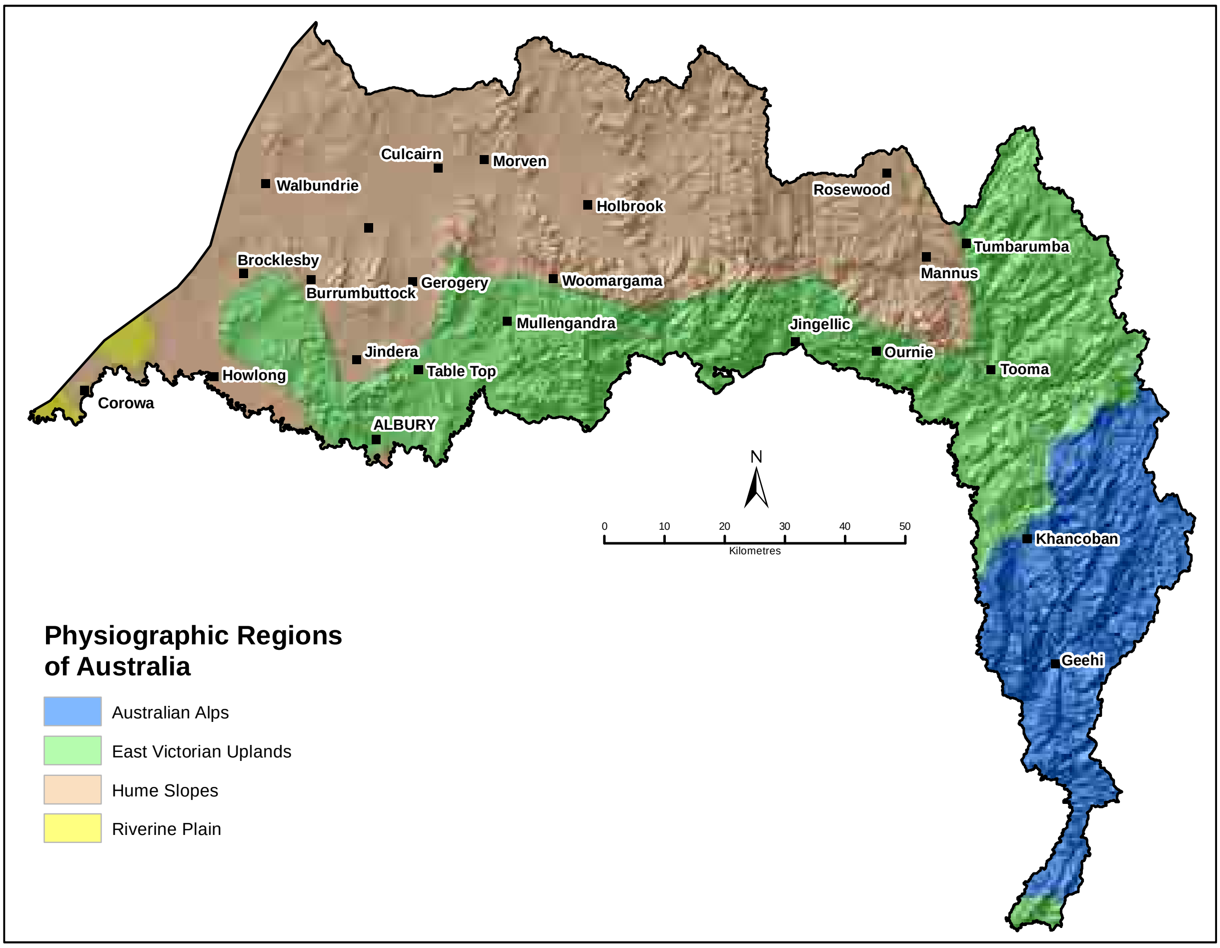


Figure 2: Distribution of Australian physiographic regions across the Eastern Murray study area (Source: Pain *et al.* 2011).

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.

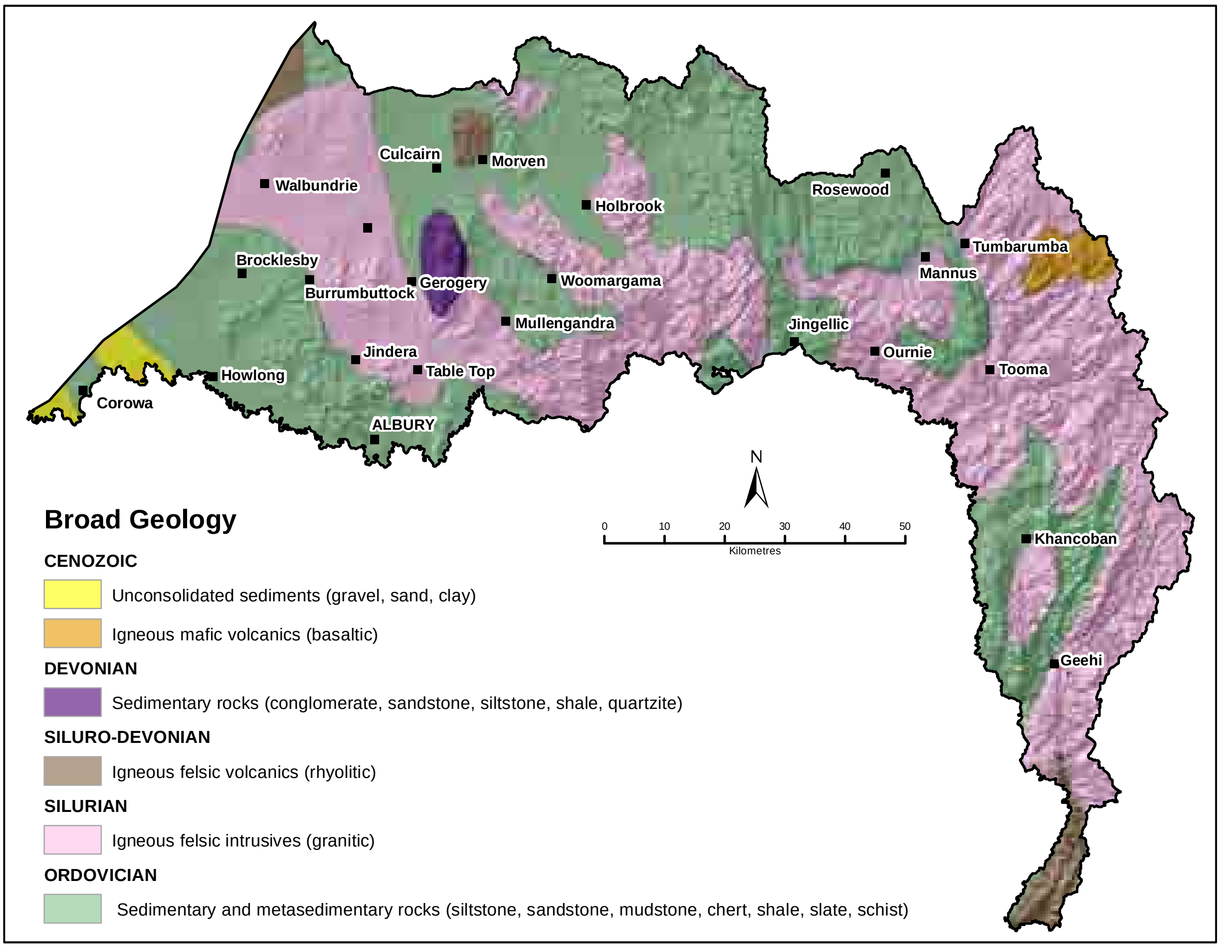


Figure 3: Geological groupings across the Eastern Murray study area.

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).

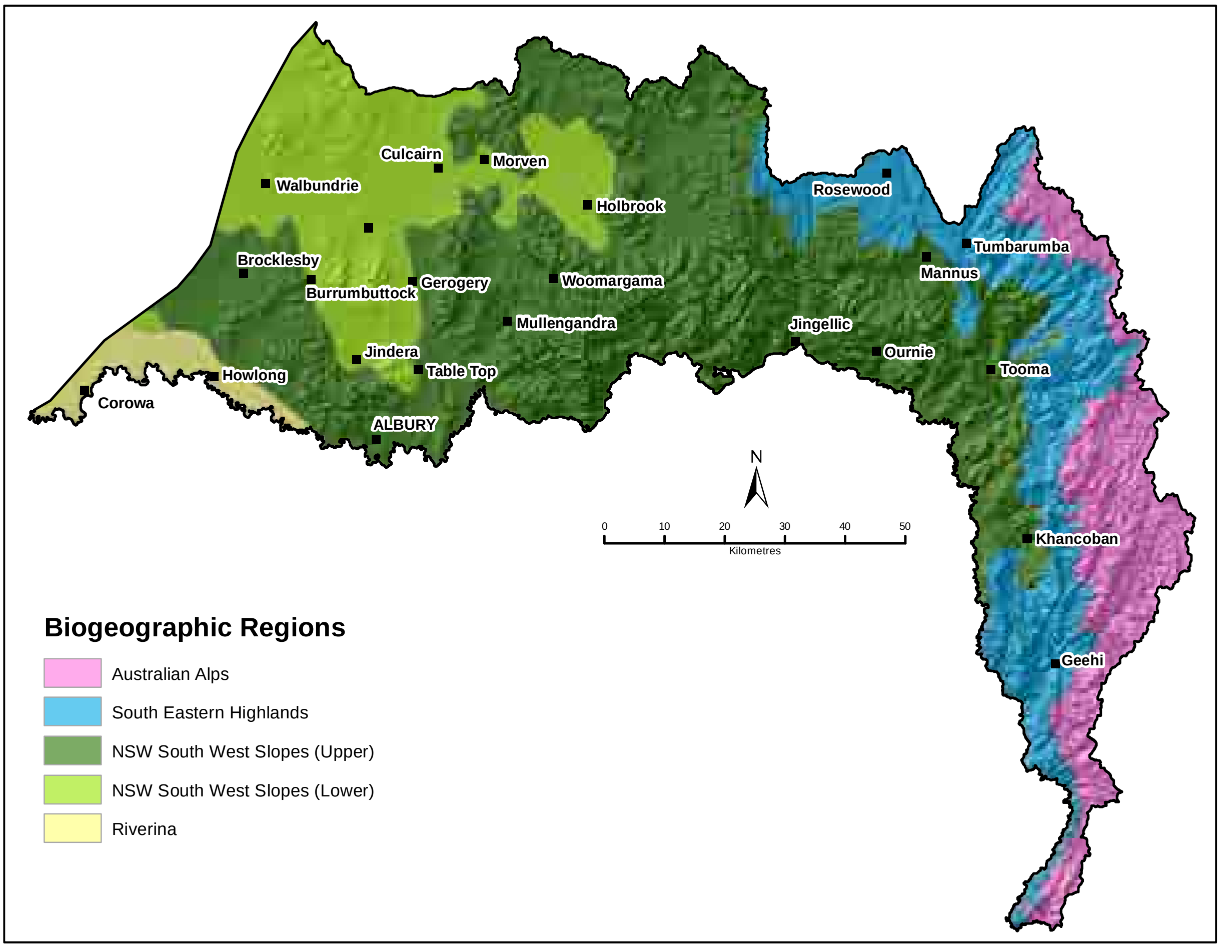


Figure 4: IBRA Regions covering the Eastern Murray study area (Department of the Environment 2012).

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.

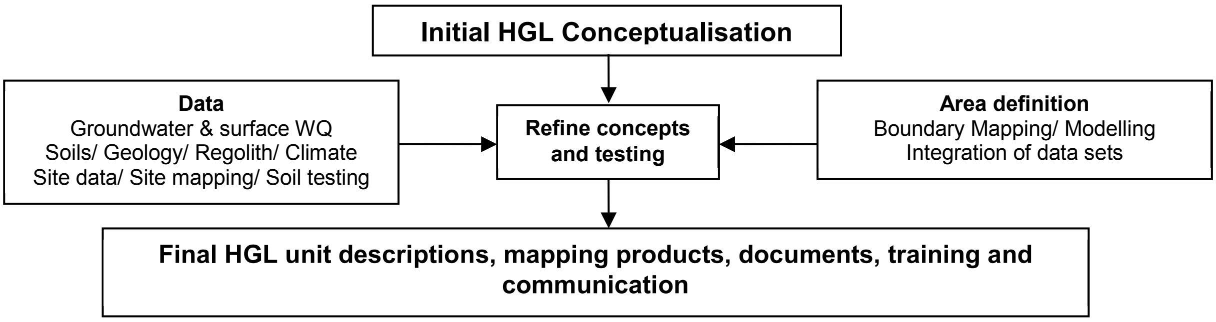


Figure 5: Steps involved in the generation of Hydrogeological Landscapes.

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.

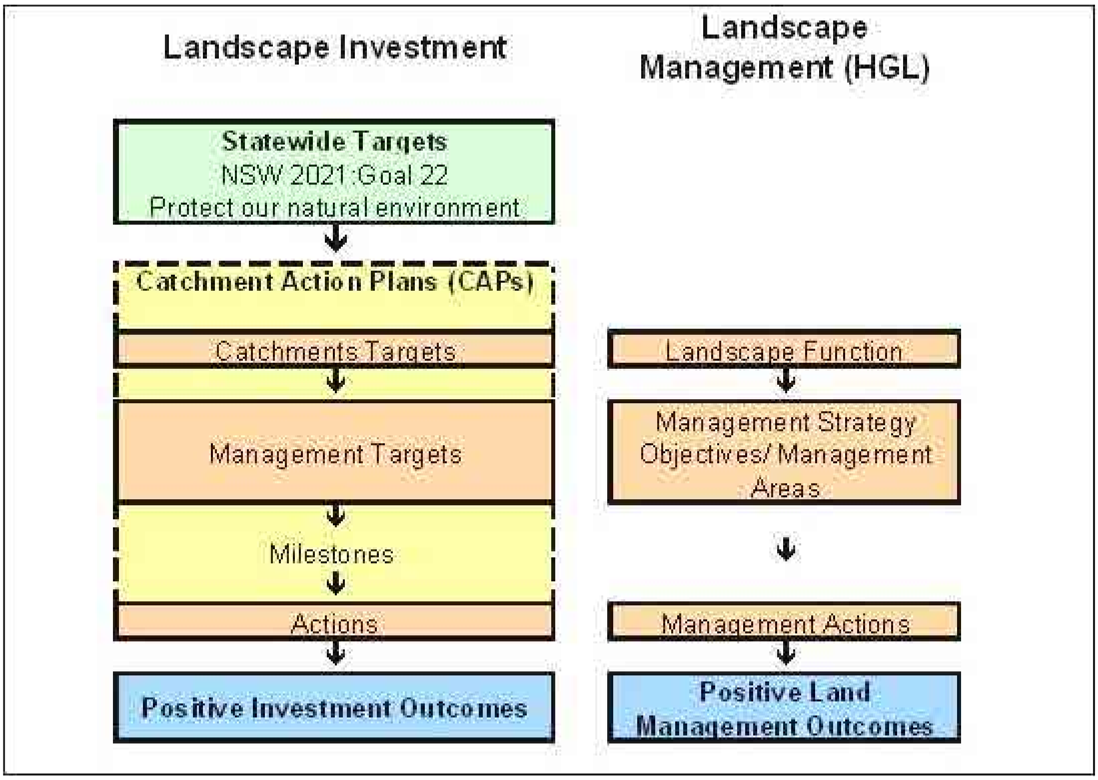


Figure 6: HGL management framework from Landscape Function to Management Actions.

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**

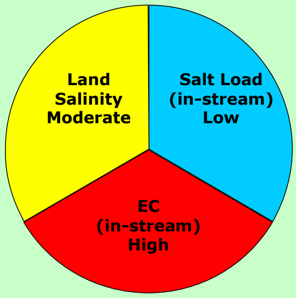


Figure 7: Example HGL unit description, with pie chart illustrating the impacts of land salinity, in-stream salt load and EC.

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).

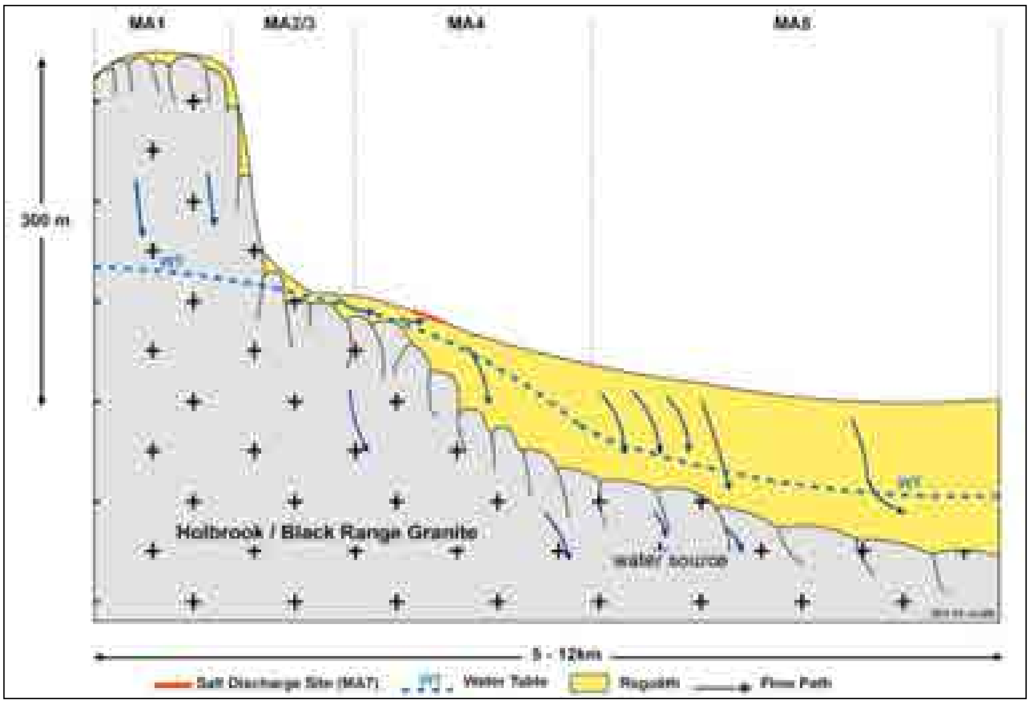


Figure 8: An example of a HGL conceptual cross-section showing the shape of the landscape and key landscape features such as soils, vegetation, salt outbreaks and water flow paths. Management areas are assigned to specific landform elements.

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).

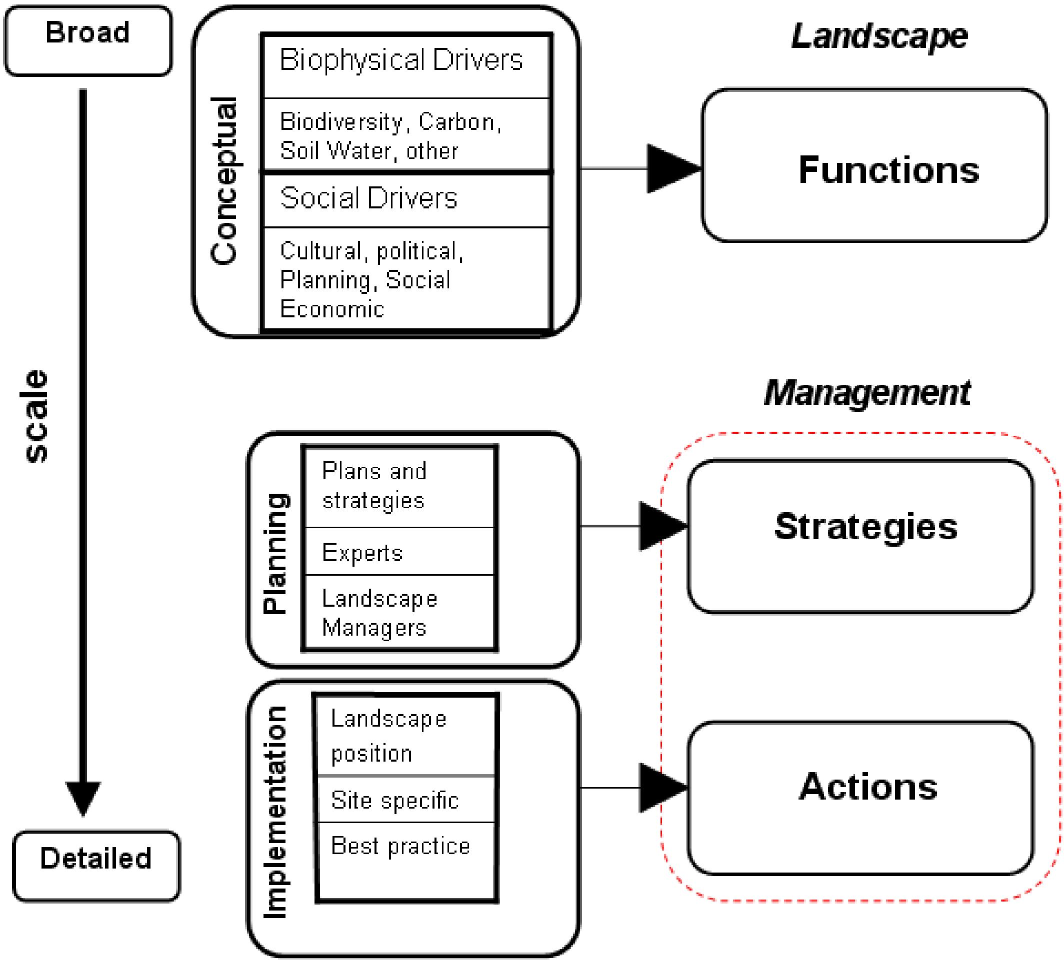


Figure 9: Scale and level of landscape functions and management strategies and actions as used in HGL.

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

References

Abraham, S.M. and Abraham, N.A. 1992, *Soil Data System: Site and Profile Information Handbook*. Department of Conservation and Land Management, Sydney (NSW)

Atkinson, G., Tille, P.J., Morse, R.J. and Murphy, C.L. 1985, *Extension of the pedosome concept to the description of soil landscapes*. New South Wales Branch Conference, Australia. Society of Soil Science Inc. Wellington (NSW)

Australian Water Resources Council, 1976, *Review of Australia's Water Resources, 1975*, Department of National Resources, Australian Government Publishing Service, Canberra

Branagan, D.F. and Packham, G.H. 2000, *Field Geology of New South Wales*, 3rd edn. New South Wales Department of Mineral Resources, Sydney

Brown, C.M. and Stephenson, A.E. 1991, Geology of the Murray Basin, Southeastern Australia, Bureau of Mineral Resources, Australia. *Bulletin, 235*, 430pp

Christian, C.S. and Stewart, G.A. 1953, General report on survey of Katherine Darwin region, 1946*. Land Res. Ser. no. 1: 27-31*, C.S.I.R.O. Australia

Coram, J. 1998, National Classification of Catchments for land and river salinity control: A catalogue of groundwater systems responsible for dryland salinity in Australia, *Publication No 98/78*. Rural Industries Research and Development Corporation, Canberra. 36 pp

Coram, J.E., Dyson, P.R., Houlder, P.A. and Evans, W.R. 2000, *Australian groundwater flow systems contributing to dryland salinity*, Bureau of Rural Sciences for the Dryland Salinity Theme of the National Land and Water Resources Audit Report

Crouch, R.J. 1978 *Landform* in Albury District Technical manual, Soil Conservation Service of NSW

DECCW, 2009, *BIOCLIM climatic modelling for NSW*, Department of Environment, Climate Change and Water, Sydney

DECCW, 2010, *Reconnaissance soil and land resources of the Murray CMA*, Department of Environment, Climate Change and Water, Sydney

Department of the Environment, 2012, *Interim Biogeographic Regionalisation for Australia (IBRA), Version 7 (Regions),* Australian Government, Department of the Environment, [Accessed 10 November 2014] www.environment.gov.au/metadataexplorer/full_metadata.jsp?docId=%7B573FA186-1997-4F8B-BCF8-58B5876A156B%7D

Domenico, P.A. and Schwartz, F.W. 1998, *Physical and Chemical Hydrogeology*, 2nd edn, John Wiley and Sons, New York, NY, 824 pp

Driscoll, F. 1989, *Groundwater and Wells*, 3rd edn, Johnson Filtration Systems, St. Paul, MN

Eggleton, R.A. 2001, The Regolith Glossary: surficial geology, soils and landscapes, Cooperative Research Centre for Landscape Evolution and Mineral Exploration, Canberra www.crcleme.org.au/Pubs/Monographs/RegolithGlossary.pdf

Emery, K.A. 1986, *Rural land capability mapping*, Soil Conservation Service of NSW, Sydney (NSW)

Fetter, C.W. 1994, *Applied Hydrogeology*, Merrill Publishing Company, Columbus, Ohio, 592 pp

Freeze, R.A. and Cherry, J.A. 1979, *Groundwater*, Prentice-Hall Inc., Englewood Cliffs, New Jersey, 604pp

Geoscience Australia, 2011, Australian stratigraphic units database, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int

Hazelton, P.A. 1992, Soil Landscapes of the Kiama 1:100 000 Sheet Report, Department of Conservation & Land Management. Sydney (NSW)

Houghton, P.D. and Charman, P.E.V. 1986, *Glossary of terms used in soil conservation*, Soil Conservation Service of NSW

Isbell, R.F. 2002, *The Australian Soil Classification (Second Edition).* Commonwealth Scientific and Industrial Research Organisation (CSIRO) Publishing, Canberra (ACT)

Johnston, W.H. 1978 *Landform* in Albury District Technical manual, Soil Conservation Service of NSW

Milford, H.B., McGaw, A.J.E. and Nixon, K.J. (eds) 2001, *Soil Data Entry Handbook, 3rd edn*, NSW Department of Land and Water Conservation, Sydney, NSW

Morse, R.J., Atkinson, G. and Craze, B. 1982, *Soil Data Card Handbook*, Soil Conservation Service of NSW Technical Handbook No. 4, Sydney, NSW, Aust

National Committee on Soil and Terrain, 2009, *Australian soil and land survey field handbook*, 3rd ed, CSIRO Publishing, Collingwood, Vic

Natural Heritage Trust, 2001, *Australian Dryland Salinity Assessment 2000: Extent, Impact, Processes, Monitoring and Management Options*. National Land and Water Resources Audit Canberra (ACT)

National Land and Water Resource Audit (NLWRA), 2001, *Australian Dryland Salinity Assessment 2000: Extent, Impacts, Processes, Monitoring and Management Options*, National Land & Water Resources Audit, Turner, ACT

Neuendorf, K.K.E., Mehl Jr, J.P. and Jackson, J.A. 2011, *Glossary of Geology*, 5th Edition (revised). American Geological Institute

Northcote, K.H. 1979, *A Factual Key for the Recognition of Australian Soils*, 4th edition, Rellim Technical Publications, Glenside, SA, pp123

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, Office of Environment and Heritage, Sydney, [Accessed: 10 November 2014] www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

Pain, C.F., Gregory, L., Wilson, P. and McKenzie, N. 2011, *The Physiographic Regions of Australia – Explanatory Notes*, Australian Collaborative Land Evaluation Program and National Committee on Soil and Terrain, ACLEP, Canberra, 30 pp.

Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia

Scheibner, E. 1999, *The Geological Evolution of New South Wales – A Brief Review*, 32 pp. Geological Survey of New South Wales, Sydney

Scott, K.M. and Pain, C.F. 2008, *Regolith science*, CSIRO Publishing, Collingwood, Vic

Sheahan, M. 1998, Introduction to the South West Slopes region and its plant communities, in *South west slopes revegetation guide (south of the Murrumbidgee River)*, ed F. Stelling, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

Stace, H.C.T., Hubble, G.D., Brewer, R., Northcote, K.G. ,Sleeman, J.R., Mulcahy, M.J. and Hallsworth, E.G. 1968, *A Handbook of Australian Soils*, Rellim Technical Publications, Glenside, (S.A). pp 435

Stelling, F. 1998, *South west slopes revegetation guide (south of the Murrumbidgee River)*, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

Taylor, G. and Eggleton, R. A. 2001, *Regolith geology and geomorphology*, J. Wiley, Chichester, New York

Van Dijk, A. I. J. M., Cheng, X., Austin, J., Gilfedder, M. and Hairsine, P. B. 2004, *Predicted stream flow and salinity changes after afforestation in the Southwest Goulburn*, public client report, Commercial Environmental Forestry project, CSIRO Land and Water

Walker, P.J. 1991, Land System of Western NSW, *Technical Report No. 25*, Soil Conservation Service of NSW, Sydney

Walker, G., Gilfedder, M., Evans, R., Dyson P. and Stuaffacher, M. 2003, *Groundwater Flow Systems Framework – Essential Tools for Planning Salinity Management*, MDBC publication

Wilford, J., James, J. and Halas, L. 2008, *Defining and evaluating Hydrogeological-Landscapes (HLs) in upland regions of eastern Australia for salinity and water resource management*, 2nd International Salinity Forum30 March - 3 April 2008, Adelaide Convention Centre, Adelaide

Wilford, J., Nicholson, A. and Summerell, G. 2010, 'Hydrogeological-Landscapes system: a framework for managing water resources', *AusGeo News*, March 2010, issue No. 97. www.ga.gov.au/ausgeonews/ausgeonews201003/hydro.jsp

Winter, T.C. 2001, *The concept of hydrologic landscapes*. JAWRA Journal of the American Water Resources Association, 37: 335–349

Wooldridge, A., Nicholson, A., Muller R., Jenkins, B. R., Wilford, J. and Winkler, M. 2015, *Guidelines for managing salinity in rural areas*, NSW Office of Environment and Heritage, Sydney, NSW

Appendices

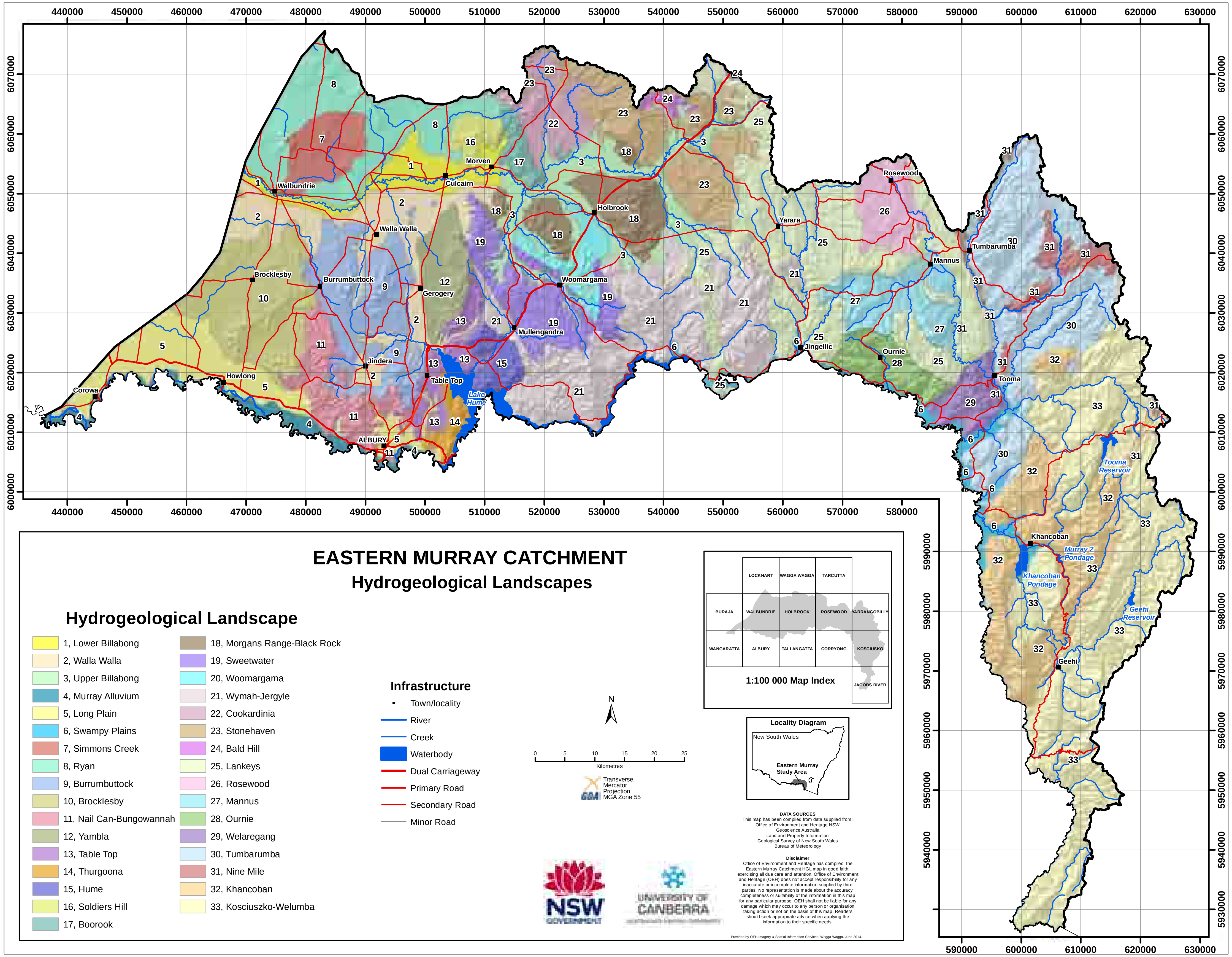
Appendix A: **Eastern Murray HGL map and summary table**

Appendix B: **Eastern Murray HGL unit descriptions**

Appendix C: **Data sources**

Appendix D: **Dataset attribute table information and colour schemes**

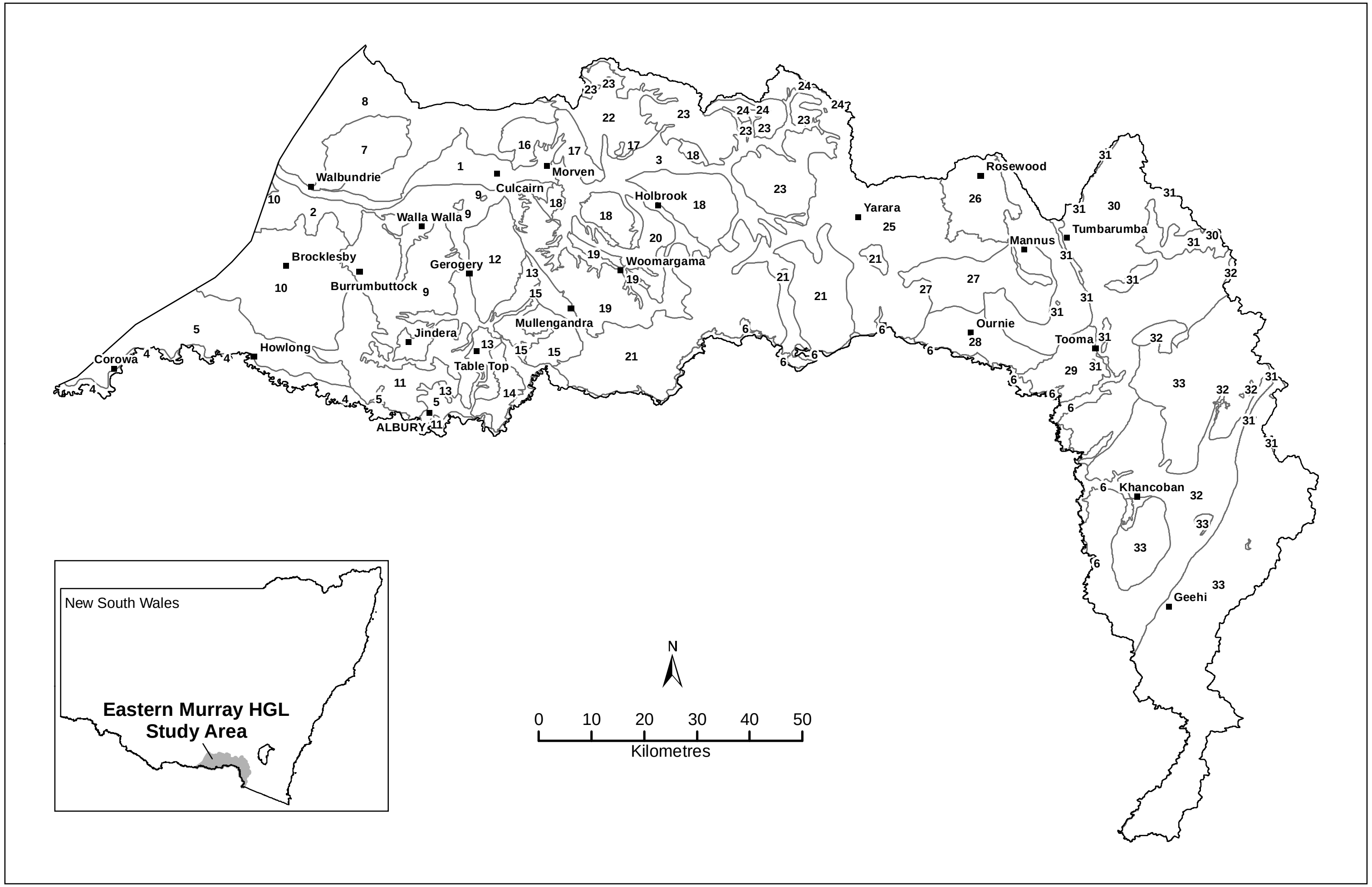
Appendix A: Eastern Murray HGL Map and Summary Table



Murray HGL assessment summary

No.	HGL Name	Function	Strategy	Land Salinity	Salt Load (in-stream)	EC (in-stream)	Salt Availability	Salt store	Likelihood	Impact	Overall hazard	Confidence
1	Lower Billabong	C,D,F	1,4,7	Low	High	High	High	Moderate	High	High	Very High	High
2	Walla Walla	E,G,I	4,11	Moderate	Low	Low	High	Moderate	Moderate	Low	Low	Low
3	Upper Billabong	B,C,D,G	4,7,10	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Low
4	Murray Alluvium	A,B,C,E	10,4	Low	Low	Low	Moderate	Moderate	Low	Low	Very Low	Low
5	Long Plain	G,E	6,1,4	Moderate	Low	Low	Low	High	Low	Moderate	Low	Low
6	Swampy Plains	A,B,C	10	Low	Low	Low	Moderate	Low	Low	Low	Very Low	Low
7	Simmons Creek	F,I,D,G	3,4,6,11	High	Moderate	High	Moderate	High	High	Moderate	High	High
8	Ryan	D,G	1,4,6	Moderate	Moderate	Moderate	Moderate	High	Moderate	Moderate	Moderate	Medium
9	Burrumbuttock	B,D,G	4,2,6,1	Moderate	Moderate	Low	Moderate	High	Low	Moderate	Low	Medium
10	Brocklesby	D,G	1,4,2,6	High	Moderate	Moderate	Moderate	High	Moderate	Moderate	Moderate	Medium
11	Nail Can-Bungowannah	D,G,B	1,4,6	High	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Low
12	Yambla	A,B,D	1,4,10	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Low
13	Table Top	D,G	1,4,6	Moderate	Moderate	Moderate	Moderate	Moderate	High	Moderate	High	Low
14	Thurgoona	A,B,D,G	10,4,1	Moderate	Moderate	Low	Moderate	Moderate	Low	Moderate	Low	Low
15	Hume	D,F,G	1,4,6	High	Moderate	Moderate	Moderate	High	Moderate	Moderate	Moderate	Low
16	Soldiers Hill	A,B,G	1,4,10	Moderate	Low	Low	Low	Low	Moderate	Low	Low	Low
17	Boorook	D,G	1,4,6	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Low	Low	Low
18	Morgans Range-Black Rock	A,B,G	1,4,10	Moderate	Low	Low	High	Moderate	Moderate	Moderate	Moderate	Low
19	Sweetwater	A,C,D,G,B	1,4,6,7	Moderate	Moderate	Moderate	High	Moderate	High	Moderate	High	Low
20	Woomargama	B,D,G	1,4,	Moderate	Moderate	Low	High	Moderate	Moderate	Low	Low	Low
21	Wymah-Jergyle	A,B,C,G	10,4	Moderate	Low	Low	Moderate	Low	Moderate	Low	Low	Low
22	Cookardinia	A,B,C,D	10,4,1	Low	Moderate	Low	High	Moderate	High	Low	Moderate	Low
23	Stonehaven	B,C,G,D	4,2	Moderate	Moderate	Moderate	Moderate	Moderate	High	Low	Moderate	Low
24	Bald Hill	D,F,G	1,4,6	Moderate	High	Moderate	Moderate	Moderate	High	Moderate	High	Low
25	Lankeys	A,B,C,D,G	10,4,1	Moderate	Moderate	Low	High	Low	High	Low	Moderate	Medium
26	Rosewood	A,B,C	10,4	Low	Low	Low	Moderate	Low	High	Low	Moderate	Medium
27	Mannus	A,B,C,D,G	10,4,1	Moderate	Moderate	Low	Moderate	Low	High	Low	Moderate	Low
28	Ournie	A,B,C	10,4	Moderate	Low	Moderate	Moderate	Low	High	Low	Moderate	Low
29	Welaregang	B,C,F	4,6,10	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Low
30	Tumbarumba	A,B,C	10,4	Low	Low	Low	Moderate	Low	Moderate	Low	Low	Medium
31	Nine Mile	A,B,C	10,4	Low	Low	Low	Moderate	Low	Moderate	Low	Low	Low
32	Khancoban	A,B,C	10,4	Low	Low	Low	High	Low	Low	Low	Very Low	High
33	Kosciuszko-Welumba	A,B,C	10,4	Low	Low	Low	Moderate	Low	Low	Low	Very Low	High

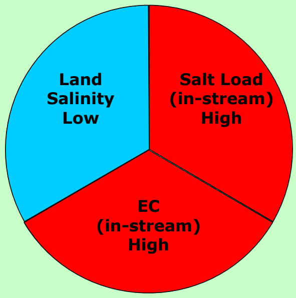
Appendix B: Eastern Murray HGL Unit descriptions



1. Lower Billabong
2. Walla Walla
3. Upper Billabong
4. Murray Alluvium
5. Long Plain
6. Swampy Plains
7. Simmons Creek
8. Ryan
9. Burrumbuttock
10. Brocklesby
11. Nail Can-Bungowannah
12. Yambla
13. Table Top
14. Thurgoona
15. Hume
16. Soldiers Hill
17. Boorook
18. Morgans Range-Black Rock
19. Sweetwater
20. Woomargama
21. Wymah-Jergyle
22. Cookardinia
23. Stonehaven
24. Bald Hill
25. Lankeys
26. Rosewood
27. Mannus
28. Ournie
29. Welaregang
30. Tumbarumba
31. Nine Mile
32. Khancoban
33. Kosciuszko-Welumba

1. Lower Billabong Hydrogeological Landscape

LOCALITIES	**Culcairn, Walbundrie**
MAP SHEET	**Jerilderie 1:250 000** **Wagga Wagga 1:250 000**
CONFIDENCE LEVEL	**High**



OVERVIEW

The Lower Billabong Hydrogeological Landscape (HGL) extends along the Billabong Creek from Morven to the edge of the study area west of Walbundrie (Figure 1). The HGL covers an area of 163 km^2 and has a mean annual rainfall of 500–600 mm. It is characterised by a deeply incised channel in the alluvial floodplain. Airborne electromagnetic (AEM) survey studies in the area have identified the presence of two narrow palaeochannels that join near Walbundrie (Baker & McNaught, 2011).

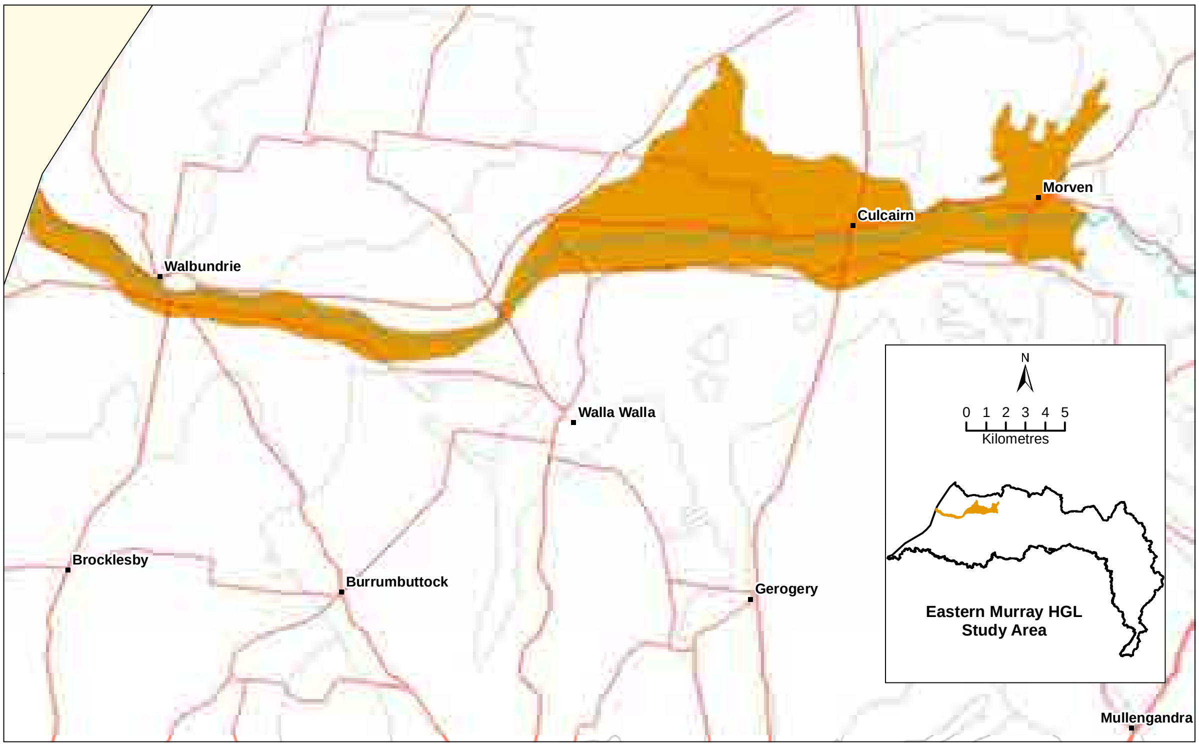


Figure 1: Lower Billabong HGL distribution map.

The Lower Billabong HGL is a depositional environment characterised by extensive alluvial floodplains, ancient channel deposits and alluvial terraces with sparse narrow drainage lines Localised gilgai have been noted. Regolith materials are dominated by unconsolidated

Quaternary channel and flood plain sediments; typically sands, gravels and clays. A shallow salty aquifer is confined to the palaeochannels. The deeper fresh aquifer is more extensive (Figure 2). Soils are typically very deep. Sodic soils in the lowest parts of this HGL combined with the shape of the landscape commonly lead to waterlogging problems.

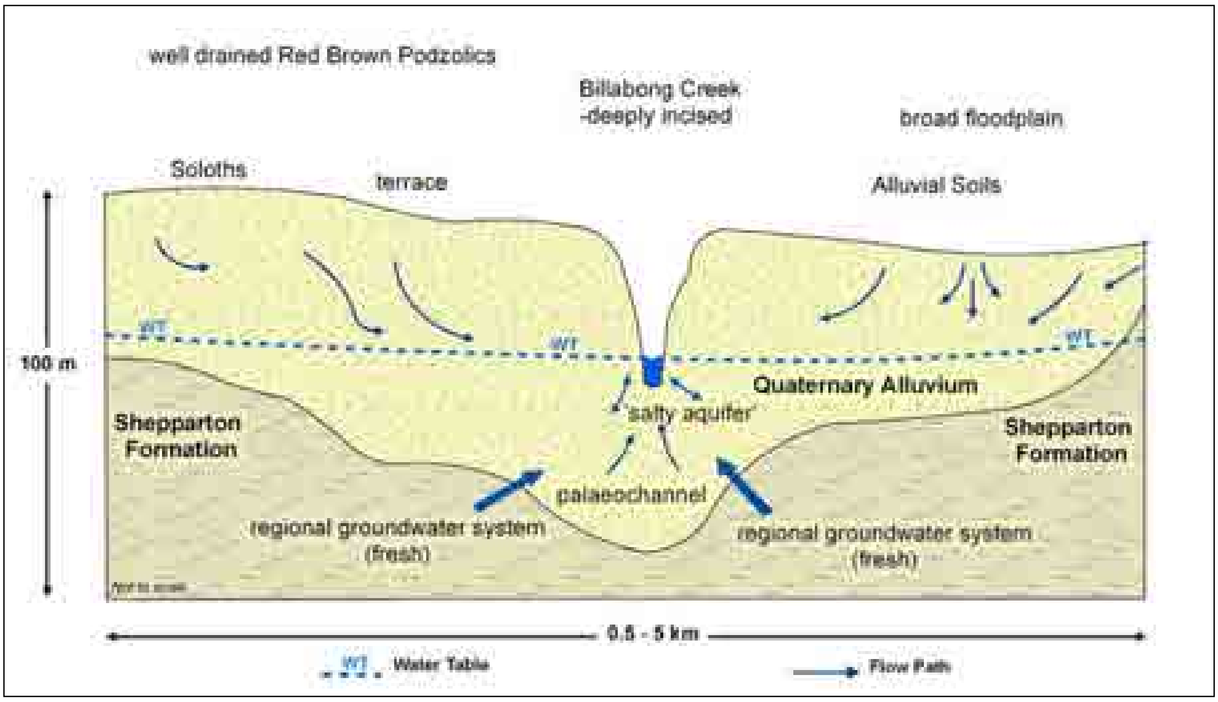


Figure 2: Conceptual cross-section for Lower Billabong HGL showing the distribution of regolith and landforms, salt sites if present, and flow paths of water infiltrating the system.

Outbreaks of land salinity are uncommon, but high EC and salt loads are observed (Table 1) along specific reaches of Billabong Creek within this HGL, in particular Kangaroo Creek and downstream of Walbundrie (English *et al.* 2002; DAFF 2012).

Table 1: Lower Billabong HGL salinity expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	Low – land salinity not observed
Salt Load (Export)	High – high EC and continual flow lead to this HGL generating high salt loads within the catchment
EC (Water Quality)	High – continuous flow of high EC water in Billabong Creek, mainly downstream of Kangaroo Creek Frequently above 2000 µS/cm with common spikes above 6000 µS/cm

Salt stored within the Lower Billabong HGL has high mobility. There is a moderate salt store that has high availability (Table 2).

Table 2: Lower Billabong HGL salt store and availability.

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

The overall salinity hazard in the Lower Billabong HGL is very high. This is due to the high likelihood that salinity issues will have potentially severe impacts (Table 3).

Table 3: Likelihood of salinity occurrence, potential impact and overall hazard of salinity for the Lower Billabong HGL.

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

FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 4.

Photo 1: The steep-sided incised channel of Billabong Creek at Morven is characteristic of the Lower Billabong HGL (Photo: OEH/W Cook).

Photo 2:The characteristic steep-sided incised channel of Billabong Creek as seen near Weeamera (Photo: OEH/W Cook).

Photo 3: Native vegetation along the riparian zone of Billabong Creek is an important feature of the Lower Billabong HGL (Photo: OEH/W Cook).

Photo 4: The view to the south-west from Morgans Lookout across the Billabong Creek flood plain is typical of the Lower Billabong HGL (Photo: OEH/R Muller).

Table 4: Summary of information used to define the Lower Billabong HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2011)*	This HGL comprises unconsolidated Quaternary channel and flood plain sediments: • alluvium – gravel, sand, silt and clay.
Annual Rainfall	500–600 mm
Regolith and Landforms	The Lower Billabong HGL is variably weathered and is characterised by broad level alluvial plains of the Billabong Creek. Slopes are typically <1%, local relief is <5 m, and this HGL is between 140–210 m elevation. The HGL features extensive broad plains with widely-spaced narrow drainage lines. There are locally preserved ancient channel deposits and low alluvial terraces. Gilgai are present on the alluvial plains in localised areas. Regolith materials are unconsolidated interbedded clay, silt, sand and gravel, riverine deposits of the Shepparton Formation and Quaternary alluvium.
Soil Landscapes *(DECCW 2010)*	This HGL corresponds closely to Culcairn soil landscape. Soils are typically very deep. Sodic subsoils have developed on areas of older terraces. Topographical lows in the western parts of the HGL have heavy cracking clay soils. Soils are typically: very deep (>1.5 m), moderately well-drained Red and Brown Chromosols and Kurosols (Red and Brown Podzolic Soils) on alluvial plains; Yellow and Grey Sodosols (Soloths) occur on the higher, older terraces; deep (1.0–1.5 m), moderately well-drained Grey and Brown Dermosols (Grey Podzolic Soils) on lower younger terraces; and, deep (1.0–1.5 m), imperfectly drained Stratic Rudosols (Alluvial Soils) in recent channels.
Land and Soil Capability *(OEH 2012)*	Class 3
Land Use	Cropping – (continuous or rotation) and grazing on improved pastures
Key Land Degradation Issues	• sodicity in lower landscape • salinity (localised) • waterlogging in lower landscape.
Native Vegetation *(Stelling 1998; Keith 2004)*	The majority of Lower Billabong HGL is managed for agriculture. Extant native vegetation on the alluvial flats tends to be mainly grey box woodland with some white box woodland. Typical tree species include *E. microcarpa* (grey box) on heavier soils, *E. camaldulensis* (river red gum) along Billabong Creek, *E. blakelyi* (Blakely's red gum) on loamy soils, *E. albens* (white box), *Callitris glaucophylla* (white cypress pine), *Brachychiton populneus* (kurrajong) and *Allocasuarina luehmannii* (bulloak). Understorey species include *Acacia acinacea* (gold-dust wattle), *A. difformis* (drooping wattle), *A. montana* (mallee wattle), *Bursaria spinosa* (sweet bursaria), *Dodonaea viscosa* subsp. *cuneata* (wedge-leaf hop-bush) and *Callistemon sieberi* (river bottlebrush) along Billabong Creek.

HYDROGEOLOGY

Aquifers within this landscape are unconfined to semi-confined, with groundwater flow occurring primarily through unconsolidated alluvial sediments. Hydraulic conductivity is high and transmissivity is moderate to high. Groundwater recharge rates are estimated to be high.

Groundwater systems are typically intermediate to regional with intermediate to long flow lengths, and are loosely defined by topographic catchments. Water quality within these systems is brackish to saline. Watertable depths are intermediate to deep. Localised perching of watertables occurs above clay lenses during wetter periods.

Medium to long residence times are typical. These landscapes have a slow to medium response time to changes in land management.

Typical values for the hydrogeological parameters of this HGL are summarised in Table 5.

Table 5: Summary of values for typical hydrogeological parameters of the Lower Billabong HGL.

Aquifer Type	Unconfined to semi-confined in unconsolidated alluvial sediments Vertical and lateral flow components Local perching above clay-rich layers (seasonal)
Hydraulic Conductivity	High Range: >10 m/day
Aquifer Transmissivity	Moderate to high Range: 2 – >100 m^2/day
Specific Yield	Moderate to high Range: 5 – >15%
Hydraulic Gradient	Gentle Range: <10%
Groundwater Salinity	Brackish to saline (shallow unconfined aquifer) Range: 1600 – >4800 µS/cm Fresh to marginal (deep semi-confined aquifer) Range: <800–1600 µS/cm
Depth to Watertable	Intermediate to deep (localised perching) Range: 2 – >8 m
Typical Sub-Catchment Size	Large (>1000 ha)
Scale (Flow Length)	Intermediate to regional Flow length: 5 – <50 km (intermediate to long)
Recharge Estimate	High
Residence Time	Medium to long (years to decades)
Responsiveness to Change	Slow to medium (years to decades)

MANAGEMENT OPTIONS

Overarching salinity management strategies have specific biophysical outcomes. These are achieved by implementing a series of targeted land management actions that take into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape to impact on salinity. Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Salinity is driven by interactions between water-use capacity of vegetation, physical soil properties and hydrogeological processes within the HGL.

Actions that influence the way water is used by vegetation or stored in the soil profile will have impacts on recharge. The influence of both continual and episodic recharge and the impacts of extreme weather events need to be considered when deciding on appropriate management actions. Short and long-term climate cycles also need to be considered as they have a bearing on salinity processes, particularly salt load and land salinity.

Landscape Salinity Functions – Lower Billabong HGL

Functions this landscape provides within a catchment scale salinity context:

- **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
- **F.** The landscape generates high salinity water.

Management Strategy Objectives – Lower Billabong HGL

Appropriate strategies pertinent to this landscape:

- **Buffer the salt store – keep it dry and immobile (1):** Vegetation can buffer stores of salt in the landscape, limiting the salinity impact. These areas are generally associated with particular soil types within the unit and also where the unit connects with adjacent colluvial units.
- **Discharge rehabilitation and management (4):** Discharge management will improve on-site and off-site salinity outcomes when vegetation is matched to salt sites.
- **Access and use of groundwater to change water balance (7):** On-farm use of groundwater for stock and domestic purposes should be encouraged.

Key Management Focus – Lower Billabong HGL

In this landscape salinity processes occur which cannot easily be influenced by land management actions taken within the local landscape. The impacts of salinity processes are mostly seen in the main channel of Billabong Creek and Kangaroo Creek.

Specific Land Management Opportunities

Specific opportunities for this HGL:

- salt interception scheme as currently operating
- a significant amount of landscape information is available due to investigations related to the salt interception scheme
- biodiversity opportunities exist along the main channel of Billabong Creek.

Specific Land Management Constraints

Constraints for land management in this HGL include:

- hard to influence with local actions—salinity is due to regional scale process
- salinity processes occur at a depth in the landscape which means that vegetation will have a low level of influence
- a high level of landscape understanding is needed to successfully implement management actions.

Specific Targeted Actions

Management areas for this HGL are illustrated in Figure 3. The specific management actions for these areas are described in Table 6.

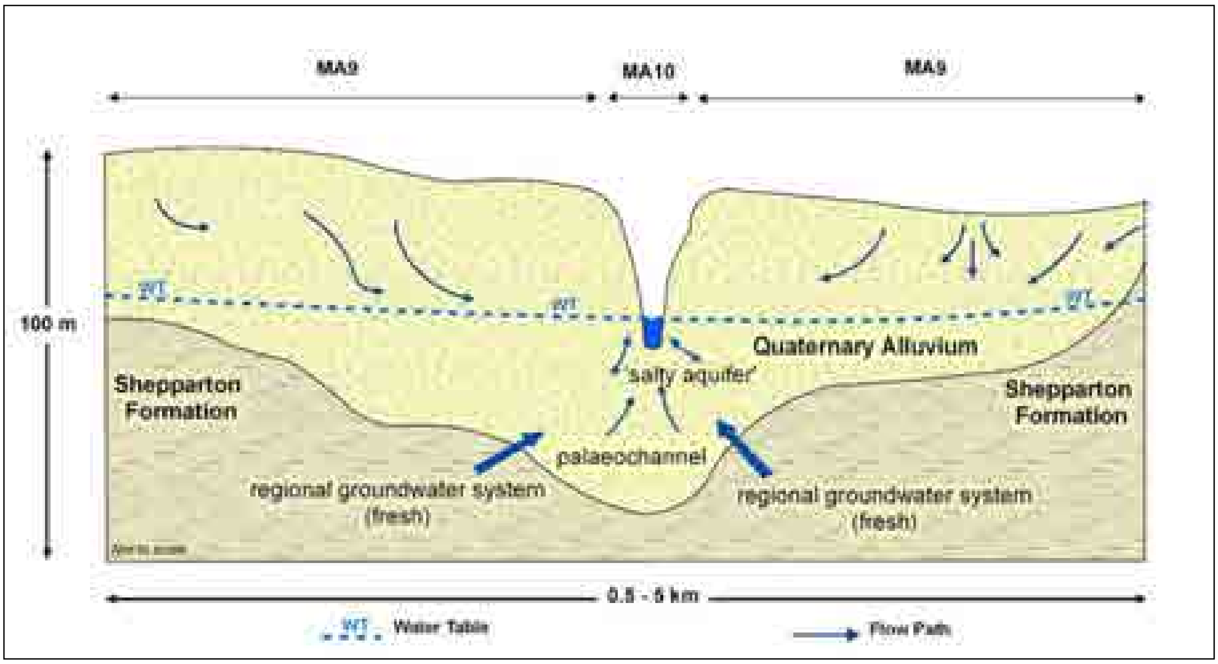


Figure 3: Management cross-section for Lower Billabong HGL showing defined management areas.

Table 6: Specific management actions for management areas within the Lower Billabong HGL.

Management Area (MA)	Action
MA9 (ALLUVIAL PLAIN)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** Maintain and improve riparian native vegetation to reduce discharge to streams **(VE4).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge (**VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).Irrigation Systems** Manage on-farm irrigation to achieve best practice **(IS1).** Manage irrigation supply systems to achieve best practice **(IS2).** **Engineering** Groundwater use for agricultural stock and domestic water supply to replace surface water storage and use **(E1).** Implement groundwater pumping and disposal **(E4).**
MA10 (ALLUVIAL CHANNEL)	**Vegetation for ecosystem services** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** Maintain and improve riparian native vegetation to reduce discharge to streams **(VE4).** **Engineering** Groundwater use for agricultural stock and domestic water supply to replace surface water storage and use **(E1).** Implement groundwater pumping and disposal **(E4).**

High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative impacts on salinity (Table 7).

Table 7: Management actions having negative salinity impacts in the Lower Billabong HGL.

At Risk Management Areas	Action
MA9 (ALLUVIAL PLAIN)	Long fallows in farming systems **(DLU1).** Annual cropping with annual plants **(DLU3).** Poor soil management – tillage causing poor structure **(DLU8).** Poor soil management – loss of surface soil layers **(DLU10).** Irrigation using inefficient on-farm water delivery practices **(DLU13).**
MA10 (ALLUVIAL CHANNEL)	Clearing and poor management of native vegetation (**DLU4)**

REFERENCES

Baker, P.A. and McNaught, I. 2011, *Identifying possible narrow palaeochannels through interpretation of airborne electromagnetic data and borehole data in the Billabong Creek area, NSW*, ABARES report to client prepared for Sustainable Resource Management Division, Department of Agriculture, Fisheries and Forestry, Canberra, www.daff.gov.au/__data/assets/pdf_file/0004/1931071/billabong-creek-300611.pdf

DAFF, 2012, *Billabong Creek project overview*, Australian Government, Department of Agriculture, Canberra, [accessed 24 April 2014] www.daff.gov.au/natural-resources/salinity/salinity-mapping/billabong-creek

DECCW, 2010, *Reconnaissance soil and land resources of the Murray CMA*, NSW Department of Environment, Climate Change and Water, Sydney

English, P., Richardson, P. and Stauffacher, M. 2002, Groundwater & Salinity Processes in Simmons Creek sub-catchment, Billabong Creek, NSW, *Technical Report 24/02*, CSIRO Land and Water, Canberra

Geoscience Australia, 2011, *Australian stratigraphic units database*, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int

Keith, D. A. 2004, *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, Hurstville, NSW Department of Environment and Conservation

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, OEH Sydney, [Accessed: 10 November 2014] www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

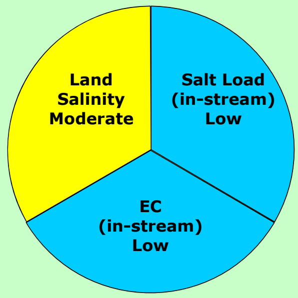
Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia, [Accessed: 10 December 2009]

Stelling, F. 1998, *South west slopes revegetation guide (south of the Murrumbidgee River)*, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

Wooldridge, A., Nicholson, A., Muller R., Jenkins, B. R., Wilford, J. and Winkler, M. 2015, *Guidelines for managing salinity in rural areas*, NSW Office of Environment and Heritage, Sydney, NSW

2. Walla Walla Hydrogeological Landscape

LOCALITIES	**Walla Walla, Gerogery, Jindera**
MAP SHEET	**Jerilderie 1:250 000** **Tallangatta 1:250 000** **Wagga Wagga 1:250 000**
CONFIDENCE LEVEL	**Low**



OVERVIEW

The Walla Walla Hydrogeological Landscape (HGL) extends from Jindera in the south to Weeamera in the north, and from Morven in the east to the edge of the study area at Walbundrie in the west (Figure 1). The HGL covers an area of 357 km^2 and receives 500 to 700 mm of rain per annum.

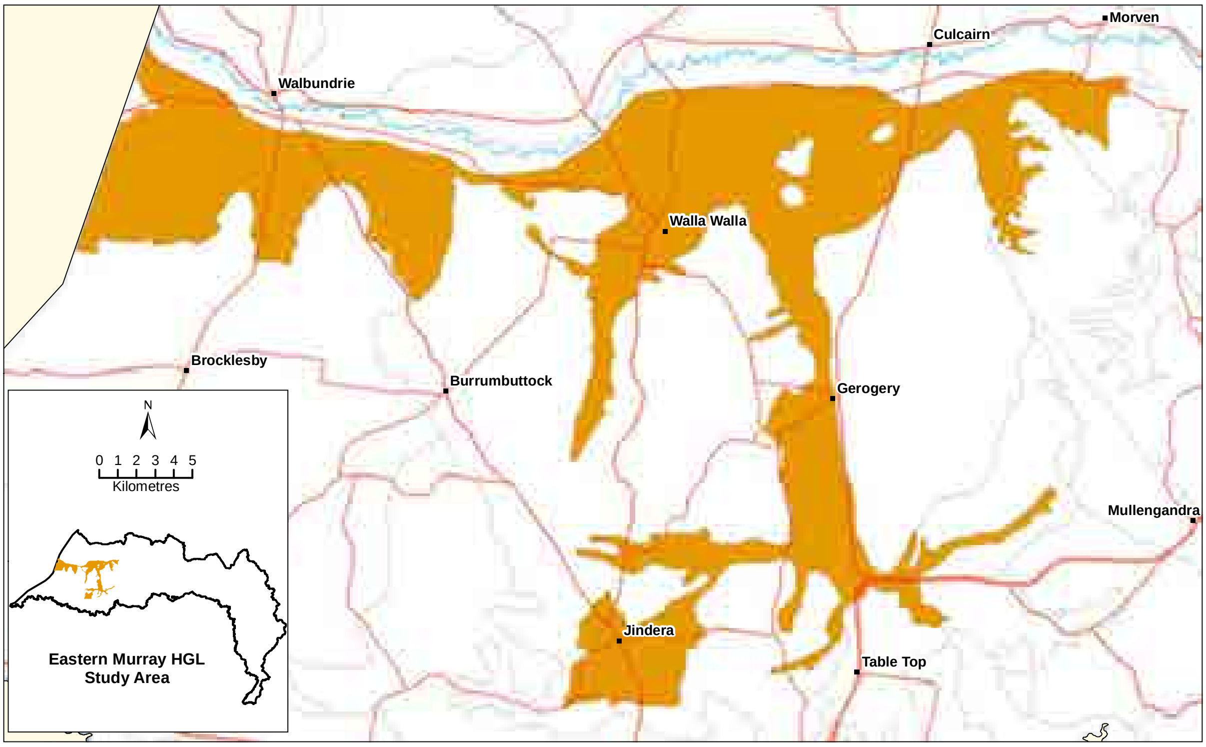


Figure 1: Walla Walla HGL distribution map.

The Walla Walla HGL is a depositional environment with extensive and broad gently sloping plains. Significant aeolian deposits of fine sand are present. It is characterised by numerous deflation basins and terraces and sparse narrow drainage lines (Figure 2). This HGL comprises unconsolidated Cainozoic fluvial and lacustrine sediments. Typically these are muds, silts, clays, sands and gravels. Soils are generally very deep. Sodic subsoils have developed on areas of older terraces. Topographical lows in the western parts of the HGL have heavy cracking clay soils. Sodic soils in the lowest parts of this HGL combined with the shape of the landscape commonly lead to waterlogging problems. Localised gully erosion is also an issue.

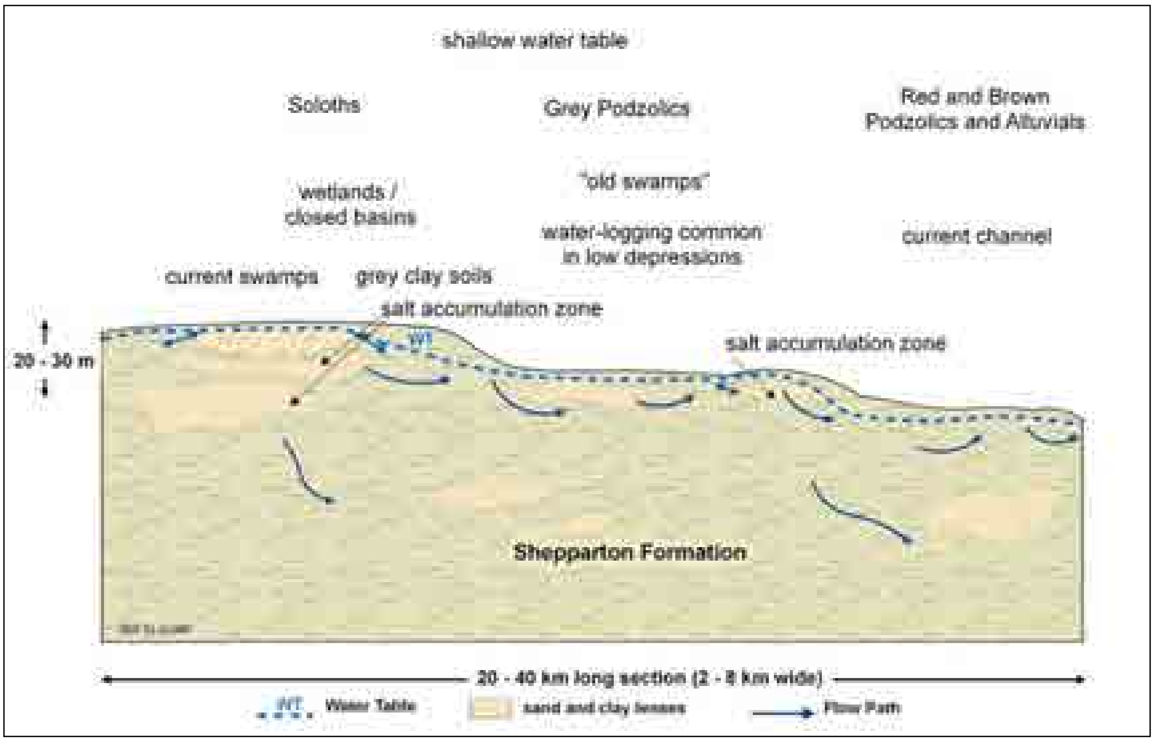


Figure 2: Conceptual cross-section for Walla Walla HGL showing the distribution of regolith and landforms, salt sites if present, and flow paths of water infiltrating the system.

Outbreaks of salinity occur within and on the margins of swampy depressions and are driven by seasonal conditions. EC and salt loads are low (Table 1). A bulge of salt store features under wetlands and on the margins of the wetlands.

Table 1: Walla Walla HGL salinity expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	Moderate land salinity in swampy depressions and seasonally in low lying areas
Salt Load (Export)	Export is low, streams are mainly terminal basins and not incised into salt bearing materials
EC (Water Quality)	Low – no observations of high EC water

Salt stored within the Walla Walla HGL has high mobility. There is a moderate salt store that has high availability (Table 2).

Table 2: Walla Walla HGL salt store and availability.

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

The overall salinity hazard in the Walla Walla HGL is low. This is due to the moderate likelihood that salinity issues will occur that have potentially limited impacts (Table 3).

Table 3: Likelihood of salinity occurrence, potential impact and overall hazard of salinity for the Walla Walla HGL.

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

LANDSCAPE FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 4.

Photo 1: The landscape between Morgans Lookout and Walla Walla is characteristic of the Walla Walla HGL (Photo: OEH/R Muller).

Photo 2: The landscape looking south of Morgans Lookout is typical of the Walla Walla HGL (Photo: OEH/A Nicholson).

Photo 3: Land salinity occurs in low-lying areas and impacts on vegetation. This can be observed in the vicinity of Burrumbuttock at the HGL boundary change (Photo: OEH/A Nicholson).

Photo 4: Land salinity occurs in low-lying areas and impacts on vegetation. Note dead and dying timber with large precipitation (white crystals) in wet years (Photo: OEH/A Nicholson).

Photo 5: Land salinity occurs in low-lying areas and impacts on vegetation. Note drainage line in background is highly impacted by salinity as well as the foreground (Photo: OEH/A Nicholson).

Table 4: Summary of information used to define the Walla Walla HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2011)*	This HGL comprises unconsolidated Cenozoic fluvial and lacustrine sediments. Key lithologies include: • lake and swamp deposits – mud, silt, minor sand and travertine • colluvium and/or residual deposits – boulders, gravel and sand; may include minor alluvial or sand plain deposits • Shepparton Formation – unconsolidated to poorly consolidated mottled variegated clay, silty clay with lenses of polymictic, coarse to fine sand and gravel; partly modified by pedogenesis.
Annual Rainfall	500–700 mm
Regolith and Landforms	The Walla Walla HGL is variably weathered and characterised by extensive to broad, gently inclined plains of primary and reworked alluvium, with locally preserved low alluvial terraces, and aeolian fine sand veneer deposits mantling the plains. Slopes are typically <5%, local relief is 10–30 m, and this HGL is between 210–300 m elevation. The HGL features numerous deflation basins and terraces with widely spaced narrow drainage lines. Regolith materials are unconsolidated interbedded clay, silt, sand and gravel, primary and reworked riverine deposits of the Shepparton Formation and Quaternary alluvium. These sediments are overlain by widespread aeolian veneer deposits of wind-blown fine sand. The source of this fine sand is both local (from deflation basins such as Doodle Comer Swamp) and distal (from the Riverine Plain to the north and west). There are also minor slope-wash accumulations adjacent to higher relief areas.

Soil Landscapes *(DECCW 2010)*	This HGL contains a number of soil landscapes. Most of the HGL is occupied by Culcairn soil landscape but there are also significant areas of Henty, Gerogery and Kindra. Doodle Comer Swamp soil landscape occupies large swampy depressions. Sodic subsoils have developed on areas of older terraces. Topographical lows in the western parts of the HGL have heavy cracking clay soils. Soils are typically: very deep (>1.5 m), moderately well-drained Red and Brown Chromosols and Kurosols (Red and Brown Podzolic Soils) on alluvial plains; Yellow and Grey Sodosols (Soloths) occur on the higher, older terraces; deep (1.0–1.5 m), moderately well-drained Grey and Brown Dermosols (Grey Podzolic Soils) on lower younger terraces; deep (1.0–1.5 m), imperfectly drained Stratic Rudosols (Alluvial Soils) in recent channels; and, dominantly very deep (>1.5 m) Grey Vertosols (Grey Clays) in swamps. Some sites show evidence of fine wind-blown sand inclusions.
Land and Soil Capability *(OEH 2012)*	Class 4
Land Use	Cropping – (continuous or rotation) and grazing on improved pastures and grazing on volunteer (self establishing), naturalised (sown-reverted), native or improved pastures
Key Land Degradation Issues	• sodicity in lower landscape • salinity (isolated) • waterlogging (common) • gully erosion (localised) • poor soil structure • acidity • sheet erosion.
Native Vegetation *(Stelling 1998; Keith 2004)*	The majority of native vegetation has been cleared. Extant native vegetation on the flats and gentle rises tends to be white box woodland but grey box and yellow box woodland may also occur on the flats and low country, and Blakely's red gum woodland may occur with river red gum frest around the creeks. Tree species on the gentle slopes include *E. albens* (white box) on fertile sites, *E. blakelyi* (Blakely's red gum) on loamy soils and *E. dwyeri* (Dwyer's red gum) on well drained sites, *Callitris glaucophylla* (white cypress pine), *Acacia implexa* (hickory wattle), *Brachychiton populneus* (kurrajong) and *Pittosporum angustifolium* (butterbush). Understorey species include *Acacia rubida* (red-stemmed wattle), *Hakea tephrosperma* (hooked needlewood), *Indigofera australis* (austral indigo), *Bursaria spinosa* (wweet bursaria), *Eutaxia microphylla* (mallee bush pea) and *A. montana* (mallee wattle). Around the alluvial channels, tree species can be *E. camaldulensis* (river red gum) with *Callistemon sieberi* (river bottlebrush) in the understorey.

HYDROGEOLOGY

Aquifers within this landscape are unconfined to semi-confined, with groundwater flow occurring primarily through unconsolidated alluvial sediments. Hydraulic conductivity and transmissivity are moderate. Groundwater recharge rates are estimated to be moderate to high.

Groundwater systems are typically local to intermediate with short to intermediate flow lengths, and are loosely defined by topographic catchments. Water quality within these systems is fresh to marginal. Watertable depths are shallow to intermediate. Localised perching of watertables occurs above clay lenses during wetter periods.

Medium residence times are typical. These landscapes have a medium response time to changes in land management.

Typical values for the hydrogeological parameters of this HGL are summarised in Table 5.

Table 5: Summary of values for typical hydrogeological parameters of the Walla Walla HGL.

Aquifer Type	Unconfined to semi-confined in unconsolidated alluvial sediments Vertical and lateral flow components Local perching above clay-rich layers (seasonal)
Hydraulic Conductivity	Moderate Range: 10^{-2}–10 m/day
Aquifer Transmissivity	Moderate Range: 2–100 m^2/day
Specific Yield	Low to moderate Range: <15%
Hydraulic Gradient	Gentle Range: <10%
Groundwater Salinity	Fresh to marginal Range: <800–1600 µS/cm
Depth to Watertable	Shallow to intermediate (localised perching) Range: <8 m
Typical Sub-Catchment Size	Small to medium (<1000 ha)
Scale (Flow Length)	Local to intermediate Flow length: <15 km (short to intermediate)
Recharge Estimate	Moderate to high
Residence Time	Medium (years)
Responsiveness to Change	Medium (years)

MANAGEMENT OPTIONS

Overarching salinity management strategies have specific biophysical outcomes. These are achieved by implementing a series of targeted land management actions that take into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape to impact on salinity. Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Salinity is driven by interactions between water-use capacity of vegetation, physical soil properties and hydrogeological processes within the HGL.

Actions that influence the way water is used by vegetation or stored in the soil profile will have impacts on recharge. The influence of both continual and episodic recharge and the impacts of extreme weather events need to be considered when deciding on appropriate management actions. Short and long-term climate cycles also need to be considered as they have a bearing on salinity processes, particularly salt load and land salinity.

Landscape Salinity Functions– Walla Walla HGL

Functions this landscape provides within a catchment scale salinity context:

- **E.** The landscape receives and stores salt load through irrigation or surface flow.
- **G.** The landscape contains important land assets (including infrastructure and high value agricultural land) on which salinity processes impact.
- **I.** The landscape contains high hazard for acid sulfate processes.

Management Strategy Objectives – Walla Walla HGL

Appropriate strategies pertinent to this landscape.

- **Discharge rehabilitation and management (4):** The salt sites are medium to large in size with considerable waterlogging evident. Discharge management will reduce onsite and offsite impacts of salt discharge to streams, particularly when vegetation is matched to site characteristics.
- **Manage and avoid acid sulfate hazards (11):** Inland acid sulfate soil processes are a possibility within this unit and hazards need to be considered in ongoing management.

Key Management Focus – Walla Walla HGL

Wetland management should focus on the bulge of salt store under wetlands and on the margins of the wetlands. Management of waterlogged areas should recognise the cyclic nature of waterlogging.

Specific Land Management Opportunities

Specific opportunities for this HGL:

- Soils with a high cation exchange capacity (CEC) have a greater capacity to interact and bind elements and compounds in the soil and can buffer salinity within soil profiles.
- Opportunity to combine wetland management with salinity management.
- Many saline and waterlogged sites disappear in dry times. This provides an opportunity to implement works to manage the waterlogging and salinity in wetter times.

Specific Land Management Constraints

Constraints for land management in this HGL include:

- Sodic B horizons occur in many soil types, particularly in soil types which are affected by waterlogging and salinity.
- Seasonal waterlogging occurs particularly during low growth periods of the year.
- Access to saline, waterlogged areas can be difficult.
- Inland acid sulfate hazards occur.

Specific Targeted Actions

Management areas for this HGL are illustrated in Figure 3. The specific management actions for these areas are described in Table 6.

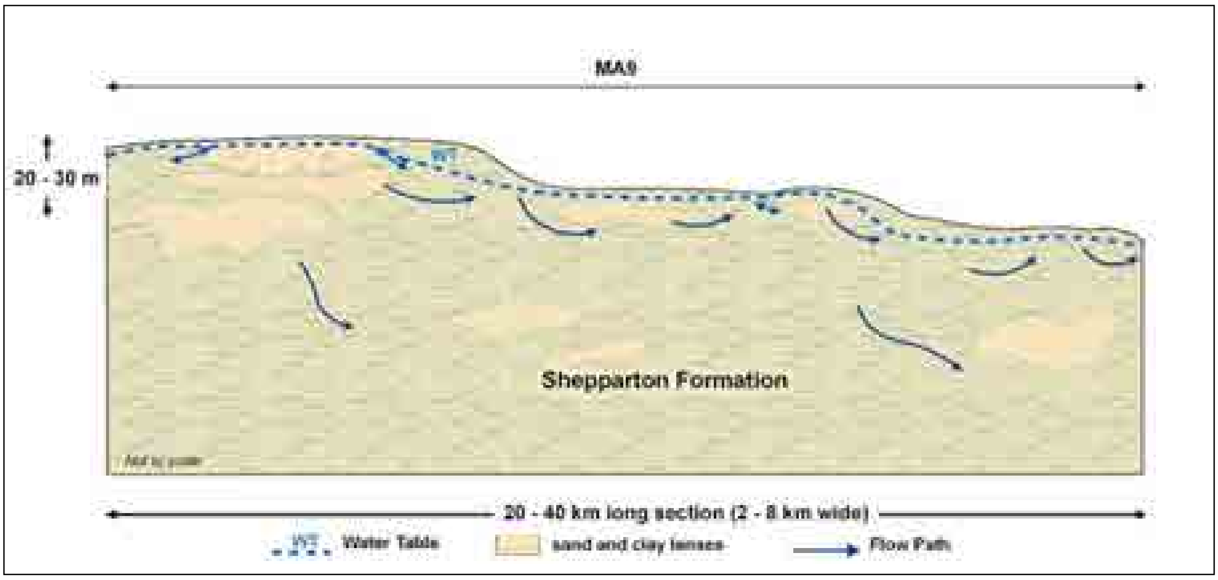


Figure 3: Management cross-section for Walla Walla HGL showing defined management areas.

Table 6: Specific management actions for management areas within the Walla Walla HGL.

Management Area (MA)	Action
MA9 (WETLANDS/SWAMPS)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** **Vegetation for production** Maintain and improve native pastures to manage recharge **(VP5).**
MA9 (OLD SWAMPS)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** Maintain and improve riparian native vegetation to reduce discharge to streams **(VE4).** Establish and manage trees that are integrated into farming logistics to reduce recharge **(VE5).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge (**VP1).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**
MA9 (CURRENT CHANNEL)	**Vegetation for ecosystem function** Maintain and improve riparian native vegetation to reduce discharge to streams **(VE4).** Establish and manage trees that are integrated into farming logistics to reduce recharge **(VE5).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge (**VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**

High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative impacts on salinity (Table 7).

Table 7: Management actions having negative salinity impacts in the Walla Walla HGL.

At Risk Management Areas	Action
MA9 (WETLANDS/SWAMPS)	Clearing and poor management of native vegetation **(DLU4).** Do not drain – mobilisation of acid sulfate materials.
MA9 (OLD SWAMPS)	Long fallows in cropping systems **(DLU1).** Annual cropping with annual plants **(DLU3).** Clearing and poor management of native vegetation **(DLU4).** Deep ripping of soils to maximise water infiltration to subsoil **(DLU11).**
MA9 (CURRENT CHANNEL)	Long fallows in farming systems **(DLU1).** Annual cropping with annual plants **(DLU3).**

REFERENCES

DECCW, 2010, *Reconnaissance soil and land resources of the Murray CMA*, NSW Department of Environment, Climate Change and Water, Sydney

Geoscience Australia, 2011, *Australian stratigraphic units database*, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int

Keith, D. A. 2004, *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, Hurstville, NSW Department of Environment and Conservation

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, Office of Environment and Heritage, Sydney, [Accessed: 10 November 2014] www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

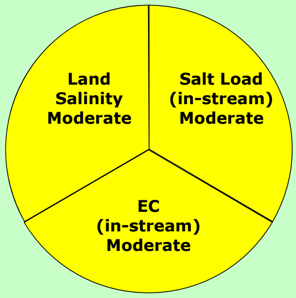
Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia

Stelling, F. 1998, *South west slopes revegetation guide (south of the Murrumbidgee River)*, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

Wooldridge, A., Nicholson, A., Muller R., Jenkins, B. R., Wilford, J. and Winkler, M. 2015, *Guidelines for managing salinity in rural areas*, NSW Office of Environment and Heritage, Sydney, NSW

3. Upper Billabong Hydrogeological Landscape

LOCALITIES	**Morven, Holbrook, Little Billabong**
MAP SHEET	**Wagga Wagga 1:250 000**
CONFIDENCE LEVEL	**Low**



OVERVIEW

The Upper Billabong Hydrogeological Landscape (HGL) extends east from Morven upstream to Little Billabong, Yarra Yarra Junction, Reddalls Valley and Woomargama (Figure 1). The HGL covers an area of 335 km^2 and receives 600 to 800 mm of rain per annum.

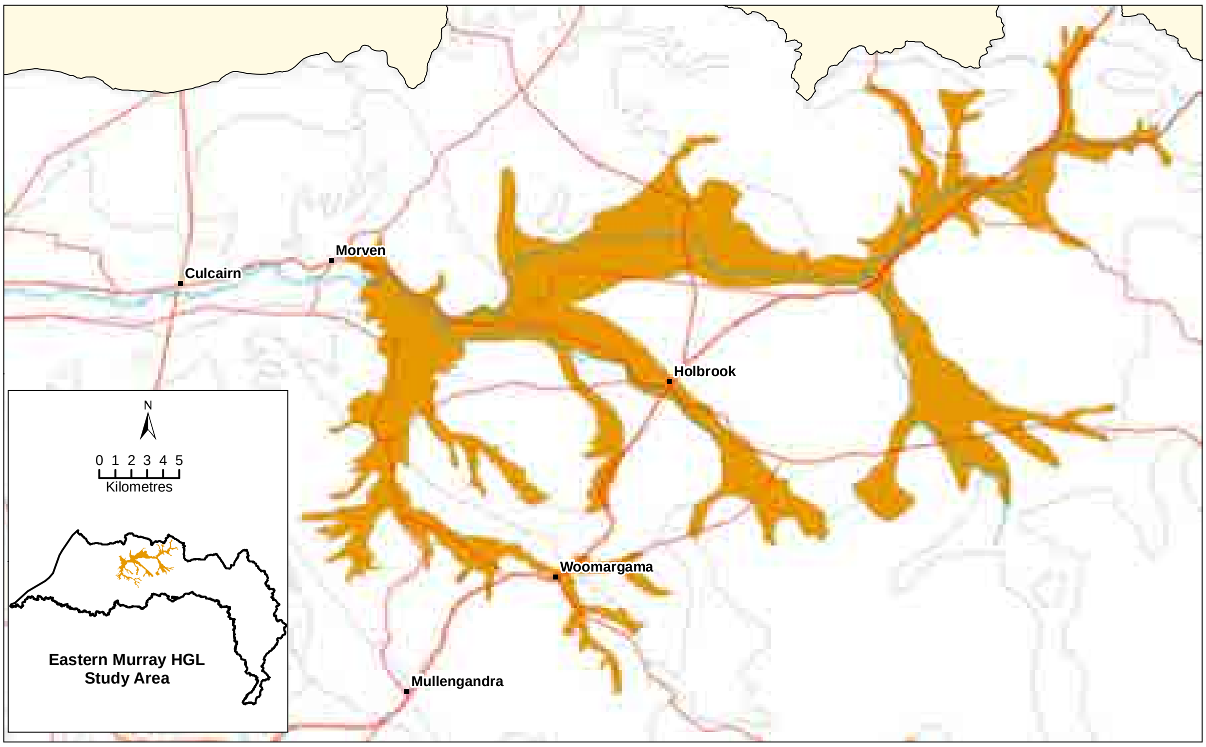


Figure 1: Upper Billabong HGL distribution map.

The Upper Billabong HGL is a depositional environment characterised by extensive alluvial plains with a number of terrace sequences in major tributaries, narrowing in the upper catchment (Figure 2). This HGL comprises unconsolidated Quaternary channel and flood plain sediments. Typically these are sands, gravels and clays. Soils are typically deep and moderately well-drained on terraces and imperfectly drained in recent channels.

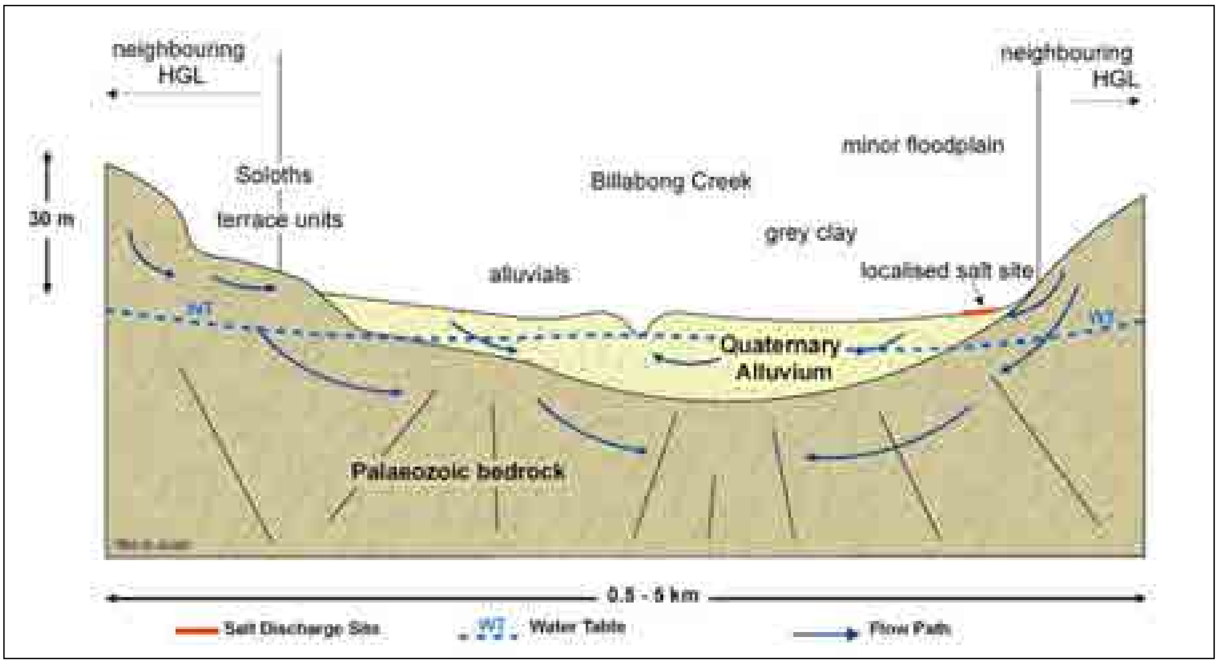


Figure 2: Conceptual cross-section for Upper Billabong HGL showing the distribution of regolith and landforms, salt sites if present, and flow paths of water infiltrating the system.

The occurrence of land salinity, salt load and EC are all moderate (Table 1). Salt outbreaks occur adjacent to colluvial slopes of surrounding HGLs.

Table 1: Upper Billabong HGL salinity expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	Moderate – outbreaks are related to adjacent HGL units
Salt Load (Export)	Export is moderate – perennial flow frequently above 500 µS/cm
EC (Water Quality)	Moderate – EC commonly observed between 500 and 1000 µS/cm. EC will vary and cycle with rainfall events

Salt stored within the Upper Billabong HGL has moderate mobility. There is a moderate salt store that has moderate availability (Table 2).

Table 2: Upper Billabong HGL salt store and availability.

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

The overall salinity hazard in the Upper Billabong HGL is moderate. This is due to the moderate likelihood that salinity issues will occur that have potentially significant impacts (Table 3).

Table 3: Likelihood of salinity occurrence, potential impact and overall hazard of salinity for the Upper Billabong HGL.

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

LANDSCAPE FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 4.

Photo 1: The Billabong Creek channel near Ralvona in the lower reaches of the Upper Billabong HGL is incised with steep sides (Photo: OEH/W Cook).

Photo 2: Stream-bank erosion, such as is seen at Mountain Creek, is common in the Upper Billabong HGL (Photo: OEH/W Cook).

Photo 3: Land salinisation is generally related to the colluvial slopes of adjacent HGLs. This example is in the upper reaches of Ten Mile Creek (Photo: OEH/W Cook).

Photo 4: The broad alluvial plain at Little Billabong quickly narrows as the stream channel approaches Lunts Sugarloaf (Stonehaven HGL) (Photo: OEH/R Muller).

Photo 5: The broad alluvial plains present at Little Billabong are characteristic of the larger tributaries of the Upper Billabong HGL (Photo: OEH/R Muller).

Photo 6: At Four Mile Creek, through-flow from the Stonehaven HGL flows out on to the adjacent alluvial plain of the Upper Billabong HGL, resulting in waterlogged and saline areas (Photo: OEH/R Muller).

Table 4: Summary of information used to define the Upper Billabong HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2011)*	This HGL comprises unconsolidated Quaternary channel and flood plain sediments: • aluvium – gravel, sand, silt and clay.
Annual Rainfall	600–800 mm
Regolith and Landforms	The Upper Billabong HGL is variably weathered and is characterised by extensive level alluvial plains of Billabong Creek, and broad plains with a number of terrace sequences in major tributaries, narrowing in the upper catchment. Slopes are typically <2%, local relief is <5m, and this HGL is between 230–350 m elevation. The HGL features inset floodplains, broad plains with widely spaced narrow drainage lines and numerous terrace sequences. Gilgai are present on the alluvial plains in localised areas. Regolith materials are unconsolidated interbedded clay, silt, sand and gravel, riverine deposits of Quaternary alluvium.
Soil Landscapes *(DECCW 2010)*	This HGL is covered mostly by Mountain Creek and Billabong Creek soil landscapes with small patches of Four Mile Creek at the upper margins. Soils include: very deep (>1.5 m), moderately well-drained Brown, Yellow and Grey Sodosols (Soloths) on the higher, older terraces; deep (1.0–1.5 m), moderately well drained Yellow and Brown Dermosols (Yellow and Brown Earths) on lower younger terraces; deep (1.0–1.5 m), imperfectly drained Stratic Rudosols (Alluvial Soils) in recent channels; and, small areas of Grey Vertosols (Grey Clays) with gilgai micro-relief on back plain. Soil structure is poor as a result of topsoil and organic matter loss through cultivation, or where stock have trampled wet soils. Localised areas of waterlogging and plough pans are common. There are localised areas of gully erosion and extensive stream-bank erosion.
Land and Soil Capability *(OEH 2012)*	Class 4
Land Use	Grazing on volunteer, naturalised, native or improved pastures with areas of cropping
Key Land Degradation Issues	• gully erosion (localised) • seasonal waterlogging • extensive stream-bank erosion • poor soil structure • acidity.

Native Vegetation *(Stelling 1998; Keith 2004)*	Much of the native vegetation in Upper Billabong HGL has been cleared. Extant native vegetation on the alluvial gravels, sand, silt and clay include Yellow Box woodland, Grey Box woodland and Blakely's Red Gum woodland. Typical tree species include *E. microcarpa* (grey box) on heavier soils, *E. camaldulensis* (river red gum) along Billabong Creek, *E. blakelyi* (Blakely's red gum) on loamy soils, *E. melliodora* (yellow box), *Callitris glaucophylla* (white cypress pine), *Brachychiton populneus* (kurrajong) and *Allocasuarina luehmannii* (bulloak). Understorey species include *Acacia acinacea* (gold-dust wattle), *A. difformis* (drooping wattle), *A. montana* (mallee wattle), *A. paradoxa* (kangaroo thorn), *Bursaria spinosa* (sweet bursaria), *Dodonaea viscosa* ssp. *cuneata* (wedge-leaf hop-bush) and *Callistemon sieberi* (river bottlebrush) along Billabong Creek.

HYDROGEOLOGY

Aquifers within this landscape are unconfined to semi-confined with groundwater flow primarily through unconsolidated alluvial sediments. Hydraulic conductivity and transmissivity are moderate to high. Groundwater recharge rates are estimated to be high.

Groundwater systems are typically local to intermediate with short to intermediate flow lengths, and are loosely defined by topographic catchments. Water quality within these systems is fresh to marginal. Watertable depths are intermediate. Localised perching of watertables occurs above clay lenses during wetter periods.

Short to medium residence times are typical. These landscapes have a medium to fast response time to changes in land management.

Typical values for the hydrogeological parameters of this HGL are summarised in Table 5.

Table 5: Summary of values for typical hydrogeological parameters of the Upper Billabong HGL.

Aquifer Type	Unconfined to semi-confined in unconsolidated alluvial sediments Vertical and lateral flow components Local perching above clay-rich layers (seasonal)
Hydraulic Conductivity	Moderate to high Range: 10^{-2}–>10 m/day
Aquifer Transmissivity	Moderate to high Range: 2–>100 m^2/day
Specific Yield	Moderate to high Range: 5–>15%
Hydraulic Gradient	Gentle Range: <10%

Groundwater Salinity	Fresh to marginal Range: <1600 µS/cm
Depth to Watertable	Intermediate (localised perching) Range: 2–8 m
Typical Sub-Catchment Size	Moderate to large (100–>1000 ha)
Scale (Flow Length)	Local to intermediate Flow length: <30 km (short to intermediate)
Recharge Estimate	High
Residence Time	Short to medium (months to years)
Responsiveness to Change	Fast to medium (months to years)

MANAGEMENT OPTIONS

Overarching salinity management strategies have specific biophysical outcomes. These are achieved by implementing a series of targeted land management actions that take into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape to impact on salinity. Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Salinity is driven by interactions between water-use capacity of vegetation, physical soil properties and hydrogeological processes within the HGL.

Actions that influence the way water is used by vegetation or stored in the soil profile will have impacts on recharge. The influence of both continual and episodic recharge and the impacts of extreme weather events need to be considered when deciding on appropriate management actions. Short and long-term climate cycles also need to be considered as they have a bearing on salinity processes, particularly salt load and land salinity.

Landscape Salinity Functions – Upper Billabong HGL

Functions this landscape provides within a catchment scale salinity context:

- **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
- **G.** The landscape contains important land assets (including infrastructure and high value agricultural land) on which salinity processes impact.

Management Strategy Objectives – Upper Billabong HGL

Appropriate strategies pertinent to this landscape:

- **Discharge rehabilitation and management (4):** The salt sites are medium to large, with considerable waterlogging evident. Discharge management will improve on-site and off-site salinity outcomes when vegetation is matched to salt sites.
- **Access and use groundwater to change the water balance (7):** Relatively small changes in groundwater balance can influence on-site and off-site impacts of salinity processes. On-farm use of groundwater for stock and domestic purposes should be encouraged.
- **Maintain and maximise runoff (10):** This HGL contributes significant fresh water as dilution flow to the system, particularly the adjoining Lower Billabong HGL. The fresh runoff mitigates the high salt load and stream salinity which are present in Billabong Creek. The volume of water leaving this HGL is also important for downstream users and ecosystems.

Key Management Focus – Upper Billabong HGL

Improved grazing management particularly on discharge areas should be the focus of salinity management. Salt sites are numerous and are also waterlogged, with potential for increased pasture production. The salt sites have the potential to be remediated with a focus on active management of discharge areas.

The impacts of salinity on major infrastructure (e.g. Hume Highway, local roads and Holbrook township) are an important management considerations.

Specific Land Management Opportunities

Specific opportunities for this HGL:

- High watertables in low areas offer potential for pastures/grazing systems based on pastures with salt and waterlogging tolerance. These areas can be productive if included as part of a well-managed grazing landscape.
- Saline areas are localised and easily targeted.

Specific Land Management Constraints

Constraints for land management in this HGL include:

- The climate will influence the ability of pasture systems to reduce recharge and manage discharge.
- Land salinity gets wet for long periods of time – waterlogging and access are issues to be managed.
- Salinity actions on farms in this HGL will result in off-site benefits.

Specific Targeted Actions

Management areas for this HGL are illustrated in Figure 3. The specific management actions for these areas are described in Table 6.

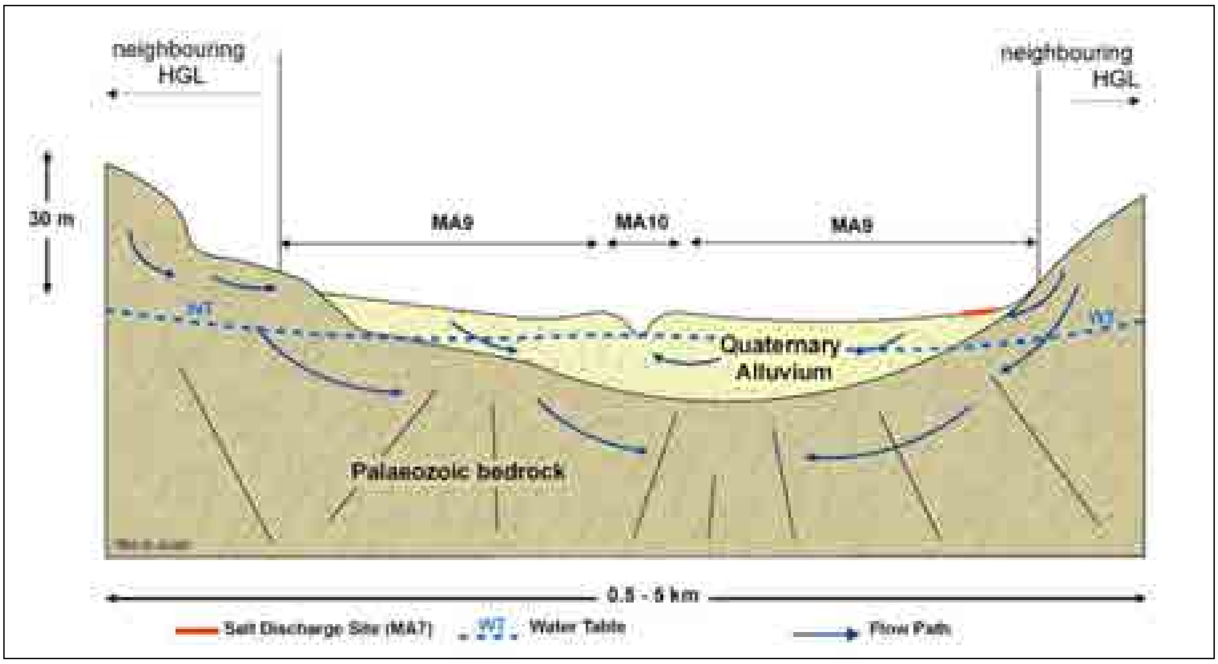


Figure 3: Management cross-section for Upper Billabong HGL showing defined management areas.

Table 6: Specific management actions for management areas within the Upper Billabong HGL.

Management Area (MA)	Action
MA9 (ALLUVIAL PLAIN)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** Maintain and improve riparian native vegetation to reduce discharge to streams **(VE4).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge (**VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).** **Irrigation Systems** Manage on-farm irrigation to achieve best practice **(IS1).**

Management Area (MA)	Action
MA7 (SALT SITE)	**Salt land rehabilitation** Fence and isolate salt land and discharge areas to promote revegetation **(SR1).** Establish and manage salt land pasture systems to improve productivity **(SR2).** Establish forestry systems on salt land to improve productivity **(SR3).** Undertake rehabilitation to ameliorate land salinity processes and reduce land degradation **(SR4).**
MA10 (ALLUVIAL CHANNEL)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** Maintain and improve riparian native vegetation to reduce discharge to streams **(VE4).**

High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative impacts on salinity (Table 7).

Table 7: Management actions having negative salinity impacts in the Upper Billabong HGL.

At Risk Management Areas	Action
MA9 (ALLUVIAL PLAIN)	Long fallows in farming systems **(DLU1).** Poor management of grazing pastures **(DLU2).** Annual cropping with annual plants **(DLU3).** Poor soil management – loss of surface soil layers **(DLU10).** Poor targeting of land suitable for irrigation **(DLU14).**
MA10 (ALLUVIAL CHANNEL)	Clearing and poor management of native vegetation **(DLU4).**
MA7 (SALT SITE)	Locating infrastructure on discharge areas **(DLU7).** Deep ripping of soils to maximise water infiltration to subsoil **(DLU11).**

REFERENCES

DECCW, 2010, *Reconnaissance soil and land resources of the Murray CMA*, NSW Department of Environment, Climate Change and Water, Sydney

Geoscience Australia, 2011, *Australian stratigraphic units database*, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int

Keith, D. A. 2004, *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, Hurstville, NSW Department of Environment and Conservation

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, OEH Sydney, [Accessed: 10 November 2014] www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

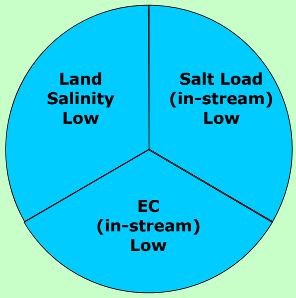
Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia

Stelling, F. 1998, *South west slopes revegetation guide (south of the Murrumbidgee River)*, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

Wooldridge, A., Nicholson, A., Muller R., Jenkins, B. R., Wilford, J. and Winkler, M. 2015, *Guidelines for managing salinity in rural areas*, NSW Office of Environment and Heritage, Sydney, NSW

4. Murray Alluvium Hydrogeological Landscape

LOCALITIES	**South Albury, Cooks Lagoon, Lesters Lagoon**
MAP SHEET	**Jerilderie 1:250 000** **Wangaratta 1:250 000**
CONFIDENCE LEVEL	**Low**



OVERVIEW

The Murray Alluvium Hydrogeological Landscape (HGL) extends along the Murray River from Lake Hume to the edge of the study area at Walbundrie (Figure 1). The HGL covers an area of 95 km^2 and receives 550 to 700 mm of rain per annum. This is a regulated river system.

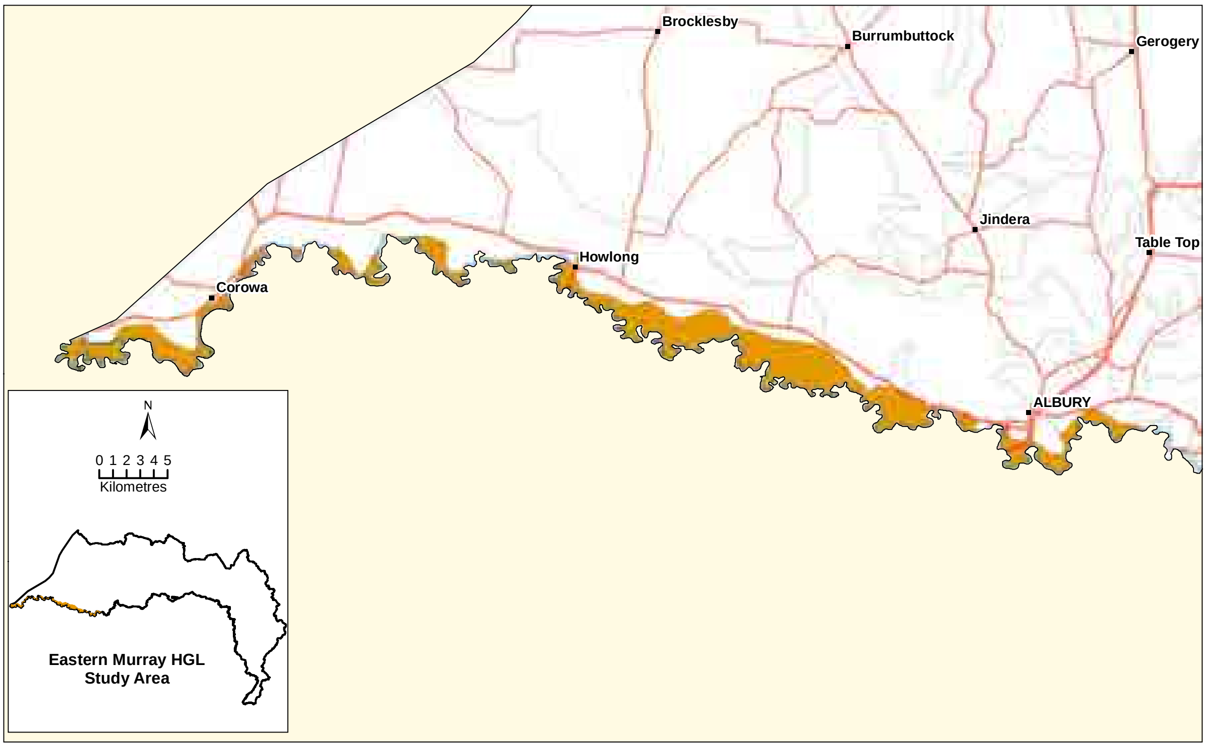


Figure 1: Murray Alluvium HGL distribution map.

The Murray Alluvium HGL is a depositional environment characterised by alluvial floodplains with flood-runners, ox-bows and levees (Figure 2). This HGL comprises unconsolidated Quaternary channel and flood plain sediments. Typically these are sands, gravels and clays. Small patches of windblown sand occur locally as sandy rises. Topsoils in logged and cleared areas are generally thinner and have less organic carbon than undisturbed areas. Stream-bank erosion and compaction due to vehicular traffic are the most common land degradation issues in this HGL.

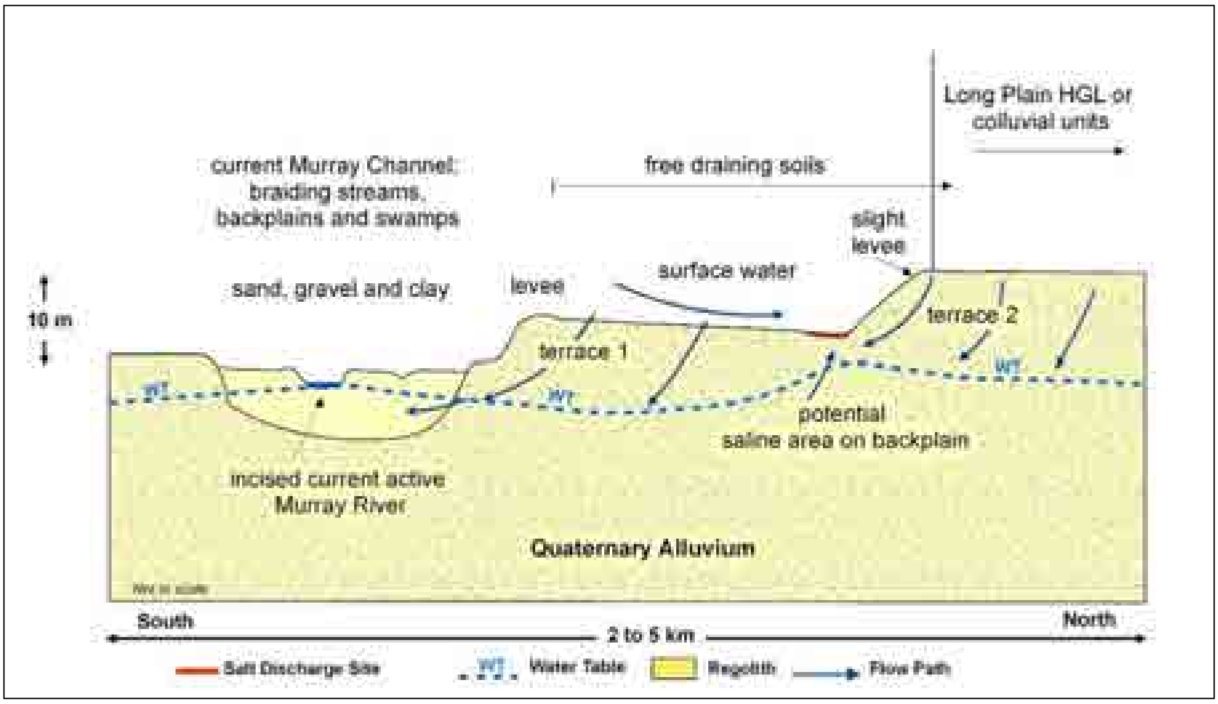


Figure 2: Conceptual cross-section for Murray Alluvium HGL showing the distribution of regolith and landforms, salt sites if present, and flow paths of water infiltrating the system.

Land salinity is occasionally observed on the back plain adjacent to the Long Plain HGL. Impacts from salt load and EC are low (Table 1).

Table 1: Murray Alluvium HGL salinity expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	Low – land salinity is occasionally observed on the back plain adjacent to the Long Plain HGL
Salt Load (Export)	Low – main Murray River flow is fresh; little local load impact
EC (Water Quality)	Low – dominated by Murray River / Lake Hume influences

Salt stored within the Murray Alluvium HGL has moderate mobility. There is a moderate salt store that has moderate availability (Table 2).

Table 2: Murray Alluvium HGL salt store and availability.

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

The overall salinity hazard in the Murray Alluvium HGL is very low. This is due to the low likelihood that salinity issues will occur that have potentially limited impacts (Table 3).

Table 3: Likelihood of salinity occurrence, potential impact and overall hazard of salinity for the Murray Alluvium HGL.

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

LANDSCAPE FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 4.

Photo 1: Distinct river terraces are a characteristic feature of the Murray Alluvium landscape at Howlong (Photo: OEH/A Nicholson).

Photo 2: The Murray Alluvium HGL has a floodplain adjacent to the Murray River (far background) that is broad in places and has small streams adjacent to terrace elements (Photo: OEH/A Nicholson).

Photo 3:The flat flood plain above an area of stream-bank erosion is common in the Murray Alluvium HGL (Photo: OEH/A Nicholson).

Photo 4:At Wirlinga, upstream of Albury, the alluvial floodplain of the Murray Alluvium HGL is broad and cleared, and is primarily used for grazing (Photo: OEH/R Muller).

Photo 5: The broad floodplain adjacent to the Murray River at Wirlinga is characteristic of the wider sections of the Murray Alluvium HGL (Photo: OEH/R Muller).

Table 4: Summary of information used to define the Murray Alluvium HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2011)*	This HGL comprises unconsolidated Quaternary channel and flood plain sediments: • alluvium – gravel, sand, silt and clay.
Annual Rainfall	550–700 mm
Regolith and Landforms	The Murray Alluvium HGL is variably weathered and is characterised by broad level alluvial plains of Quaternary sediments deposited by the Murray River system, downstream of Lake Hume. The river is inset 3–5 m below adjacent alluvial plains, and was subject to seasonal flooding prior to river regulation. Slopes are typically 0–5%, but up to 50% on banks, local relief is <10m and this HGL is between 60–160 m elevation. The HGL features stream channels and banks, flood-runners, ox-bows, levees, and floodplains. Regolith materials are unconsolidated interbedded clay, silt, sand and gravel, Quaternary to Recent riverine deposits of the Murray River. Due to the dynamic nature of alluvial deposition and reworking, the distribution of materials is highly variable and challenging to predict.

Soil Landscapes *(DECCW 2010)*	This HGL corresponds closely to Wakool River soil landscape. Small patches of the Wait-a-While soil landscape occur on areas of stagnant alluvial plain. Soils are typically: Epipedal and Crusty Grey and Black Vertosols (Cracking Grey Clays) and Eutrophic Brown Chromosols (Brown Clays) occurring along floodplains. Silty/fine sandy Grey Kandosols (Grey Earths/Alluvial Soils) occur locally along channels where pedogenesis has yet to alter materials. Small patches of windblown sand also occur locally as sandy rises, commonly overlying sodic clays at depth – sandy Brown Sodosols and Arenic Rudosols (NSG). Red and Brown Sub-plastic Chromosols and Sodosols (Red-brown Earths/transitional Red-brown Earths) are found at the upper margins of the HGL, well away from the active river course. Topsoils in logged or cleared areas are generally thinner and have less organic carbon than undisturbed areas. Salt is often associated with particular stratigraphic soil layers.
Land and Soil Capability *(OEH 2012)*	Class 3
Land Use	Cropping and grazing, with large areas wetlands and areas of urban development around Albury and towns along the Murray River
Key Land Degradation Issues	• stream-bank erosion on outside meander bends • some soil compaction due to vehicle access.
Native Vegetation *(Stelling 1998; Keith 2004)*	Vegetation within Murray Alluvium HGL is typically river red gum woodland which has characteristically developed on the riverine deposits of clay, silt, sand and gravel surrounding the Murray River, forming alluvial loams and clay soils. Tree species can include *E. camaldulensis* (river red gum) along with *E. bridgesiana* (apple box) where the soils are moderately fertile and well drained, *E. blakelyi* (Blakely's red gum), *E. bridgesiana* (apple box) and *Acacia dealbata* (silver wattle), and *Callitris glaucophylla* (white cypress pine) and *E. melliodora* (yellow box) on lighter soils. Understorey species may include *Acacia acinacea* (gold-dust wattle), *A. paradoxa* (kangaroo thorn), *Callistemon sieberi* (river bottlebrush), *Exocarpos strictus* (dwarf cherry) and *Bursaria spinosa* (sweet bursaria).

HYDROGEOLOGY

Aquifers within this landscape are unconfined with groundwater flow occurring primarily through unconsolidated alluvial sediments. Hydraulic conductivity and transmissivity are moderate to high. Groundwater recharge rates are estimated to be high.

Groundwater systems are typically local with short flow lengths, and are loosely defined by topographic catchments. Water quality within these systems is fresh to marginal. Watertable depths are shallow to intermediate. Localised perching of watertables occurs above clay lenses during wetter periods.

Short to medium residence times are typical. These landscapes have a medium to fast response time to changes in land management.

Typical values for the hydrogeological parameters of this HGL are summarised in Table 5.

Table 5: Summary of values for typical hydrogeological parameters of the Murray Alluvuim HGL.

Aquifer Type	Unconfined in unconsolidated alluvial sediments Vertical and lateral flow components Local perching above clay-rich layers (seasonal)
Hydraulic Conductivity	Moderate to high Range: 10^{-2}–>10 m/day
Aquifer Transmissivity	Moderate to high Range: 2–>100 m^2/day
Specific Yield	Moderate to high Range: 5–>15%
Hydraulic Gradient	Gentle Range: <10%
Groundwater Salinity	Fresh to marginal Range: <1600 µS/cm
Depth to Watertable	Shallow to intermediate (localised perching) Range: <8 m
Typical Sub-Catchment Size	Small (<100 ha)
Scale (Flow Length)	Local Flow length: <5 km (short)
Recharge Estimate	High
Residence Time	Short to medium (months to years)
Responsiveness to Change	Fast to medium (months to years)

MANAGEMENT OPTIONS

Overarching salinity management strategies have specific biophysical outcomes. These are achieved by implementing a series of targeted land management actions that take into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape to impact on salinity. Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Salinity is driven by interactions between water-use capacity of vegetation, physical soil properties and hydrogeological processes within the HGL.

Actions that influence the way water is used by vegetation or stored in the soil profile will have impacts on recharge. The influence of both continual and episodic recharge and the impacts of extreme weather events need to be considered when deciding on appropriate management actions. Short and long-term climate cycles also need to be considered as they have a bearing on salinity processes, particularly salt load and land salinity.

Landscape Salinity Functions – Murray Alluvium HGL

Functions this landscape provides within a catchment scale salinity context:

- **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
- **E.** The landscape receives and stores salt load through irrigation or surface flow.

Management Strategy Objectives – Murray Alluvium HGL

Appropriate overall strategies pertinent to this landscape:

- **Maintain or maximise runoff (10):** This unit conducts large water flows which are mostly influenced by large storages and the runoff from other landscapes.
- **Discharge rehabilitation and management (4):** Salt sites are not common and generally exhibit minor salinity symptoms. The sites are frequently waterlogged. Discharge management will improve on-site and off-site salinity outcomes.

Key Management Focus – Murray Alluvium HGL

Management should be closely linked to river and flow management. This HGL will not have large impacts on the salinity outcome within the Murray River. It is the transition zone for water derived from other landscapes.

Specific Land Management Opportunities

Specific opportunities for this HGL:

- There are wetland management opportunities in this HGL.

Specific Land Management Constraints

Constraints for land management in this HGL include:

- Areas with in this HGL are impacted by flow regimes and flooding.

Specific Targeted Actions

Management areas for this HGL are illustrated in Figure 3. The specific management actions for these areas are described in Table 6.

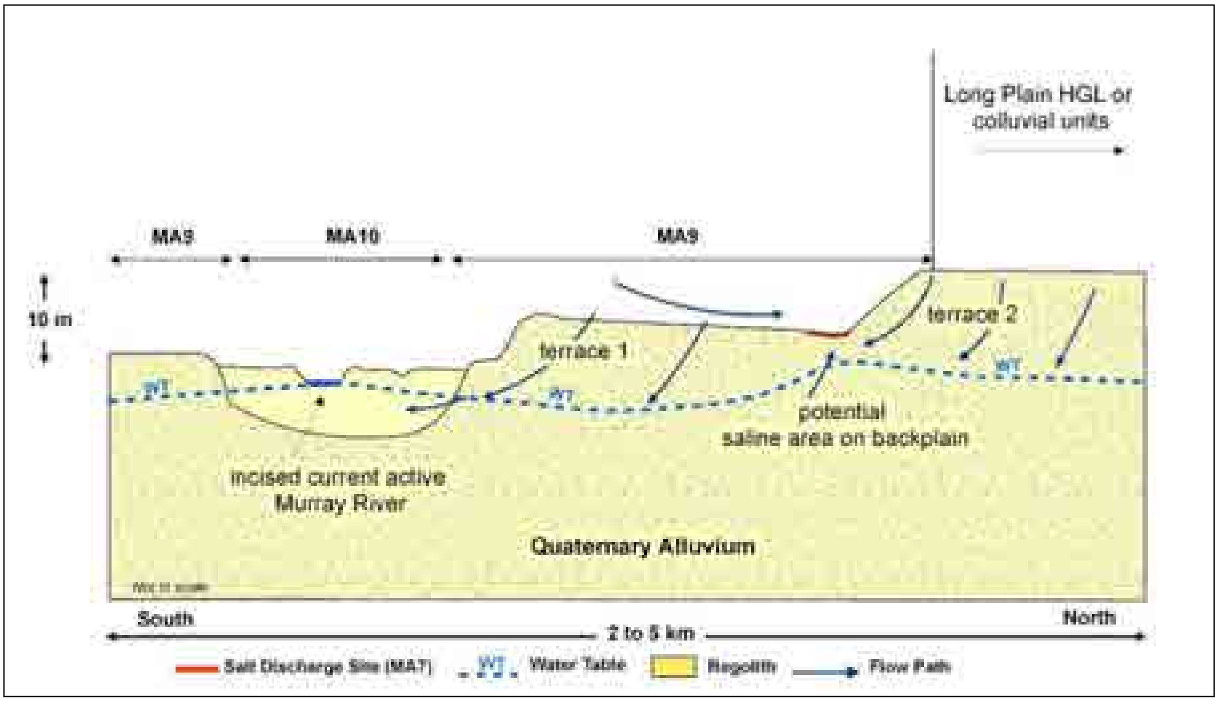


Figure 3: Management cross-section for Murray Alluvium HGL showing defined management areas.

Table 6: Specific management actions for management areas within the Murray Alluvium HGL.

Management Area (MA)	Action
MA9 (ALLUVIAL PLAIN)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** Maintain and improve riparian native vegetation to reduce discharge to streams **(VE4).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge (**VP1).**
MA10 (ALLUVIAL CHANNEL)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** Maintain and improve riparian native vegetation to reduce discharge to streams **(VE4).**

High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative impacts on salinity (Table 7).

Table 7: Management actions having negative salinity impacts in the Long Plain HGL.

At Risk Management Areas	Action
MA9/10 (ALLUVIAL PLAIN)	Locating infrastructure on discharge areas **(DLU7).** Irrigation using inefficient on-farm water delivery practices **(DLU13).**

REFERENCES

DECCW, 2010, *Reconnaissance soil and land resources of the Murray CMA*, NSW Department of Environment, Climate Change and Water, Sydney

Geoscience Australia, 2011, *Australian stratigraphic units database*, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int

Keith, D. A. 2004, *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, Hurstville, NSW Department of Environment and Conservation

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, OEH Sydney, [Accessed: 10 November 2014] www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

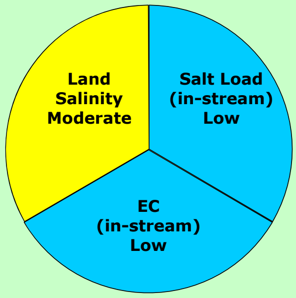
Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia

Stelling, F. 1998, *South west slopes revegetation guide (south of the Murrumbidgee River)*, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

Wooldridge, A., Nicholson, A., Muller R., Jenkins, B. R., Wilford, J. and Winkler, M. 2015, *Guidelines for managing salinity in rural areas*, NSW Office of Environment and Heritage, Sydney, NSW

5. Long Plain Hydrogeological Landscape

LOCALITIES	**Corowa, Howlong, Albury, Splitters Creek**
MAP SHEET	**Jerilderie 1:250 000** **Tallangatta 1:250 000** **Wangaratta 1:250 000**
CONFIDENCE LEVEL	**Low**



OVERVIEW

The Long Plain Hydrogeological Landscape (HGL) is present in several areas along the Murray River between Lake Hume in the east to Corowa at the western edge of the study area (Figure 1). The HGL covers an area of 319 km^2 and receives 550 to 700 mm of rain per annum.

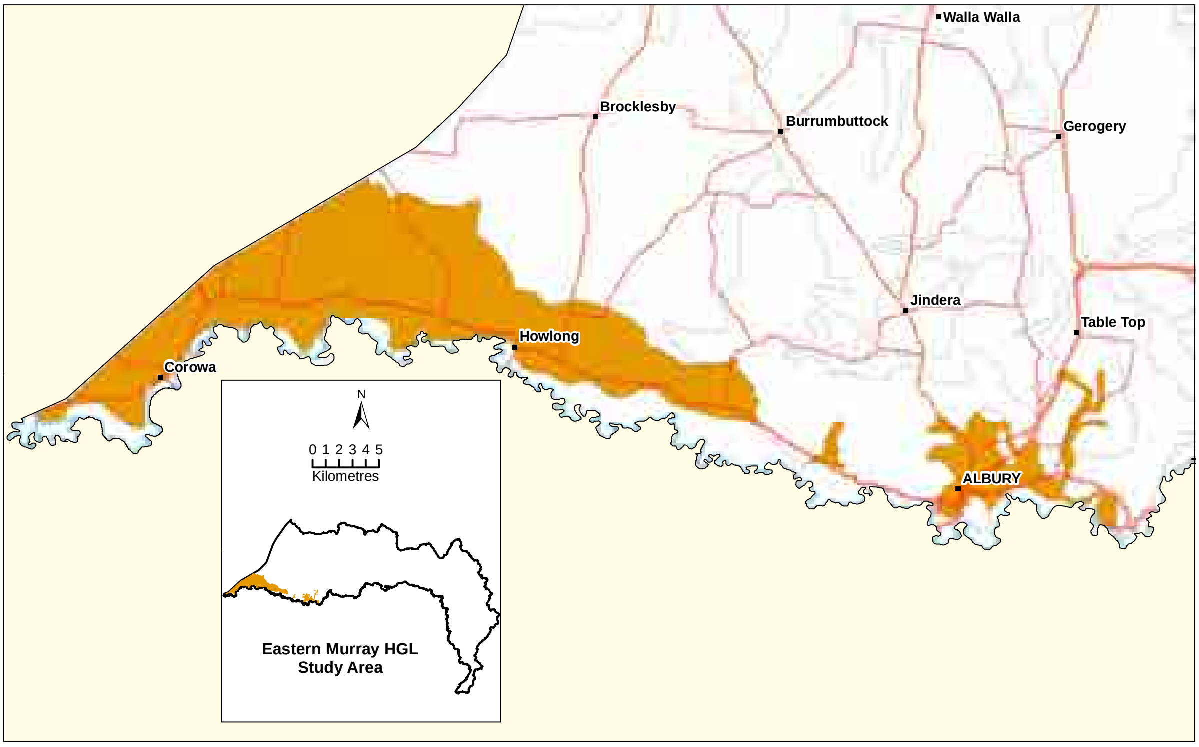


Figure 1: Long Plain HGL distribution map.

The Long Plain HGL is a depositional environment with broad level plains and back-plains on alluvium (Figure 2). It is characterised by sparse narrow linear drainage lines. Gilgai occur locally. This HGL comprises unconsolidated Cenozoic fluvial and lacustrine sediments including clays, silts and sands from various past flow regimes of the Murray River and associated palaeochannels. Wind erosion is common at exposed sites, and waterlogging is common in low depressions.

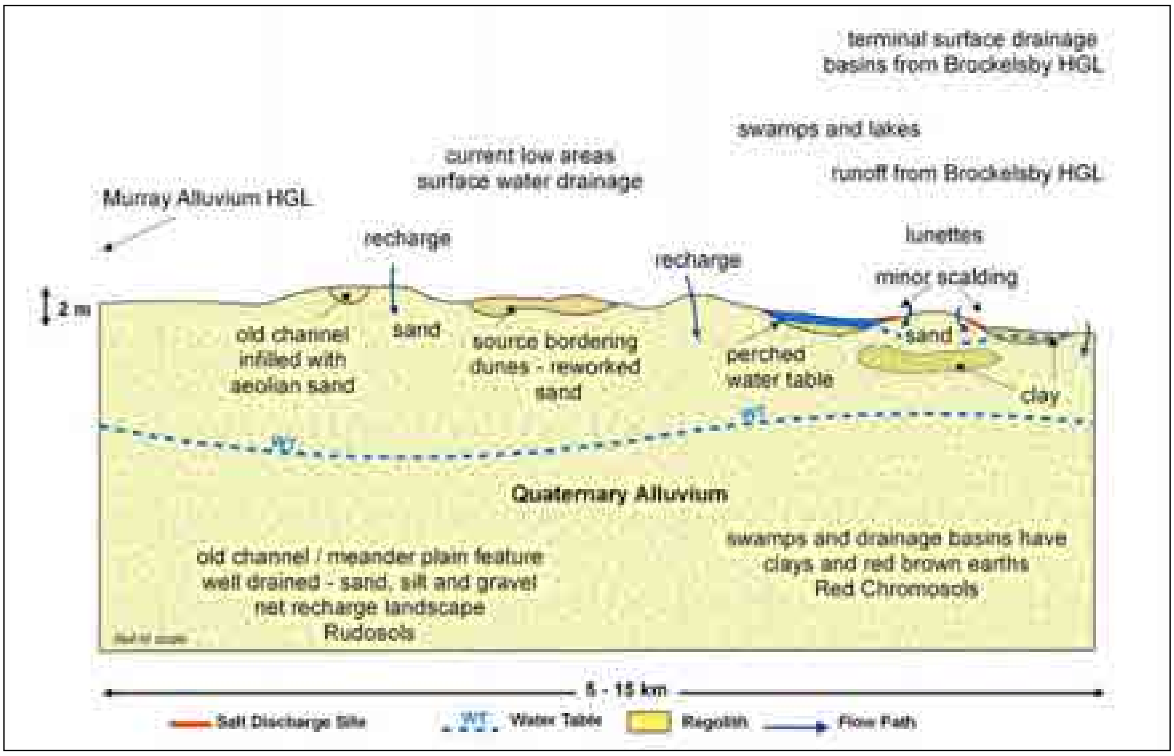


Figure 2: Conceptual cross-section for Long Plain HGL showing the distribution of regolith and landforms, salt sites if present, and flow paths of water infiltrating the system.

Moderate land salinity outbreaks occur adjacent to lunettes, swamps and lakes, and are associated with heavier soils leading to localised perching. Expressions of salt load and EC are low (Table 1).

Table 1: Long Plain HGL salinity expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	Moderate – salinity outbreaks occur adjacent to lunettes, swamps and lakes, and are associated with heavier soils leading to localised perching
Salt Load (Export)	Low – flows from this HGL result in low export
EC (Water Quality)	Low – poor connection between surface water and groundwater. Surface flow is intermittent

Salt stored within the Long Plain HGL has moderate mobility. There is a high salt store that has low availability (Table 2).

Table 2: Long Plain HGL salt store and availability.

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

The overall salinity hazard in the Long Plain HGL is low. This is due to the low likelihood that salinity issues will occur that have potentially significant impacts (Table 3).

Table 3: Likelihood of salinity occurrence, potential impact and overall hazard of salinity for the Long Plain HGL.

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

LANDSCAPE FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 4.

Photo 1: A small pocket of the old alluvial surface that constitutes the Long Plain HGL occurs at Splitters Creek, west of Albury (Photo: OEH/R Muller).

Photo 2: At Splitters Creek, the old alluvial surface of the Long Plain HGL grades into the hills of the surrounding Nail Can-Bungowannah HGL (Photo: OEH/R Muller).

Photo 3: Terracing in flow lines is evident in the Long Plain HGL at Splitters Creek (Photo: OEH/R Muller).

Photo 4: West of Albury (and the Nail Can-Bungowannah HGL), a prominent terrace delineates the Murray Alluvium HGL at the base of the terrace from the Long Plain HGL at the top of the terrace (Photo: OEH/R Muller).

Photo 5: Low depressions in the Long Plain HGL are prone to waterlogging during wet periods (Photo: OEH/R Muller).

Photo 6: Gum Swamp is a prominent feature of the Long Plain HGL. Swampy areas are common in this HGL due to its low lying nature (Photo: OEH/R Muller).

Photo 7: West of Howlong, the terrace delineating to older Long Plain HGL alluvial surface from the present floodplain of the Murray Alluvium HGL is steep and high (Photo: OEH/R Muller).

Table 4: Summary of information used to define the Long Plain HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2011)*	This HGL comprises unconsolidated Cenozoic fluvial and lacustrine sediments. Key lithologies include: • lake and swamp deposits – mud, silt, minor sand and travertine • colluvium and/or residual deposits – boulders, gravel and sand; may include minor alluvial or sand plain deposits • Shepparton Formation – unconsolidated to poorly consolidated mottled variegated clay, silty clay with lenses of polymictic, coarse to fine sand and gravel; partly modified by pedogenesis.
Annual Rainfall	550–700 mm
Regolith and Landforms	The Long Plain HGL is variably weathered and is characterised by extensive level alluvial plains, primary and reworked riverine deposits of the Shepparton Formation and Quaternary alluvium. Slopes are typically <3%, with local relief <9 m, and this HGL is between 60–180 m elevation. The HGL includes widely spaced narrow linear drainage lines. There are locally preserved ancient channel deposits (paleochannels), and wind-blown fine sand deposits forming sandy rises. Gilgai are present on the alluvial plains in localised areas. Regolith materials are unconsolidated interbedded clay, silt, sand and gravel, riverine deposits of the Shepparton Formation and Quaternary alluvium.

Soil Landscapes *(DECCW 2010)*	This HGL overlaps mostly with the Wait-a-While soil landscape and to a lesser extent, the Kindra soil landscape. Minor occurrences of Ettamogah, Livingstone and Wakool River soil landscapes. Coleambally soil landscape occupies areas of aeolian sands. Soils are typically: Haplic and Sodic Hypercalcic Red Chromosols (Red-brown Earths), and Haplic Eutrophic and Duric Red Dermosols (Brown Podzolic Soils and Non-calcic Brown Soils) on colluvial plain, at the upper margins of the HGL; Epipedal and Crusty Grey and Black Vertosols (Cracking Grey Clays) and Eutrophic Brown Chromosols (Brown Clays) along floodplains; silty/fine sandy Grey Kandosols (Grey Earths/Alluvial Soils) along channels where pedogenesis has yet to alter materials; and, Arenic Rudosols (Siliceous Sands) on higher sandy ridges. Wind erosion is common at exposed sites. Waterlogging is common on low unchannellised sites. Salt is often associated with particular stratigraphic soil layers.
Land and Soil Capability *(OEH 2012)*	Class 4
Land Use	Cropping (continuous or rotation) and grazing on improved pastures; dryland and irrigated farming; some horticulture. Urban and peri-urban land use is significant
Key Land Degradation Issues	• structural decline (topsoil) • wind erosion • poor drainage in low lying areas • salinity (localised) • scalding where topsoil loss exposes sodic subsoils.
Native Vegetation *(Stelling 1998; Keith 2004)*	Vegetation within Long Plain HGL tends to be grey box woodland which has developed on the riverine deposits of clay, silt, sand and gravel along the extensive plain. Tree species can include *E. microcarpa* (grey box) on heavier soils, *E. albens* (white box), *E. blakelyi* (Blakely's red gum), *Allocasuarina luehmannii* (bulloak) and *Callitris glaucophylla* with (white cypress pine) and *E. melliodora* (yellow box) on lighter soils. Understorey species may include *Acacia acinacea* (gold-dust wattle), *A. paradoxa* (kangaroo thorn), *A. pycnantha* (golden wattle), *A. montana* (mallee wattle) and *Bursaria spinosa* (sweet bursaria).

HYDROGEOLOGY

Aquifers within this landscape are unconfined to semi-confined with groundwater flow occurring primarily through unconsolidated alluvial sediments. Hydraulic conductivity and transmissivity are moderate. Groundwater recharge rates are estimated to be moderate to high.

Groundwater systems are typically local to intermediate with short to intermediate flow lengths, and are loosely defined by topographic catchments. Water quality within these systems is fresh to marginal. Watertable depths are shallow to intermediate. Localised perching of watertables occurs above clay lenses during wetter periods.

Medium residence times are typical. These landscapes have a medium response time to changes in land management.

Typical values for the hydrogeological parameters of this HGL are summarised in Table 5.

Table 5: Summary of values for typical hydrogeological parameters of the Long Plain HGL.

Aquifer Type	Unconfined to semi-confined in unconsolidated alluvial sediments Vertical and lateral flow components Local perching above clay-rich layers (seasonal)
Hydraulic Conductivity	Moderate Range: 10^{-2}–10 m/day
Aquifer Transmissivity	Moderate Range: 2–100 m^2/day
Specific Yield	Low to moderate Range: <15%
Hydraulic Gradient	Gentle Range: <10%
Groundwater Salinity	Fresh to marginal Range: <1600 µS/cm
Depth to Watertable	Shallow to intermediate (localised perching) Range: <8 m
Typical Sub-Catchment Size	Small to medium (<1000 ha)
Scale (Flow Length)	Local to intermediate Flow length: <25 km (short to intermediate)
Recharge Estimate	Moderate to high
Residence Time	Medium (years)
Responsiveness to Change	Medium (years)

MANAGEMENT OPTIONS

Overarching salinity management strategies have specific biophysical outcomes. These are achieved by implementing a series of targeted land management actions that take into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape to impact on salinity. Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Salinity is driven by interactions between water-use capacity of vegetation, physical soil properties and hydrogeological processes within the HGL.

Actions that influence the way water is used by vegetation or stored in the soil profile will have impacts on recharge. The influence of both continual and episodic recharge and the impacts of extreme weather events need to be considered when deciding on appropriate management actions. Short and long-term climate cycles also need to be considered as they have a bearing on salinity processes, particularly salt load and land salinity.

Landscape Salinity Functions – Long Plain HGL

Functions this landscape provides within a catchment scale salinity context:

- **G.** The landscape contains important land assets (including infrastructure and high value agricultural land) on which salinity processes impact.
- **E.** The landscape receives and stores salt load through irrigation or surface flow.

Management Strategy Objectives – Long Plain HGL

Appropriate strategies pertinent to this landscape:

- **Dry out the landscape with diffuse actions over most of the landscape (6):** Encourage plant growth and increase plant water use in order to use excess soil moisture and shallow groundwater. Healthy, actively growing vegetation will also act as a buffer to groundwater accessions in wet seasonal conditions. This is important in both dryland and irrigated areas.
- **Buffer the salt store – keep it dry and immobile (1):** Saline soils can be located and targeted for actions during dry times which can buffer salinity during wet times.
- **Discharge rehabilitation and management (4):** Saline areas occur in specific sections of this HGL. Management of waterlogging and salt land will be specific for these areas.

Key Management Focus – Long Plain HGL

Managing surface water, waterlogging and salinity should focus on how components of the landscape influence salinity processes. The management should include perennial pastures within the mixed farming landscape.

Management of irrigation practises can have a direct impact on salinity situation. Irrigation planning and management is an important management focus. Irrigation is significant within this landscape. Irrigation has the potential to increase salinity occurrence by increasing recharge. Irrigation can potentially mitigate salinity processes by reducing the upward pressure of groundwater, and results in salt loads from streams and groundwater being redistributed into soils in irrigated areas.

Specific Land Management Opportunities

- Salt land areas are small and easy to target.
- High watertables sometimes occur in specific areas. This offers the potential for pasture/grazing systems based on pastures which have salt and waterlogging tolerance.

Specific Land Management Constraints

Constraints for land management in this HGL include:

- Waterlogging and access can be an issue.
- Cycles of wetting and drying occur which can be in decadal cycles.

Specific Targeted Actions

Management areas for this HGL are illustrated in Figure 3. The specific management actions for these areas are described in Table 6.

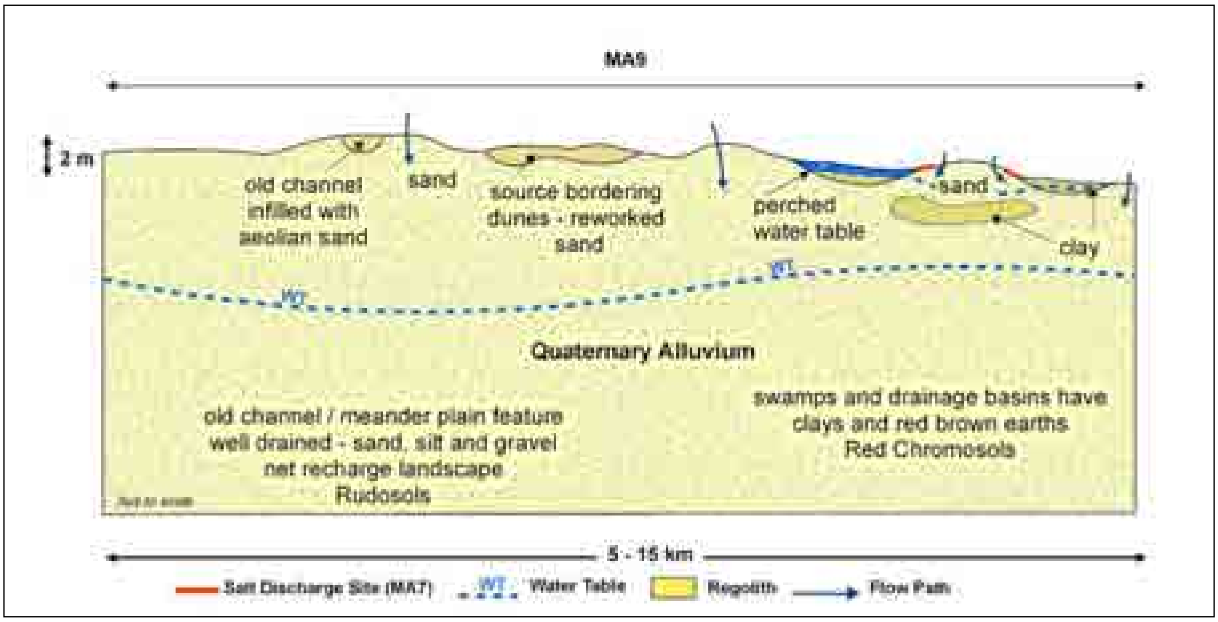


Figure 3: Management cross-section for Long Plain HGL showing defined management areas.

Table 6: Specific management actions for management areas within the Long Plain HGL.

Management Area (MA)	Action
MA9 (ALLUVIAL PLAIN)	**Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge (**VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** **Irrigation Systems** Manage on-farm irrigation to achieve best practice **(IS1).**
MA7 (CLAY SCALD)	**Salt land rehabilitation** Fence and isolate salt land and discharge areas for saline site rehabilitation **(SR1).** Rehabilitation of salt land to minimise onsite and offsite degradation **(SR4).**
MA9 (LUNETTE)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** Establish and manage trees that are integrated into farming logistics to reduce recharge **(VE5).**
MA9 (SWAMPS)	**Vegetation for ecosystem function** Maintain and improve riparian native vegetation to reduce discharge to streams **(VE4).** **Vegetation for production** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**
MA9 (OLD CHANNELS)	**Irrigation Systems** Manage on-farm irrigation to achieve best practice **(IS1).**

High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative impacts on salinity (Table 7).

Table 7: Management actions having negative salinity impacts in the Long Plain HGL.

At Risk Management Areas	Action
MA9 (ALLUVIAL PLAIN)	Long fallows in farming systems **(DLU1).** Loading of soils with salt through irrigation and flow management **(DLU15).**
MA7 (CLAY SCALD)	Poor management of grazing pastures **(DLU2).**
MA9 (LUNETTE)	Clearing and poor management of native vegetation **(DLU4).**
MA9 (SWAMPS)	Poor management of grazing pastures **(DLU2).**

REFERENCES

DECCW, 2010, *Reconnaissance soil and land resources of the Murray CMA*, NSW Department of Environment, Climate Change and Water, Sydney

Geoscience Australia, 2011, *Australian stratigraphic units database*, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int>

Keith, D. A. 2004, *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, Hurstville, NSW Department of Environment and Conservation

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, OEH Sydney, [Accessed: 10 November 2014] www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

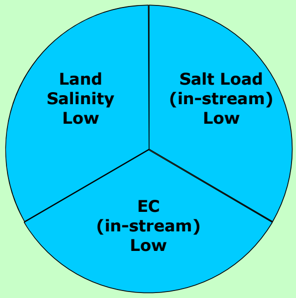
Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia

Stelling, F. 1998, *South west slopes revegetation guide (south of the Murrumbidgee River)*, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

Wooldridge, A., Nicholson, A., Muller R., Jenkins, B. R., Wilford, J. and Winkler, M. 2015, *Guidelines for managing salinity in rural areas*, NSW Office of Environment and Heritage, Sydney, NSW

6. Swampy Plains Hydrogeological Landscape

LOCALITIES	Greg Greg, Jingellic, Khancoban Dam, Bringenbrong
MAP SHEET	Tallangatta 1:250 000 Wagga Wagga 1:250 000
CONFIDENCE LEVEL	Low



OVERVIEW

The Swampy Plains Hydrogeological Landscape (HGL) extends from upstream of Lake Hume to Khancoban (Figure 1). The HGL covers an area of 118 km^2 and receives 800 to 1000 mm of rain per annum.

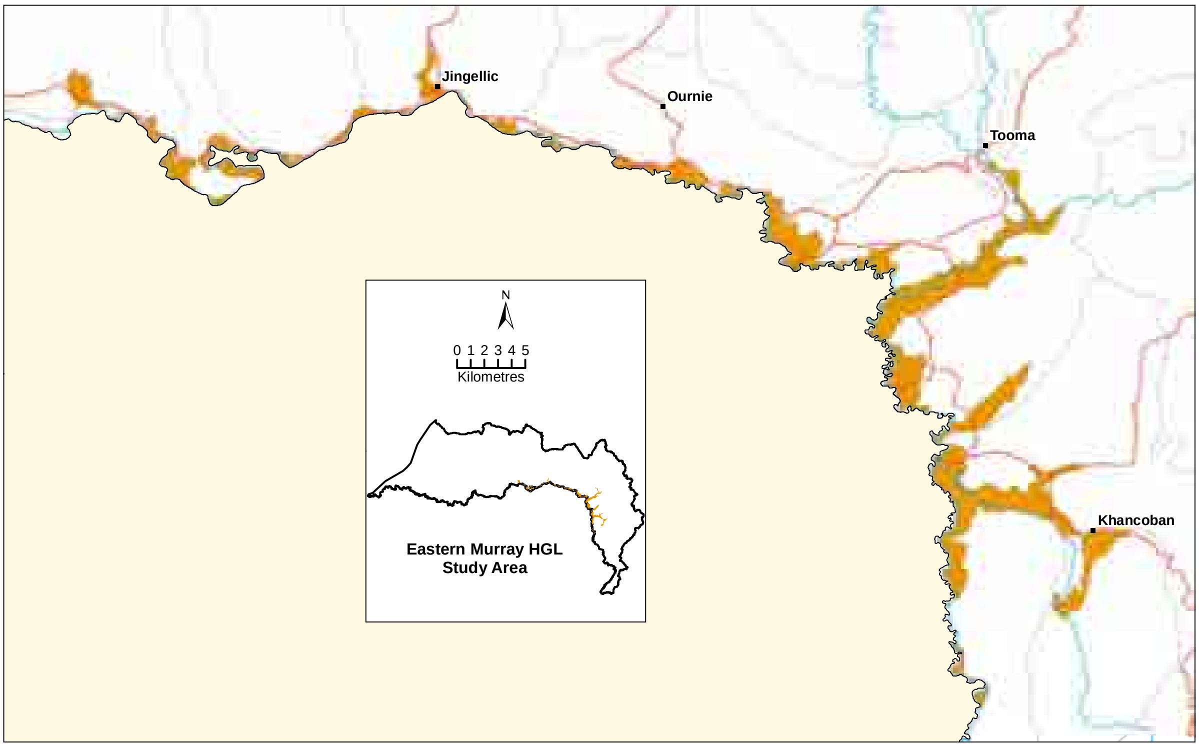


Figure 1: Swampy Plains HGL distribution map.

The Swampy Plains HGL is a depositional environment characterised by extensive alluvial plains. Landform patterns are diverse, including broad floodplains, oxbows and large terraces (Figure 2). This HGL comprises unconsolidated Quaternary channel and flood plain sediments. Typically these are sands, gravels and clays. Layered gravely flood deposits are common in the channels of tributaries. Gully erosion on narrow valley in-fills and waterlogging are the most common land degradation issues in this HGL.

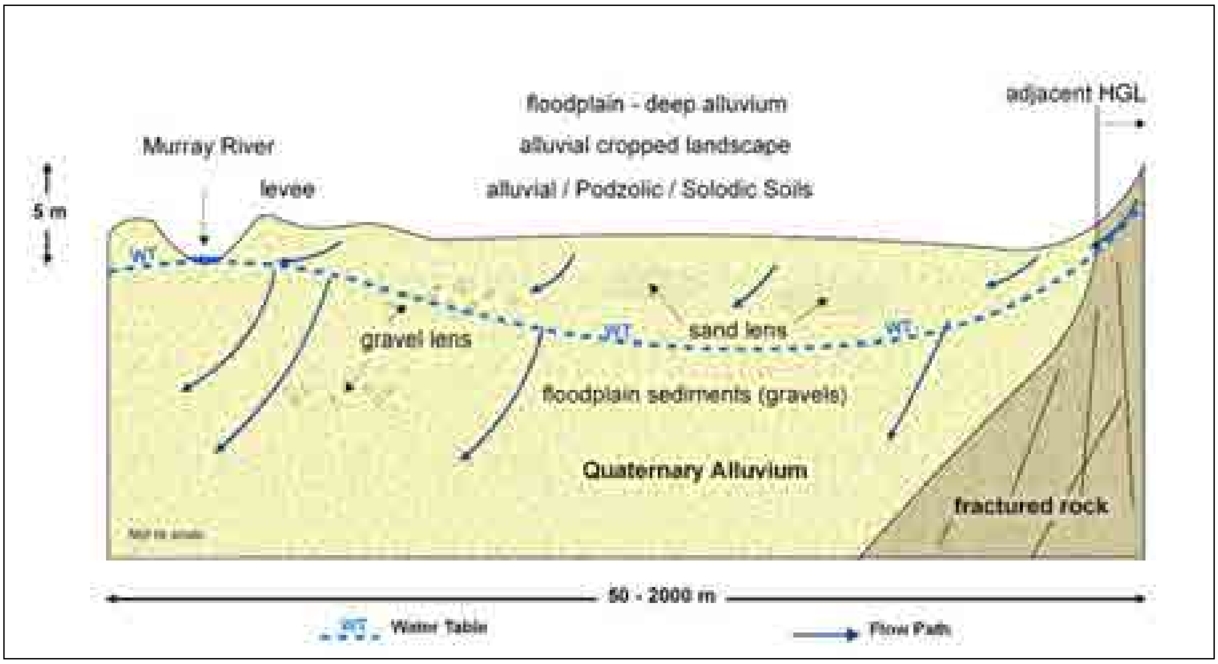


Figure 2: Conceptual cross-section for Swampy Plain HGL showing the distribution of regolith and landforms, salt sites if present, and flow paths of water infiltrating the system.

Land salinity is not seen in this landscape; however it is prone to waterlogging during wetter climatic periods. Salt load and EC are also low for this HGL (Table 1).

Table 1: Swampy Plains HGL salinity expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	Low – no salt observed, but this landscape is prone to waterlogging during wetter climatic periods
Salt Load (Export)	Low export – close proximity to Murray River and high rainfall environment
EC (Water Quality)	Water EC is low. High rainfall influences water quality

Salt stored within the Swampy Plains HGL has low mobility. There is a low salt store that has moderate availability (Table 2).

Table 2: Swampy Plains HGL salt store and availability.

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

The overall salinity hazard in the Swampy Plains HGL is very low. This is due to the low likelihood that salinity issues will occur that have potentially limited impacts (Table 3).

Table 3: Likelihood of salinity occurrence, potential impact and overall hazard of salinity for the Swampy Plains HGL.

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

LANDSCAPE FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 4.

Photo 1: In the upper Murray, oxbows and old channels are common features of the Swampy Plains HGL, and are subject to inundation from the Murray River. These are evident east of Jingellic (Photo: OEH/R Muller).

Photo 2:East of Jingellic, the broad alluvial floodplain is mostly used for grazing, with minor irrigation of pastures (Photo: OEH/R Muller).

Photo 3: East of Jingellic, the broad floodplain contains oxbows and terraces, and is primarily a grazing landscape (Photo: OEH/R Muller).

Photo 4: The waterlogging seen in flatter elements of the landscape between Bringenbrong and Khancoban is a common feature of the Swampy Plains HGL (Photo: OEH/R Muller).

Photo 5: Near Dora Dora, the Murray River meanders across a broad alluvial flood plain surrounded by steeper slopes of adjacent HGLs (Photo: OEH/A Nicholson).

Photo 6:Typical Swampy Plains landscape indicating highly fertile agricultural land with minor waterlogging (Photo: OEH/A Nicholson).

Table 4: Summary of information used to define the Swampy Plains HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2011)*	This HGL comprises unconsolidated Quaternary channel and flood plain sediments: • alluvium – gravel, sand, silt and clay.
Annual Rainfall	800–1000 mm
Regolith and Landforms	The Swampy Plains HGL is variably weathered and is characterised by broad alluvial plains of Quaternary alluvium of the Murray River and its major tributaries, in the east of the catchment. Slopes are typically <3%, local relief is <10 m, and this HGL is between 200–240 m elevation. The HGL features broad floodplains, oxbows and large terraces. Regolith materials are unconsolidated interbedded clay, silt, sand and gravel, riverine deposits of Quaternary alluvium.
Soil Landscapes *(DECCW 2010)*	This HGL is dominated by Jingellic soil landscape. There is minor Galah Flat soil landscape along some upper Murray River tributaries. Soils include: Brown and Grey Dermosols (Brown Podzolic Soils) on the Murray River floodplain; Red and Brown Sodosols (Solodic Soils) on older terraces; Stratic Rudosols (Alluvial Soils) with layered gravely flood deposits are common in channels of tributaries; and, Stratic Rudosols and Hydrosols (Alluvial Soils) with dark brown clay loamy topsoils occur on floodplains of tributary streams.
Land and Soil Capability *(OEH 2012)*	Class 5
Land Use	Grazing on volunteer, naturalised, native or improved pastures; minor areas of irrigated cropping
Key Land Degradation Issues	• gully erosion on narrow valley in-fills • waterlogging.
Native Vegetation *(Stelling 1998; Keith 2004)*	Vegetation within Swampy Plains HGL is typically river red gum woodland. Tree species include *Eucalyptus bridgesiana* (apple box), *Acacia dealbata* (silver wattle) and *A. melanoxylon* (blackwood) along with *E. camaldulensis* (river red gum). Understorey species are typically *Bursaria lasiophylla* (hairy bursaria), *Callistemon sieberi* (river bottlebrush) and *Hymenanthera dentata* (tree violet).

HYDROGEOLOGY

Aquifers within this landscape are unconfined with groundwater flow occurring primarily through unconsolidated alluvial sediments. Hydraulic conductivity and transmissivity are moderate to high. Groundwater recharge rates are estimated to be high.

Groundwater systems are typically local with short flow lengths, and are loosely defined by topographic catchments. Water quality within these systems is fresh. Watertable depths are intermediate to deep. Localised perching of watertables occurs above clay lenses during wetter periods.

Short to medium residence times are typical. These landscapes have a medium to fast response time to changes in land management.

Typical values for the hydrogeological parameters of this HGL are summarised in Table 5.

Table 5: Summary of values for typical hydrogeological parameters of the Swampy Plains HGL.

Aquifer Type	Unconfined in unconsolidated alluvial sediments Vertical and lateral flow components Local perching above clay-rich layers (seasonal)
Hydraulic Conductivity	Moderate to high Range: 10^{-2}–>10 m/day
Aquifer Transmissivity	Moderate to high Range: 2–>100 m^2/day
Specific Yield	Moderate to high Range: 5–>15%
Hydraulic Gradient	Gentle Range: <10%
Groundwater Salinity	Fresh Range: <800 µS/cm
Depth to Watertable	intermediate to deep (localised perching) Range: >2 m
Typical Sub-Catchment Size	Small (<100 ha)
Scale (Flow Length)	Local Flow length: <5 km (short)
Recharge Estimate	High
Residence Time	Short to medium (months to years)
Responsiveness to Change	Fast to medium (months to years)

MANAGEMENT OPTIONS

Overarching salinity management strategies have specific biophysical outcomes. These are achieved by implementing a series of targeted land management actions that take into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape to impact on salinity. Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Salinity is driven by interactions between water-use capacity of vegetation, physical soil properties and hydrogeological processes within the HGL.

Actions that influence the way water is used by vegetation or stored in the soil profile will have impacts on recharge. The influence of both continual and episodic recharge and the impacts of extreme weather events need to be considered when deciding on appropriate management actions. Short and long-term climate cycles also need to be considered as they have a bearing on salinity processes, particularly salt load and land salinity.

Landscape Salinity Functions – Swampy Plains HGL

Functions this landscape provides within a catchment scale salinity context:

- **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.

Management Strategy Objectives – Swampy Plains HGL

Appropriate strategies pertinent to this landscape:

- **Maintain or maximise runoff (10):** This unit conducts large water flows which are mostly influenced by large storages, flow regime management and the runoff from other landscapes.

Key Management Focus – Swampy Plains HGL

Grazing management is the key focus for this unit. This includes management of pasture systems based on perennial plants in both well-drained and poorly-drained parts of the landscape. Grazing infrastructure and management should consider waterlogged areas as sensitive.

Parts of this HGL are irrigated. The location and type of irrigation system should be taken into account for areas of variable drainage.

Specific Land Management Opportunities

Specific opportunities for this HGL:

- Waterlogged and seasonally wet areas exist in parts of this HGL. These areas offer potential for pasture/grazing systems based on pastures which have waterlogging tolerance.

Specific Land Management Constraints

Constraints for land management in this HGL include:

- Seasonal waterlogging occurs during low growth periods of the year.

Specific Targeted Actions

Management areas for this HGL are illustrated in Figure 3. The specific management actions for these areas are described in Table 6.

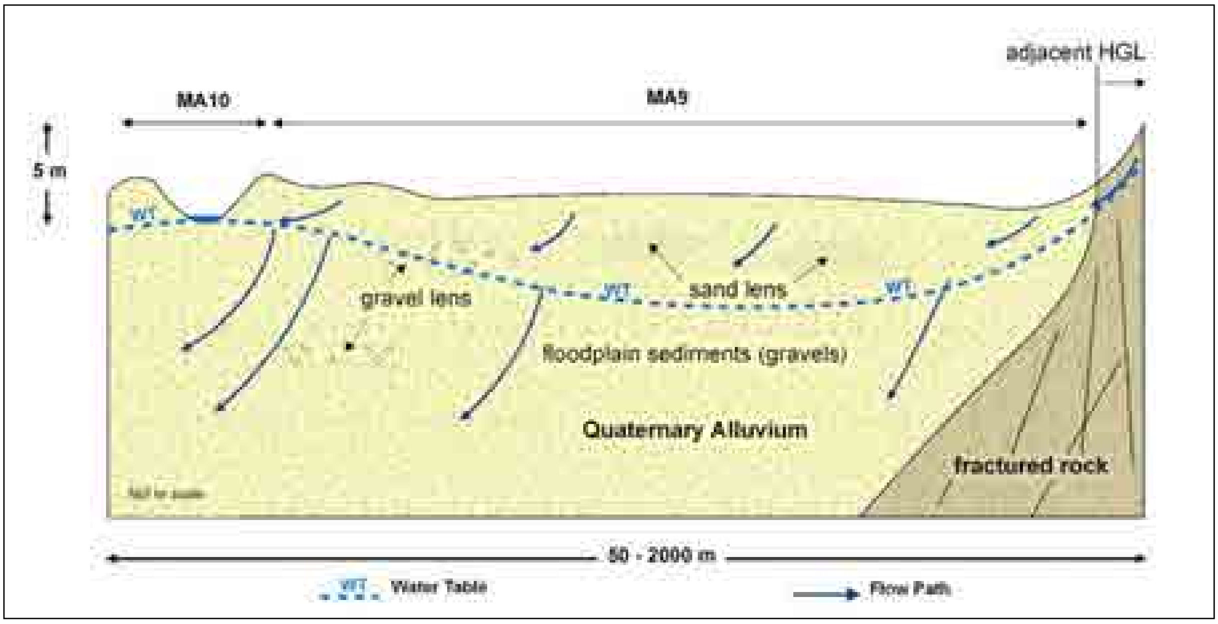


Figure 3: Management cross-section for Swampy Plains HGL showing defined management areas.

Table 6: Specific management actions for management areas within the Swampy Plains HGL.

Management Area (MA)	Action
MA9 (ALLUVIAL PLAIN)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** Maintain and improve riparian native vegetation to reduce discharge to streams **(VE4).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** **Irrigation systems** Manage on-farm irrigation to achieve best practice **(IS1).**
MA10 (ALLUVIAL CHANNEL)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** Maintain and improve riparian native vegetation to reduce discharge to streams **(VE4).**

High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative impacts on salinity (Table 7).

Table 7: Management actions having negative salinity impacts in the Swampy Plains HGL.

At Risk Management Areas	Action
MA9 (ALLUVIAL PLAIN)	Locating infrastructure on discharge areas **(DLU7).** Poor soil management – tillage causing poor structure **(DLU8).** Poor targeting of land suitable for irrigation **(DLU14).**
MA10 (ALLUVIAL CHANNEL)	Clearing native vegetation **(DLU4).**

REFERENCES

DECCW, 2010, *Reconnaissance soil and land resources of the Murray CMA*, NSW Department of Environment, Climate Change and Water, Sydney

Geoscience Australia, 2011, *Australian stratigraphic units database*, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int

Keith, D. A. 2004, *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, Hurstville, NSW Department of Environment and Conservation

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, OEH Sydney, [Accessed: 10 November 2014] www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

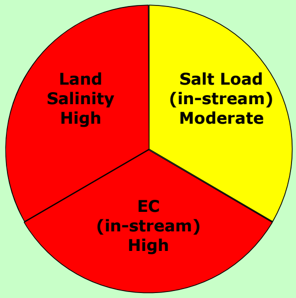
Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia

Stelling, F. 1998, *South west slopes revegetation guide (south of the Murrumbidgee River)*, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

Wooldridge, A., Nicholson, A., Muller R., Jenkins, B. R., Wilford, J. and Winkler, M. 2015, *Guidelines for managing salinity in rural areas*, NSW Office of Environment and Heritage, Sydney, NSW

7. Simmons Creek Hydrogeological Landscape

LOCALITIES	**Alma Park, The Big Swamp**
MAP SHEET	**Jerilderie 1:250 000**
CONFIDENCE LEVEL	**High**



OVERVIEW

The Simmons Creek Hydrogeological Landscape (HGL) is north-west of Walbundrie in the Alma Park area (Figure 1). The HGL covers an area of 136 km^2 and has a mean annual rainfall of 550 to 600 mm.

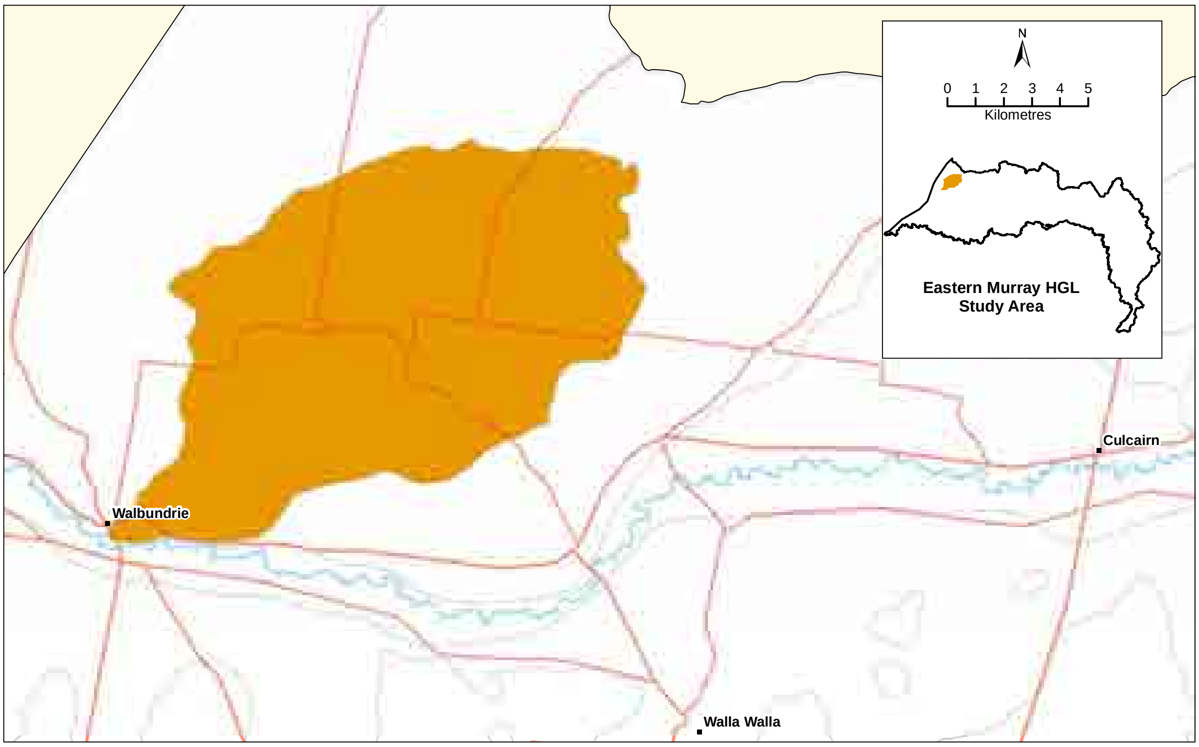


Figure 1: Simmons Creek HGL distribution map.

The Simmons Creek HGL environment has both depositional and erosional elements. It is characterised by gently undulating broad plains of thick alluvial and windblown clays with gently inclined foot-slopes and fans on principally granite-derived colluvium (Figure 2). Drainage lines are widely spaced and shallow. This HGL comprises Ordovician metasediments intruded by Siluro-Devonian granitic rocks. These are overlain by unconsolidated Quaternary colluvium, alluvium and rare lacustrine (lake) deposits. Soils are very deep and imperfectly to moderately well-drained on upper and mid-slopes, deep and imperfectly drained on lower slopes, and very deep and well-drained on fans. Severe branching gully erosion occurs in valley depressions (associated with sodic soils).

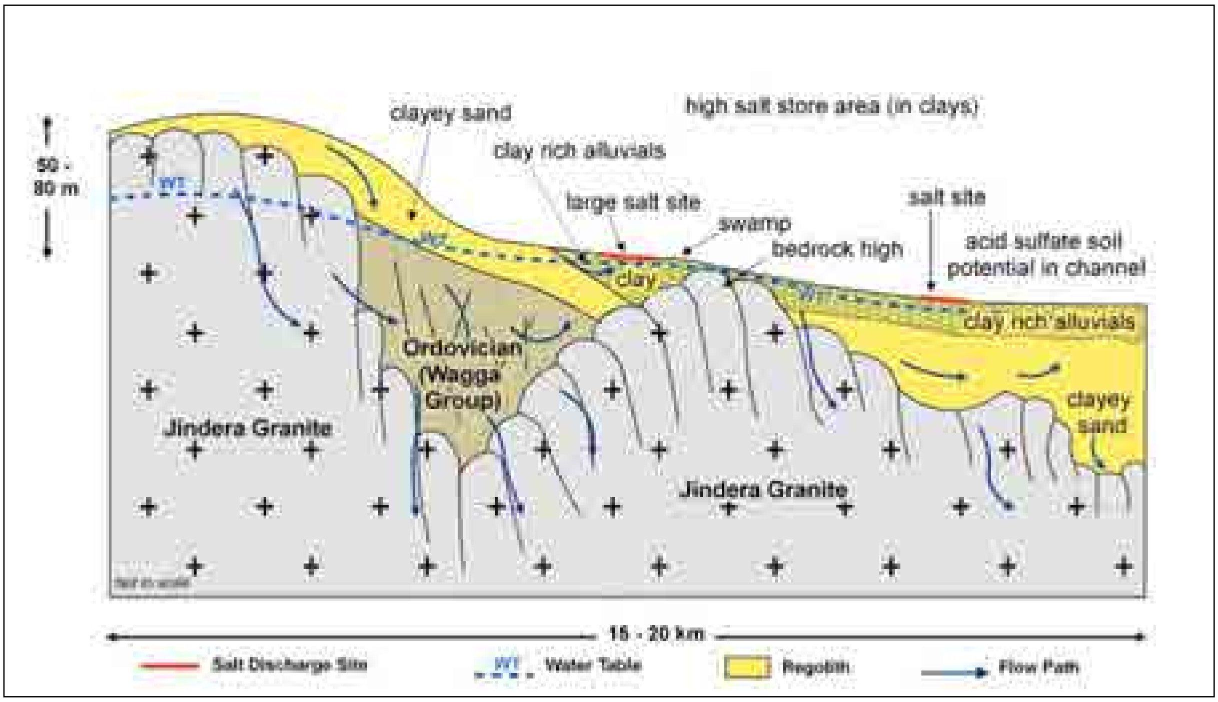


Figure 2: Conceptual cross-section for Simmons Creek HGL showing the distribution of regolith and landforms, salt sites if present, and flow paths of water infiltrating the system *(diagram modified from English et al. 2002)*.

The Simmons Creek sub-catchment has been identified as a significant contributor of salinity the Billabong Creek (English *et al*. 2002; DAFF 2012). Salt is related to subsurface constrictions across the catchment and a high level of salt storage in lower areas. Salt load impacts are moderate and EC is high (Table 1). There are significant occurrences of acid sulfate soils in the lower landscape elements.

Table 1: Simmons Creek HGL salinity expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	High – salt is related to subsurface constrictions across the catchment and high levels of salt storage in lower areas. There are significant acid sulfate soils in the lower landscape
Salt Load (Export)	Moderate – Simmons Creek typically has low flows
EC (Water Quality)	High – stream EC is very high and often acidic

Salt stored within the Simmons Creek HGL has high mobility. There is a high salt store that has moderate availability (Table 2).

Table 2: Simmons Creek HGL salt store and availability.

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

The overall salinity hazard in the Simmons Creek HGL is high. This is due to the high likelihood that salinity issues will occur that have potentially significant impacts (Table 3).

Table 3: Likelihood of salinity occurrence, potential impact and overall hazard of salinity for the Simmons Creek HGL.

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

LANDSCAPE FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 4.

Photo 1: Low gradient slopes and clay-rich soils make the Simmons Creek HGL prone to waterlogging (Photo: OEH/R Muller).

Photo 2: Low rises with gently inclined slopes are common in the Simmons Creek HGL (Photo: OEH/R Muller).

Photo 3:The upper elements of the Simmons Creek HGL have steeper slopes, are better drained, and used primarily for cropping and grazing (Photo: OEH/R Muller).

Photo 4: Bedrock highs and clay rich soils in the Simmons Creek HGL result in the development of wetlands, such as Wiesner's Swamp (Photo: OEH/R Muller).

Photo 5: Low slopes, bedrock highs and clay rich soils in the Simmons Creek HGL result in flow lines becoming saturated and waterlogged during wet seasons (Photo: OEH/R Muller).

Photo 6: Simmons Creek near the confluence with the Billabong Creek, with clear water and high EC (19600 µS/cm) (Photo: OEH/A Nicholson).

Photo 7: Black sulfidic sediments are found in the lower reaches of Simmons Creek (Photo: OEH/A Nicholson).

Table 4: Summary of information used to define the Simmons Creek HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2011)*	This HGL comprises Ordovician metasediments that have been intruded by Silurian granitic rocks. These are overlain by unconsolidated Quaternary colluvium, alluvium and rare lacustrine (lake) deposits. Key lithologies include: • lake and swamp deposits – mud, silt, evaporites, travertine, minor sand • colluvium and/or residual deposits – boulders, gravel and sand; may include minor alluvial or sand plain deposits • Jindera Granite – pale coloured quartz/feldspar rich granite • Wagga Group – quartzose siltstone, sandstone, quartz-mica schist, mudstone and chert. Minor quartzite, graphitic schist and hornfels.
Annual Rainfall	550–600 mm

Regolith and Landforms	The Simmons Creek HGL is characterised by broad undulating alluvial plains, with isolated fine aeolian sand veneer deposits occurring in the low-lying parts of the landscape. Low hills and rises with broad crests and long, gently inclined colluvial slopes, formed on Ordovician metasediments and Silurian granitic rocks, surround the alluvial plains. Slopes are typically <2%, locally up to 8%, relief is <5 m, locally up to 50 m and this HGL is between 200–300 m elevation. The HGL features widely spaced shallow drainage lines and localised wetland areas. Regolith materials include moderately to highly weathered bedrock with colluvial cover on low hills and rises, unconsolidated interbedded clay, silt, sand and gravel, riverine deposits of Quaternary alluvium.
Soil Landscapes *(DECCW 2010)*	This HGL ranges over a number of soil landscapes. The most prominent soil landscapes are Belfrayden, Culcairn and Yarra Yarra. There are small areas of Cookardinia and Doodle Comer Swamp soil landscapes. Soils include: very deep (>1.5 m), imperfectly to moderately well-drained Red, Brown and Yellow Chromosols (Podzolic Soils) on upper and mid-slopes. Deep (1.0–1.5 m); imperfectly drained Brown and Grey Sodosols and Kurosols (Soloths and Solodized Solonetz Soils) occur on lower slopes; very deep (1.5–5.0 m), well-drained Orthic Tenosols (Earthy Sands) on fans; Mesotrophic Red Chromosols (Non-calcic Brown Soils) and Eutrophic Red Dermosols (Red Earths) on the plain; and Eutrophic Red Chromosols (Red-brown Earths) near drainage lines.
Land and Soil Capability *(OEH 2012)*	Class 5
Land Use	Grazing on volunteer, naturalised, native or improved pastures, with evidence of previous cultivation. There are significant areas of cropping (continuous or rotation). Wiesners Swamp is a designated Nature Reserve
Key Land Degradation Issues	• severe branching gully erosion in valley depressions (associated with sodic soils) • waterlogging (localised) • salinity (associated with soil types and particularly a salt bulge at depth in soil).
Native Vegetation *(Stelling 1998; Keith 2004)*	Vegetation within Simmons Creek HGL can include *Allocasuarina luehmannii* (particularly along creeks), *Callitris glaucophylla, Eucalyptus melliodora* (yellow box), *E. albens* (white box), *E. microcarpa* (grey box), *Callistemon sieberi* (also along creeks), *Acacia difformis, A. acinacea* and *Pittosporum angustifolium.* Vegetation communities fall within the classification of grey box woodland, box cypress pine woodland and Blakely's red gum woodland.

HYDROGEOLOGY

Aquifers within this landscape are unconfined to semi-confined with groundwater flow occurring primarily through fractures in bedrock and saprolite. Some flow occurs through colluvial and alluvial sediments on lower slopes and in flow lines. Hydraulic conductivity and transmissivity are moderate. Groundwater recharge rates are estimated to be moderate to high.

Groundwater systems are typically local to intermediate with short to intermediate flow lengths, and are loosely defined by topographic catchments. Water quality within these systems is marginal to brackish. Watertable depths are shallow to intermediate. Localised perching of watertables occurs above clay lenses during wetter periods.

Medium to long residence times are typical. These landscapes have a medium response time to changes in land management.

Typical values for the hydrogeological parameters of this HGL are summarised in Table 5.

Table 5: Summary of values for typical hydrogeological parameters of the Simmons Creek HGL.

Aquifer Type	Unconfined to semi-confined in fractured rock and saprolite Lateral flow through unconsolidated colluvial and alluvial sediments on lower slopes and in flow lines Some perching of watertables occurs in lacustrine deposits in flatter parts of the landscape
Hydraulic Conductivity	Moderate Range: 10^{-2}–10 m/day
Aquifer Transmissivity	Moderate Range: 2–100 m^2/day
Specific Yield	Low to moderate Range: <15%
Hydraulic Gradient	Gentle to moderate Range: <30%
Groundwater Salinity	Marginal to brackish Range: 800–4800 µS/cm
Depth to Watertable	Shallow to intermediate (localised perching) Range: <2–8 m
Typical Sub-Catchment Size	Small (<100 ha)
Scale (Flow Length)	Local to intermediate Flow length: <15 km (short to intermediate)
Recharge Estimate	Moderate to high
Residence Time	Medium to long (years to decades)
Responsiveness to Change	Medium (years)

MANAGEMENT OPTIONS

Overarching salinity management strategies have specific biophysical outcomes. These are achieved by implementing a series of targeted land management actions that take into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape to impact on salinity. Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Salinity is driven by interactions between water-use capacity of vegetation, physical soil properties and hydrogeological processes within the HGL.

Actions that influence the way water is used by vegetation or stored in the soil profile will have impacts on recharge. The influence of both continual and episodic recharge and the impacts of extreme weather events need to be considered when deciding on appropriate management actions. Short and long-term climate cycles also need to be considered as they have a bearing on salinity processes, particularly salt load and land salinity.

Landscape Salinity Functions – Simmons Creek HGL

Functions this landscape provides within a catchment scale salinity context:

- **F.** The landscape generates high salinity water.
- **I.** The landscape contains high hazard for acid sulfate processes.
- **D.** The landscape generates salt loads which enter the streams and are redistributed in the catchment.
- **G.** The landscape contains important land assets (including infrastructure and high value agricultural land) on which salinity processes impact.

Management Strategy Objectives – Simmons Creek HGL

The following list details the strategies pertinent to this landscape:

- **Stop discrete landscape recharge (3):** Particular areas can be targeted to reduce recharge and impact on high saline groundwater.
- **Discharge rehabilitation and management (4):** Saline areas are a small part of the wider landscape.
- **Dry out the landscape with diffuse actions over most of the landscape (6):** Encourage plant growth and increase plant water-use in order to use excess soil moisture and shallow groundwater. Healthy, actively growing vegetation will act as a buffer to groundwater accessions during wet seasonal conditions.
- **Manage and avoid acid sulfate hazards (11):** Inland acid sulfate sediments are exposed in the lower parts of the channel in this HGL.

Key Management Focus – Simmons Creek HGL

This landscape is saline and discharge management is highly important. A balance needs to be maintained with water management in conservation wetlands. Acid sulfate potential exists when channels are exposed to saline sediments. The salinity can be buffered in this landscape by well managed perennial pasture systems – particularly when this land use is targeted at critical points.

Specific Land Management Opportunities

Specific opportunities for this HGL:

- Discharge management can be specifically targeted.
- Well studied landscape – lots of landscape information exists.
- Multiple benefits from salt land and wetland management.

Specific Land Management Constraints

Constraints for land management in this HGL include:

- Highly saline.
- Potential acid sulfate soils.
- Water conservation for wetlands needs to be balanced against salinity management.
- High reliance by local land managers on annual cropping and annual pasture.

Specific Targeted Actions

Management areas for this HGL are illustrated in Figure 3. The specific management actions for these areas are described in Table 6.

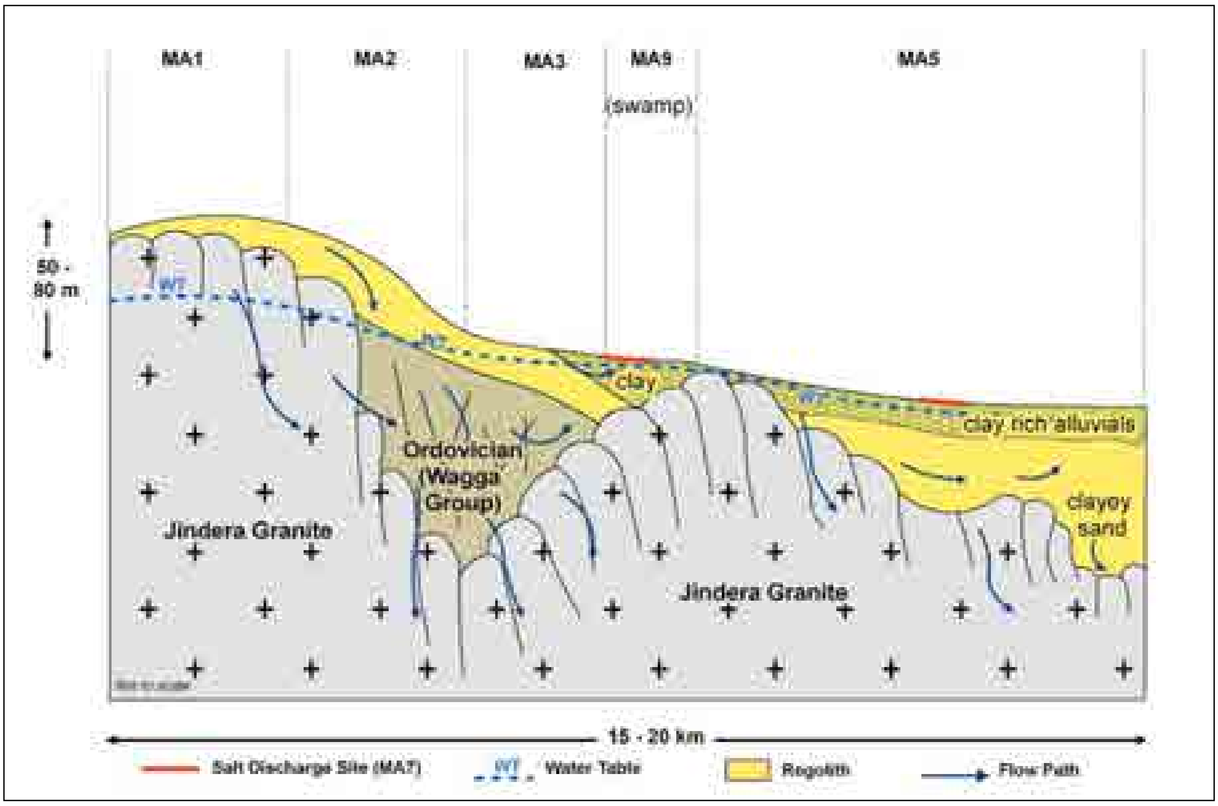


Figure 3: Management cross-section for Simmons Creek HGL showing defined management areas *(diagram modified from English et al. 2002)*.

Table 6: Specific management actions for management areas within the Simmons Creek HGL.

Management Area (MA)	Action
MA1 (RIDGES)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Establish and manage perennial pastures to manage recharge (**VP2).**
MA2 (UPPER SLOPES – EROSIONAL)	**Vegetation for ecosystem function** Establish and manage trees to intercept lateral groundwater flow **(VE2).** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Establish and manage perennial pastures to manage recharge (**VP2).**
MA3 (UPPER SLOPES – COLLUVIAL)	**Vegetation for ecosystem function** Establish and manage trees to intercept lateral groundwater flow **(VE2).** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** **Farming Systems** Implement rotational cropping with a perennial pasture component to manage recharge **(FS3).**

Management Area (MA)	Action
MA5 (LOWER SLOPES – COLLUVIAL)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** **Farming Systems** Implement rotational cropping with a perennial pasture component to manage recharge **(FS3).**
MA9 (SWAMP)	**Vegetation for ecosystem function** Establish and manage trees to intercept lateral groundwater flow **(VE2).** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** Maintain and improve riparian native vegetation to reduce discharge to streams **(VE4).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Establish and manage perennial pastures to intercept shallow lateral groundwater flow **(VP3).**
MA7 (SALT SITE)	**Salt land rehabilitation** Fence and isolate salt land and discharge areas to promote revegetation **(SR1).** Establish and manage salt land pasture systems to improve productivity **(SR2).** Undertake rehabilitation to ameliorate land salinity processes and reduce land degradation **(SR4).**

High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative impacts on salinity (Table 7).

Table 7: Management actions having negative salinity impacts in the Simmons Creek HGL.

At Risk Management Areas	Action
MA1 & MA2 (RIDGES & UPPER SLOPES – EROSIONAL)	Long fallows in farming systems **(DLU1).** Poor management of grazing pastures **(DLU2).** Annual cropping with annual plants **(DLU3).**
MA3 (UPPER SLOPES – COLLUVIAL)	Annual cropping with annual plants **(DLU3).** Clearing and poor management of native vegetation **(DLU4).**
MA5 (LOWER SLOPES – COLLUVIAL)	Acid sulfate potential exists when channels expose saline sediments
MA9 (SWAMP)	Clearing and poor management of native vegetation **(DLU4).**

REFERENCES

DAFF, 2012, *Billabong Creek project overview*, Australian Government, Department of Agriculture, Canberra

DECCW, 2010, *Reconnaissance soil and land resources of the Murray CMA*, NSW Department of Environment, Climate Change and Water, Sydney

English, P., Richardson, P. and Stauffacher, M. 2002, Groundwater & Salinity Processes in Simmons Creek sub-catchment, Billabong Creek, NSW, *Technical Report 24/02*, CSIRO Land and Water, Canberra

Geoscience Australia, 2011, *Australian stratigraphic units database*, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int

Keith, D. A. 2004, *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, Hurstville, NSW Department of Environment and Conservation

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, OEH Sydney, [Accessed: 10 November 2014] www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

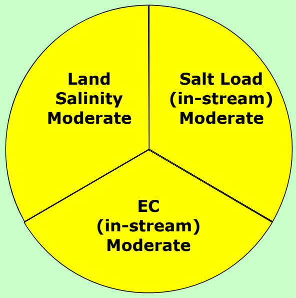
Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia

Stelling, F. 1998, *South west slopes revegetation guide (south of the Murrumbidgee River)*, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

Wooldridge, A., Nicholson, A., Muller R., Jenkins, B. R., Wilford, J. and Winkler, M. 2015, *Guidelines for managing salinity in rural areas*, NSW Office of Environment and Heritage, Sydney, NSW

8. Ryan Hydrogeological Landscape

LOCALITIES	**Mullemblah Hill, Ryan**
MAP SHEET	**Jerilderie 1:250 000** **Wagga Wagga 1:250 000**
CONFIDENCE LEVEL	**Medium**



OVERVIEW

The Ryan Hydrogeological Landscape (HGL) is north of Billabong Creek between Buckargingah Hill and Walbundrie (Figure 1). The HGL covers an area of 409 km^2 and receives 500 to 600 mm of rain per annum.

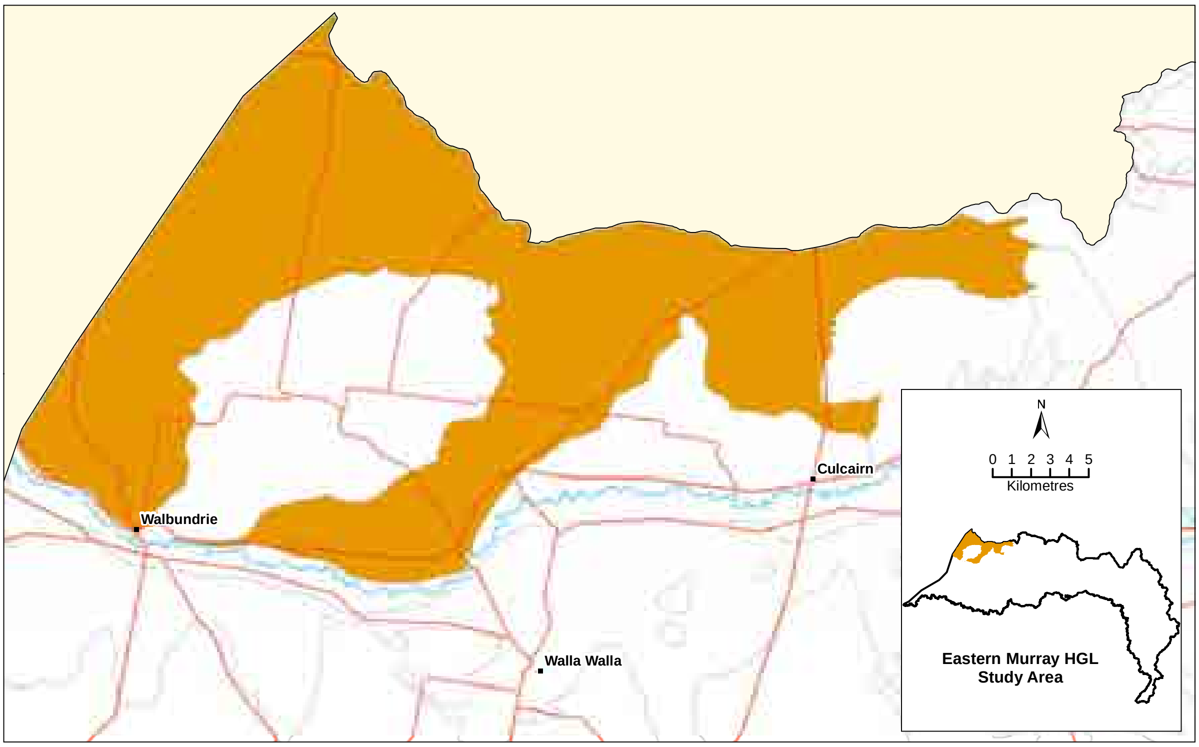


Figure 1: Ryan HGL distribution map.

The Ryan HGL environment has both depositional and erosional elements. It is characterised by broad crests and ridges; undulating rises; long waning, gently inclined foot-slopes; fans and broad, gently inclined sloping plains; and moderately broad drainage depressions (Figure 2). Significant aeolian deposits of fine sand occur in this HGL. Numerous deflation basins and terraces with sparse narrow drainage lines in the plains are present. This HGL comprises locally metamorphosed consolidated sedimentary rocks from the Ordovician period that have been intruded by granitic rocks from the Silurian period. Minor exposures of consolidated Devonian sedimentary rocks occur. These are overlain by unconsolidated Quaternary colluvium. Soils are very deep and imperfectly to moderately well-drained on upper and mid-slopes; deep and imperfectly drained on lower slopes; and very deep and well-drained on fans. Very deep soils occur on the higher, older terraces, with deep soils occurring on lower younger terraces. Deep alluvial soils are present in the recent channels. Severe branching gully erosion occurs in valley depressions (associated with sodic soils).

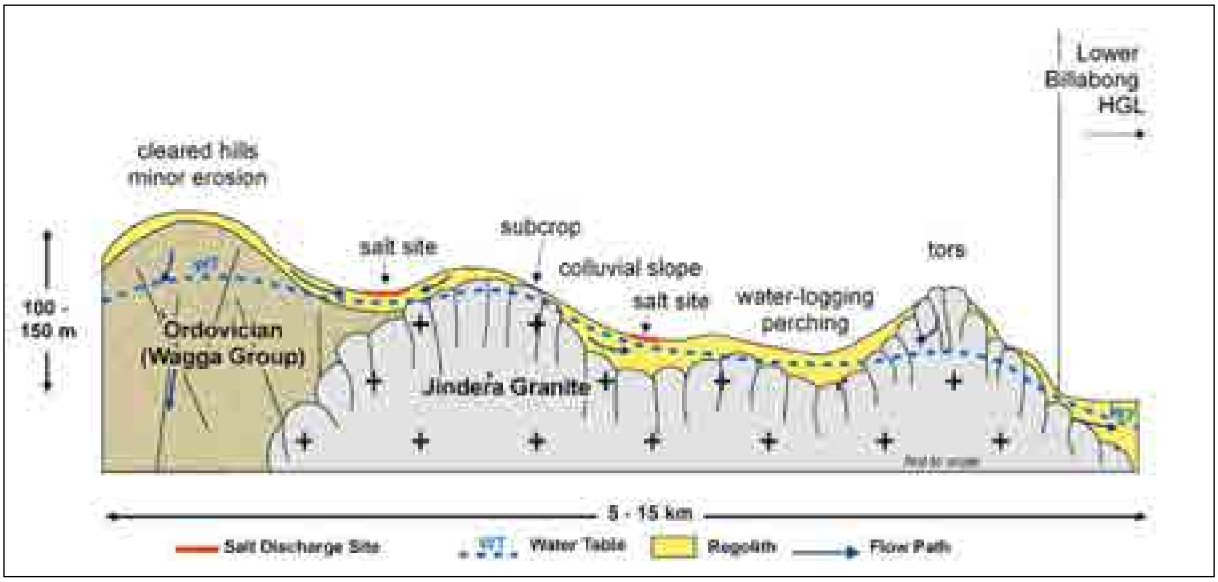


Figure 2: Conceptual cross-section for Ryan HGL showing the distribution of regolith and landforms, salt sites if present, and flow paths of water infiltrating the system.

Land salinity has been observed in the past at isolated lower colluvial and break of slope areas. These areas respond to climate cycles and disappear in dry times. Salt load and EC are moderate (Table 1).

Table 1: Ryan HGL salinity expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	Moderate – salt land has been observed in the past at isolated lower colluvial and break of slope areas. Salt land areas respond to climate cycles and disappear in dry times. Low occurrence of salt land in current and past mapping
Salt Load (Export)	Moderate – significant soil cover has capacity to store and deliver cyclic salt
EC (Water Quality)	Moderate – EC in wet times observed to be moderate

Salt stored within the Ryan HGL has high mobility. There is a high salt store that has moderate availability (Table 2).

Table 2: Ryan HGL salt store and availability.

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

The overall salinity hazard in the Ryan HGL is moderate. This is due to the moderate likelihood that salinity issues will occur that have potentially significant impacts (Table 3).

Table 3: Likelihood of salinity occurrence, potential impact and overall hazard of salinity for the Ryan HGL.

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

LANDSCAPE FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 4.

Photo 1: Granitic subcrop is common on upper slopes in the mid and southern portions of the Ryan HGL, and the colluvial slope adjacent to Billabong Creek is broad to the west of Morgans Lookout (Photo: OEH/R Muller).

Photo 2:Granite tors such as are seen at Morgans Lookout are characteristic of the granite hills that occur adjacent to Billabong Creek in the Ryan HGL (Photo: OEH/R Muller).

Photo 3: The broad rolling hills and undulating rises with long, gently inclined foot-slopes and broad, sloping plain seen in the eastern parts of the Ryan HGL are typical of the unit (Photo: OEH/R Muller).

Photo 4: Broad crests and ridges with gently- inclined foot-slopes are common features of the landscape adjacent to the higher elements of the Simmons Creek catchment (Photo: OEH/R Muller).

Photo 5: The northern extent of the Ryan HGL is dominated by cleared rolling hills of Ordovician metasediments (Photo: OEH/R Muller).

Table 4: Summary of information used to define the Ryan HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2011)*	This HGL comprises locally metamorphosed consolidated sedimentary rocks from the Ordovician period that have been intruded by granitic rocks from the Silurian period. Minor exposures of consolidated Devonian sedimentary rocks occur, overlain by unconsolidated Quaternary colluvium. Key lithologies include: • colluvium and/or residual deposits – boulders, gravel and sand; may include minor alluvial or sand plain deposits • unnamed sandstone, conglomerate, siltstone, shale and quartzite; often ferruginous • Jindera Granite – pale coloured quartz/feldspar rich granite • unnamed felsic volcanics and volcaniclastics – pale to intermediate coloured volcanic and volcaniclastic rocks rich in quartz and feldspar • Wagga Group – quartzose siltstone, sandstone, quartz-mica schist, mudstone and chert. Minor quartzite, graphitic schist and hornfels.
Annual Rainfall	500–600 mm

Regolith and Landforms	The Ryan HGL is moderately to highly weathered and is characterised by undulating hills (90–150m relief), low hills (30–90 m relief) and rises (9–30 m relief) with broad crests and ridges and long, gently inclined colluvial slopes, formed on Ordovician metasedimentary, Silurian granitic and Devonian felsic volcanic bedrock. Broad gently inclined alluvial plains (<9 m relief) with wide drainage depressions and an aeolian fine sand veneer form low-lying parts of the landscape. Slopes are typically <10%, local relief is 15–150 m and this HGL is between 120–300 m elevation. The HGL features deflation basins and terraces and widely spaced drainage lines on the plains. Regolith materials are moderately to highly weathered bedrock with colluvial cover on hills, low hills and rises, unconsolidated interbedded clay, silt, sand and gravel on the plains, riverine deposits of Quaternary alluvium, and aeolian fine sand veneer deposits.
Soil Landscapes *(DECCW 2010)*	This HGL does not correlate very well to the soil landscapes. The two main soil landscapes represented are Yarra Yarra and Culcairn. Small inclusions of Cookardinia, Belfrayden, Henty and Dora Dora soil landscapes. Soils include: very deep (>1.5 m), imperfectly to moderately well-drained Red, Brown and Yellow Chromosols (Podzolic Soils) on upper and mid-slopes; deep (1.0–1.5 m), imperfectly drained Brown and Grey Sodosols and Kurosols (Soloths and Solodized Solonetz Soils) on lower slopes; very deep (1.5–5.0 m), well-drained Orthic Tenosols (Earthy Sands) on fans; very deep Red and Brown Chromosols and Kurosols (Red and Brown Podzolic Soils); Yellow and Grey Sodosols (Soloths) occur on the higher, older terraces, with deep Grey and Brown Dermosols (Grey Podzolic Soils) occurring on lower younger terraces; deep Stratic Rudosols (Alluvial Soils) in the recent channels.
Land and Soil Capability *(OEH 2012)*	Class 4
Land Use	Roughly equal proportions of cropping and grazing
Key Land Degradation Issues	• severe branching gully erosion in valley depressions (associated with sodic soils) • waterlogging (localised) • salinity (associated with soil types and particularly a salt bulge at depth in soil).

Native Vegetation *(Stelling 1998; Keith 2004)*	Vegetation in Ryan HGL has been widely cleared for agriculture but extant native tree species in this landscape include *Eucalyptus microcarpa* (grey box) and *E. albens* (white box). Woodland species can also include *E. melliodora* (yellow box) on fertile, moist soils, *Callitris glaucophylla* (white cypress pine) and *Allocasuarina luehmannii* (bull oak) along drainage lines. *Eucalyptus blakelyi* (Blakely's red gum) and *Pittosporum angustifolium* (butterbush) may also be present. Some of the extant vegetation communities fall within classification as grey box woodland and white box woodland.

HYDROGEOLOGY

Aquifers within this landscape are unconfined to semi-confined, with groundwater flow occurring primarily through fractures in bedrock and saprolite. Some flow occurs through colluvial and alluvial sediments on lower slopes and in flow lines. Hydraulic conductivity and transmissivity are moderate. Groundwater recharge rates are estimated to be moderate to high.

Groundwater systems are typically local to intermediate with short to intermediate flow lengths, and are loosely defined by topographic catchments. Water quality within these systems is marginal. Watertable depths are intermediate.

Medium residence times are typical. These landscapes have a medium to fast response time to changes in land management.

Typical values for the hydrogeological parameters of this HGL are summarised in Table 5.

Table 5: Summary of values for typical hydrogeological parameters of the Ryan HGL.

Aquifer Type	Unconfined to semi-confined in fractured rock and saprolite Lateral flow through unconsolidated colluvial and alluvial sediments on lower slopes and in flow lines
Hydraulic Conductivity	Moderate Range: 10^{-2}–10 m/day
Aquifer Transmissivity	Moderate Range: 2–100 m^2/day
Specific Yield	Low to moderate Range: <15%
Hydraulic Gradient	Gentle to moderate Range: <30%
Groundwater Salinity	Marginal Range: 800–1600 µS/cm
Depth to Watertable	Intermediate Range: 2–8 m

Typical Sub-Catchment Size	Small to medium (<1000 ha)
Scale (Flow Length)	Local to intermediate Flow length: <10 km (short to intermediate)
Recharge Estimate	Moderate to high
Residence Time	Medium (years)
Responsiveness to Change	Fast to medium (months to years)

MANAGEMENT OPTIONS

Overarching salinity management strategies have specific biophysical outcomes. These are achieved by implementing a series of targeted land management actions that take into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape to impact on salinity. Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Salinity is driven by interactions between water-use capacity of vegetation, physical soil properties and hydrogeological processes within the HGL.

Actions that influence the way water is used by vegetation or stored in the soil profile will have impacts on recharge. The influence of both continual and episodic recharge and the impacts of extreme weather events need to be considered when deciding on appropriate management actions. Short and long-term climate cycles also need to be considered as they have a bearing on salinity processes, particularly salt load and land salinity.

Landscape Salinity Functions – Ryan HGL

Functions this landscape provides within a catchment scale salinity context:

- **D.** The landscape generates salt loads which enter the streams and are redistributed in the catchment.
- **G.** The landscape contains important land assets (including infrastructure and high value agricultural land) on which salinity processes impact.

Management Strategy Objectives – Ryan HGL

Appropriate strategies pertinent to this landscape:

- **Buffer the salt store – keep it dry and immobile (1):** There are stores of salt in discrete lower colluvial areas which perennial vegetation can buffer, limiting the salinity impact.
- **Discharge rehabilitation and management (4):** Discharge sites appear in the landscape through wet climate cycles. Improved management of these saline areas can reduce the impact of salinisation and prevent large negative impacts during wet cycles.

- **Dry out the landscape with diffuse actions over most of the landscape (6):** Encourage plant growth and increase plant water use in order to use excess soil moisture and shallow groundwater. This landscape is seen as dominated by annual vegetation systems. Perennial vegetation will act as a buffer to groundwater accessions in wet seasonal conditions.

Key Management Focus – Ryan HGL

This landscape is seen as dominated by production systems based on annual plants. The key management focus should be to introduce perennial components into the landscape and the farming systems.

The soils and landscape characteristics of this landscape mean that it is prone to high levels of groundwater recharge. Management should focus on actions which reduce the risk of excess recharge.

Specific Land Management Opportunities

Specific opportunities for this HGL:

- Using phase farming methods. Improving the extent, length of rotation and management of perennial pastures within cropping programs.
- Using dry times to establish perennial & salt tolerant pastures around saline discharge to buffer negative impacts during wet periods.
- The soils within this unit are fertile and comparatively easy to manage within a mixed farming and grazing systems.

Specific Land Management Constraints

Constraints for land management in this HGL include:

- High reliance on annual cereal production by local landholders.
- Salinity processes occur over long times periods.
- High potential recharge due to sandy surface soils and gradational soil profiles.

Specific Targeted Actions

Management areas for this HGL are illustrated in Figure 3. The specific management actions for these areas are described in Table 6.

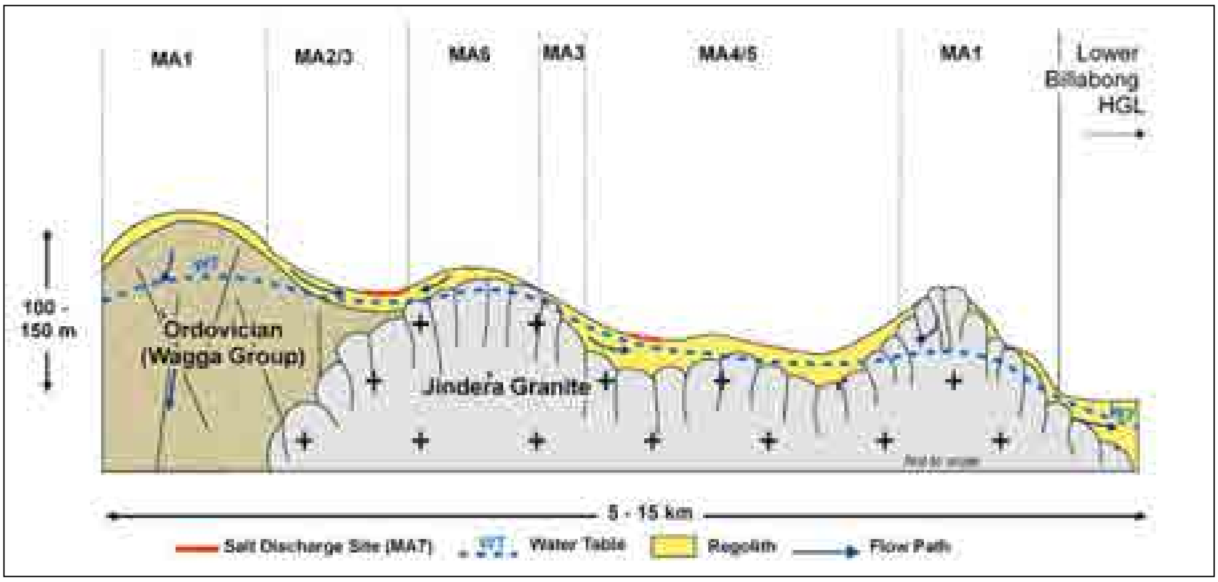


Figure 3: Management cross-section for Ryan HGL showing defined management areas.

Table 6: Specific management actions for management areas within the Ryan HGL.

Management Area (MA)	Action
MA1 (RIDGES)	**Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).** **Farming Systems** Implement pasture cropping with annual cereals in perennial pastures to manage recharge **(FS1).** Implement rotational cropping with a perennial pasture component to manage recharge **(FS3).** **Vegetation for ecosystem function (granite ridges)** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).**

Management Area (MA)	Action
MA2/3 (UPPER SLOPES – EROSIONAL & COLLUVIAL) AND MA4 (MID-SLOPES) AND MA5 (LOWER SLOPES – COLLUVIAL)	**Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** **Farming Systems** Implement pasture cropping with annual cereals in perennial pastures to manage recharge **(FS1).** Implement rotational cropping with a perennial pasture component to manage recharge **(FS3).**

High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative impacts on salinity (Table 7).

Table 7: Management actions having negative salinity impacts in the Ryan HGL.

At Risk Management Areas	Action
MA1, 2, 3, 4 & 5	Long fallows in farming systems **(DLU1).** Poor management of grazing pastures **(DLU2).** Annual cropping with annual plants **(DLU3).**

REFERENCES

DECCW, 2010, *Reconnaissance soil and land resources of the Murray CMA*, NSW Department of Environment, Climate Change and Water, Sydney

Geoscience Australia, 2011, *Australian stratigraphic units database*, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int

Keith, D. A. 2004, *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, Hurstville, NSW Department of Environment and Conservation

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, Office of Environment and Heritage, Sydney, [Accessed: 10 November 2014] www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

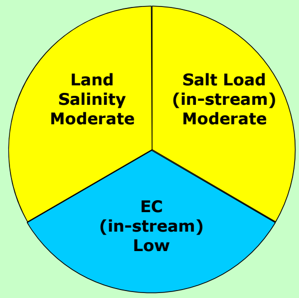
Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia

Stelling, F. 1998, *South west slopes revegetation guide (south of the Murrumbidgee River)*, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

Wooldridge, A., Nicholson, A., Muller R., Jenkins, B. R., Wilford, J. and Winkler, M. 2015, *Guidelines for managing salinity in rural areas*, NSW Office of Environment and Heritage, Sydney, NSW

9. Burrumbuttock Hydrogeological Landscape

LOCALITIES	**Burrumbuttock, Gerogery West**
MAP SHEET	**Jerilderie 1:250 000** **Wangaratta 1:250 000**
CONFIDENCE LEVEL	**Medium**



OVERVIEW

The Burrumbuttock Hydrogeological Landscape (HGL) is north of Albury between Black Range and Hurricane Hill (Figure 1). The HGL covers an area of 349 km^2 and receives 550 to 700 mm of rain per annum.

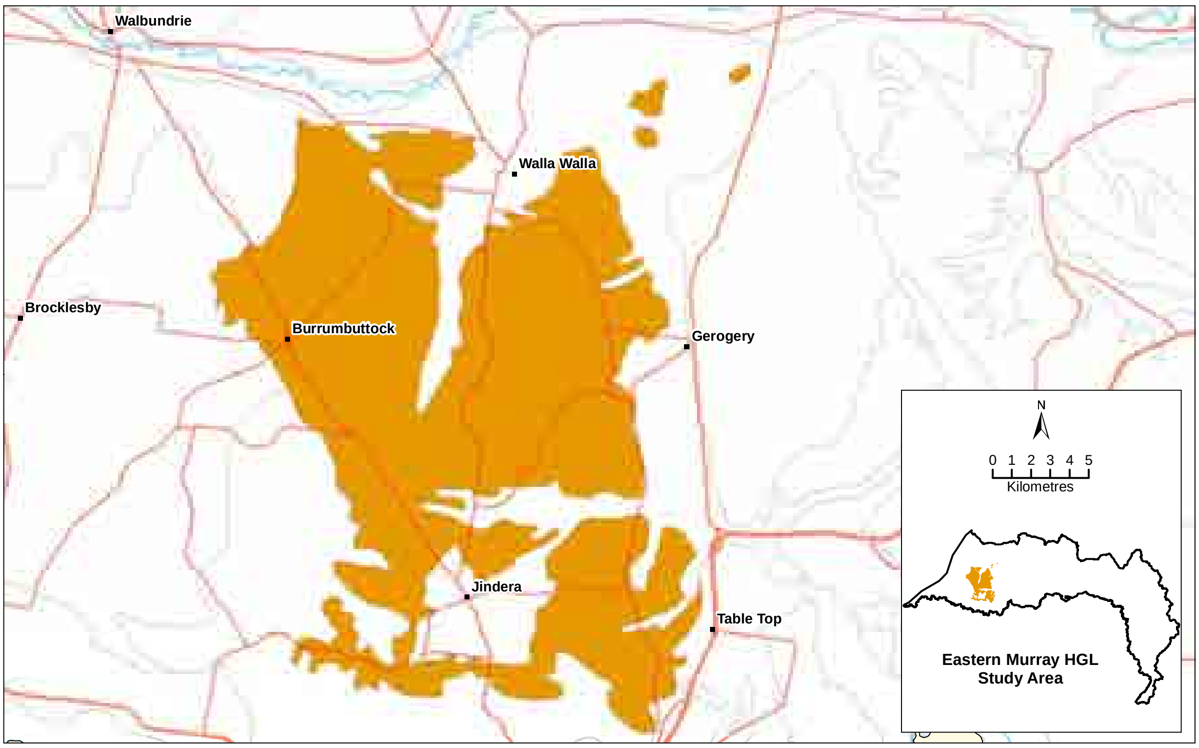


Figure 1: Burrumbuttock HGL distribution map.

The Burrumbuttock HGL is moderately to highly weathered and is characterised by rolling to steep hills, undulating residual low hills and rises, long colluvial slopes, and gently inclined foot-slopes and fans. Localised depressions (swamps) within broad to extensive low plains are present at the bottom of the landscape (Figure 2). Broad ridge crests and rises with long, straight slopes and widely spaced, narrow drainage lines are common. Granite tors occur on crests and steeper slopes along the eastern edge of the HGL, and isolated sub-crop is evident throughout. This HGL includes intrusive granitic rocks and extrusive volcanic rocks and associated sediments from the Silurian period. Unconsolidated colluvial and alluvial sediments derived from the surrounding rocks have been deposited on lower slopes and along streams that pass through. Lacustrine sediments occur in flatter parts of the landscape. Soils tend to be very deep and imperfectly to moderately well-drained on upper and mid-slopes. In areas of poor drainage swamps have developed. Sodic soils along drainage lines are fragile and readily erode. The sodic soils tend to seal and waterlog. This interacts with and contributes to salinity within this HGL.

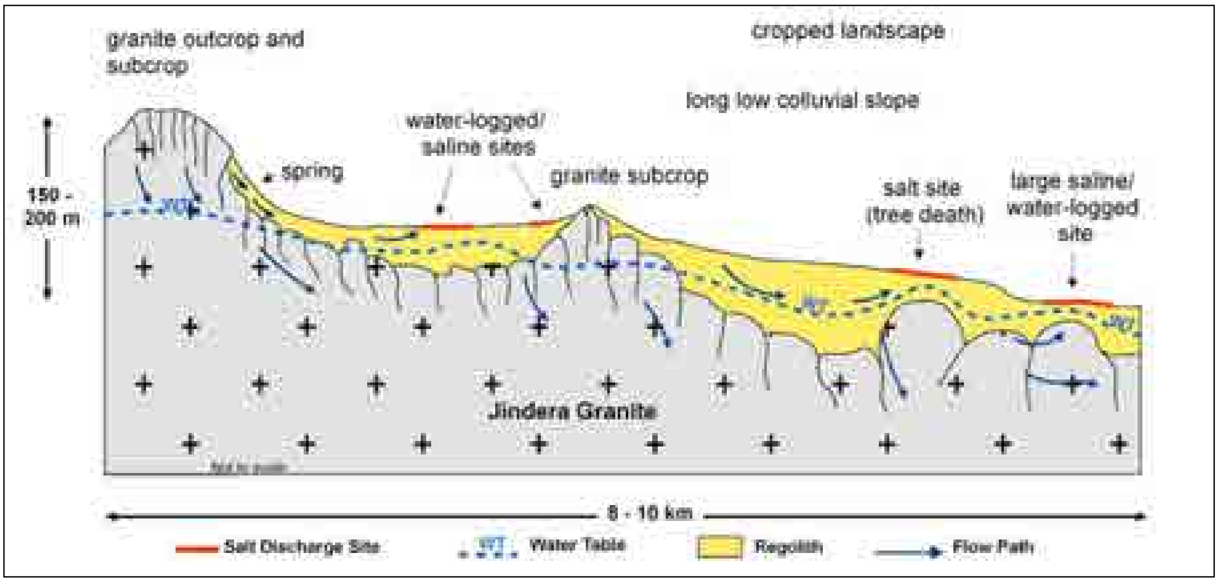


Figure 2: Conceptual cross-section for Burrumbuttock HGL showing the distribution of regolith and landforms, salt sites if present, and flow paths of water infiltrating the system.

Land salinity is typically observed in localised drainage depressions and adjacent to soil texture changes and bedrock highs. It often results from evaporative concentration of salts at waterlogged sites. Moderate salt load and low EC levels occur in this HGL (Table 1).

Table 1: Burrumbuttock HGL salinity expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	Moderate – salt sites are typically located in localised drainage depressions and adjacent to soil texture changes and bedrock highs, and are often the result of evaporative concentration of salts at waterlogged sites Salt sites mainly occur as waterlogged areas with infrequent highly saline symptoms
Salt Load (Export)	Moderate – infrequent base flow input into main flow lines during wet seasons
EC (Water Quality)	Low – during the study period insufficient flow, however it is likely that this area has moderate EC

Salt stored within the Burrumbuttock HGL has high mobility. There is a high salt store that has moderate availability (Table 2).

Table 2: Burrumbuttock HGL salt store and availability.

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

The overall salinity hazard in the Burrumbuttock HGL is low. This is due to the low likelihood that salinity issues will occur that have potentially significant impacts (Table 3).

Table 3: Likelihood of salinity occurrence, potential impact and overall hazard of salinity for the Burrumbuttock HGL.

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

LANDSCAPE FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 4.

Photo 1: Low hills with isolated tors on crests and adjacent long colluvial slopes are characteristic of the Burrumbuttock HGL (Photo: OEH/R Muller).

Photo 2: Low rises in the long, colluvial slopes are common in the Burrumbuttock HGL (Photo: OEH/R Muller).

Photo 3: Rolling hills on the north-western margin of the Burrumbuttock HGL (Photo: OEH/R Muller).

Photo 4: The rolling landscape of the Burrumbuttock HGL is used for cropping and grazing (Photo: OEH/A Nicholson).

Photo 5:Waterlogging and evaporative concentration of salts occurs at soil texture changes where long slopes run on to the alluvial plain in the Burrumbuttock HGL (Photo: OEH/A Nicholson).

Photo 6:Granite tors are a characteristic feature in the higher parts of the Burrumbuttock HGL, particularly in the east (Photo: OEH/A Nicholson).

Photo 7: Soil depth is shallow and bedrock outcrops in the higher and steeper parts of the Burrumbuttock HGL (Photo: OEH/A Nicholson).

Photo 8: Tree death and vegetation decline is an indicator of waterlogging and evaporative concentration of salts in localised drainage depressions and swamps in the Burrumbuttock HGL (Photo: OEH/A Nicholson).

Photo 9: The eastern edge of Burrumbuttock HGL is characterised by high, rocky ridges that grade down to long straight colluvial slopes with deeper soils (Photo: OEH/A Nicholson).

Photo 10: A large waterlogged site west of Walla Walla showing signs of salinisation where the long colluvial slope grades into the flatter flow-line (Photo: OEH/R Muller).

Table 4: Summary of information used to define the Burrumbuttock HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2011)*	This HGL comprises intrusive granitic rocks, extrusive volcanic rocks and associated sediments from the Silurian period. These are overlain by unconsolidated Quaternary colluvial and lake deposits. Key lithologies include: • lake and swamp deposits – mud, silt, evaporites, travertine, minor sand • colluvium and/or residual deposits – boulders, gravel and sand; may include minor alluvial or sand plain deposits • Jindera Granite – pale coloured quartz/feldspar rich granite • felsic volcanics and volcaniclastics – pale to intermediate coloured volcanic and volcaniclastic rocks rich in quartz and feldspar.
Annual Rainfall	550–700 mm.
Regolith and Landforms	The Burrumbuttock HGL is moderately to highly weathered and is characterised by hills (90–200m relief, 20–40% slope), low hills (30 –90 m relief, 3–10% slope) and rises (9–30 m relief, 2–8% slope) with broad ridge crests and gently inclined colluvial slopes, formed on Silurian felsic volcanic and granitic bedrock. Granite tors and associated subcrop are present on crests and upper slopes along the eastern margin of the HGL. Broad to extensive alluvial plains (<9 m relief, <2% slope) with widely spaced, narrow drainage lines, and localised depressions and swamps, form the low-lying parts of the landscape. Regolith materials are moderately to highly weathered bedrock with colluvial cover on hills, low hills and rises, and unconsolidated interbedded clay, silt, sand and gravel on the plains.
Soil Landscapes *(DECCW 2010)*	Five soil landscapes were identified as coinciding with this HGL. They are Yarra Yarra, Dora Dora, Doodle Comer Swamp, Culcairn and Ettamogah. Topographically, Dora Dora soil landscape represents the steepest and hilliest parts of the HGL. Soils are typically Brown and Red Kandosols and Dermosols (Red Earths). Cookardinia soil landscapes represent low hills and rises and contain Red Chromosols and Kurosols (Red Podzolic Soils) on crests and upper slopes; Brown Chromosols and Kurosols (Yellow Podzolic Soils) on mid-slopes; and, very deep Yellow and Brown Sodosols (Solodic Soils) in drainage depressions. Most of the HGL is occupied by Yarra Yarra and Ettamogah soil landscapes which occur on undulating foot-slopes, fans and rises. Soils tend to be very deep (>1.5 m) and imperfectly to moderately well-drained. Red, Brown and Yellow Chromosols (Podzolic Soils) occur on upper and mid-slopes, Brown and Grey Sodosols and Kurosols (Soloths and Solodized Solonetz Soils) occur on lower slopes, and, well-drained Orthic Tenosols (Earthy Sands) occur on fans. Kurosols, Sodosols and Stratic Rudosols (Alluvial Soils) occur on alluvial plains where water can move off site (Culcairn soil landscape). In areas of poor drainage, swamps have developed and typically contain very deep (>1.5 m) Grey Vertosols (Grey Clays) (Doodle Comer Swamp soil landscape). The sodic soils (Sodosols and Kurosols) along drainage lines are fragile and readily erode, evidenced by gullied drainage lines. The sodic soils tend to seal and waterlog. This interacts with and contributes to salinity within this HGL

Land and Soil Capability *(OEH 2012)*	Class 4
Land Use	Mixed farming (grazing, cropping)
Key Land Degradation Issues	acidity soil structure – poor cohesion erosion (related to sodicity) waterlogging.
Native Vegetation *(Stelling 1998; Keith 2004)*	Vegetation on the upper and lower slopes tends to be white box and grey box woodland dominant, with some Blakely's red gum woodland. White box woodland also occurs on the flats and gentle rises. Vegetation on the rocky outcrops tends to be Dwyer's red gum woodland with currawang and long-leaf box, as well as red stringybark dry forest on the drier slopes with south-easterly aspect. Tree species in the rocky outcrops include *Acacia doratoxylon* (currawang), *A. implexa* (hickory wattle), *Allocasuarina verticillata* (drooping sheoak) on dry ridges, *Eucalyptus goniocalyx* (long-leaf box) on dry rocky slopes, *Brachychiton populneus* (kurrajong), *E. polyanthemos* (red box) and *E. dwyeri* (Dwyer's red gum) on well drained sites, *E. albens* (white box) on more fertile slopes and ridges, *E. blakelyi* (Blakely's red gum) on loamy soils, *Callitris glaucophylla* (white cypress pine), and *C. endlicheri* (black cypress pine). Understorey species include *Acacia rubida* (red-stemmed wattle), *A. verniciflua* (varnish wattle), *Dillwynia* spp. (parrot pea), *Dodonaea viscosa* ssp. *angustissima* (narrow-leaf hop-bush), *Indigofera australis* (austral indigo) and *Pultenaea cunninghamii* (grey bush-pea). Tree species on the upper and lower slopes may also include *Acacia dealbata* (silver wattle), *Eucalyptus dealbata* (tumbledown gum), *E. melliodora* (yellow box) and *E. microcarpa* (grey box). Understorey species on the slopes may include *Bursaria spinosa* (sweet bursaria), *Daviesia ulicifolia* (gorse bitter pea) and *Indigofera adesmiifolia* (tick indigo).

HYDROGEOLOGY

Aquifers within this landscape are unconfined to semi-confined with groundwater flow occurring primarily through fractures in bedrock and saprolite. Some flow occurs through colluvial and alluvial sediments on lower slopes and in flow lines. Hydraulic conductivity and transmissivity are moderate. Groundwater recharge rates are estimated to be high.

Groundwater systems are typically local to intermediate with short to intermediate flow lengths and are loosely defined by topographic catchments. Water quality within these systems is fresh. Watertable depths are intermediate to deep, with some perching in flatter parts of the landscape.

Medium residence times are typical. These landscapes have a medium to fast response time to changes in land management.

Typical values for the hydrogeological parameters of this HGL are summarised in Table 5.

Table 5: Summary of values for typical hydrogeological parameters of the Burrumbuttock HGL.

Aquifer Type	Unconfined to semi-confined in fractured rock and saprolite Lateral flow through unconsolidated colluvial and alluvial sediments on lower slopes and in flow lines Some perching of watertables occurs in lacustrine deposits in flatter parts of the landscape
Hydraulic Conductivity	Moderate Range: <10^{-2}–10 m/day
Aquifer Transmissivity	Moderate Range: 2–50 m^2/day
Specific Yield	Moderate Range: 5–15%
Hydraulic Gradient	Gentle to moderate Range: <30%
Groundwater Salinity	Fresh Range: <800 µS/cm
Depth to Watertable	Intermediate to deep (localised perching) Range: >2 m
Typical Sub-Catchment Size	Medium (100–1000 ha)
Scale (Flow Length)	Local to intermediate Flow length: <15 km (short to intermediate)
Recharge Estimate	High
Residence Time	Medium (years)
Responsiveness to Change	Fast to medium (months to years)

MANAGEMENT OPTIONS

Overarching salinity management strategies have specific biophysical outcomes. These are achieved by implementing a series of targeted land management actions that take into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape to impact on salinity. Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Salinity is driven by interactions between water-use capacity of vegetation, physical soil properties and hydrogeological processes within the HGL.

Actions that influence the way water is used by vegetation or stored in the soil profile will have impacts on recharge. The influence of both continual and episodic recharge and the

impacts of extreme weather events need to be considered when deciding on appropriate management actions. Short and long-term climate cycles also need to be considered as they have a bearing on salinity processes, particularly salt load and land salinity.

Landscape Functions – Burrumbuttock HGL

Functions this landscape provides within a catchment scale salinity context:

- **B.** The landscape provides fresh water runoff as an important dilution flow source
- **D.** The landscape generates salt loads which enter the streams and are redistributed in the catchment
- **G.** The landscape contains important land assets (including infrastructure and high value agricultural land) on which salinity processes impact.

Landscape Management Strategies – Burrumbuttock HGL

Appropriate strategies pertinent to this landscape:

- **Discharge rehabilitation and management (4):** The saline and waterlogged sites are small to moderate in size. Discharge management will reduce the onsite degradation when vegetation is matched to salt sites.
- **Intercept shallow lateral flow and shallow groundwater (2):** Within this HGL it is possible to target shallow watertables that occur where bedrock is close to the surface. Rows of trees (8–30 rows) can be effective to intercept lateral flow. Rooting depth will intercept shallow groundwater.
- **Dry out the landscape with diffuse actions over most of the landscape (6):** This landscape is seen as dominated by production systems based on annual plants. The key management focus should be to introduce perennial components into the landscape and the farming systems, encouraging plant growth and increasing plant water use in order to use excess soil moisture and shallow groundwater. Healthy, actively growing vegetation will also act as a buffer to groundwater accessions in wet seasonal conditions.
- **Buffer the salt store – keep it dry and immobile (1):** There are stores of salt in discrete lower colluvial areas, which perennial vegetation can buffer, limiting the salinity impact.

Key Management Focus – Burrumbuttock HGL

Waterlogging is a feature of this landscape which has a salinity impact in wetter years. This landscape is seen as dominated by production systems based on annual plants. The key management focus should be to introduce perennial components into the landscape and the farming systems, recognising that some parts of the landscape will experience waterlogging and salinity during wet years.

Specific Land Management Opportunities

Specific opportunities for this HGL:

- Interception of shallow lateral flow in areas where bedrock is close to the surface.
- This landscape will have a quick response time to land management changes.

Specific Land Management Constraints

Constraints for land management in this HGL include:

- Very low perennial pasture base from which to build effective pastures.
- High level of landscape understanding is required to successfully implement interception tree plantings.
- Parts of this landscape will experience waterlogging in wet years.

Specific Targeted Actions

Management areas for this HGL are illustrated in Figure 3. The specific management actions for these areas are described in Table 6.

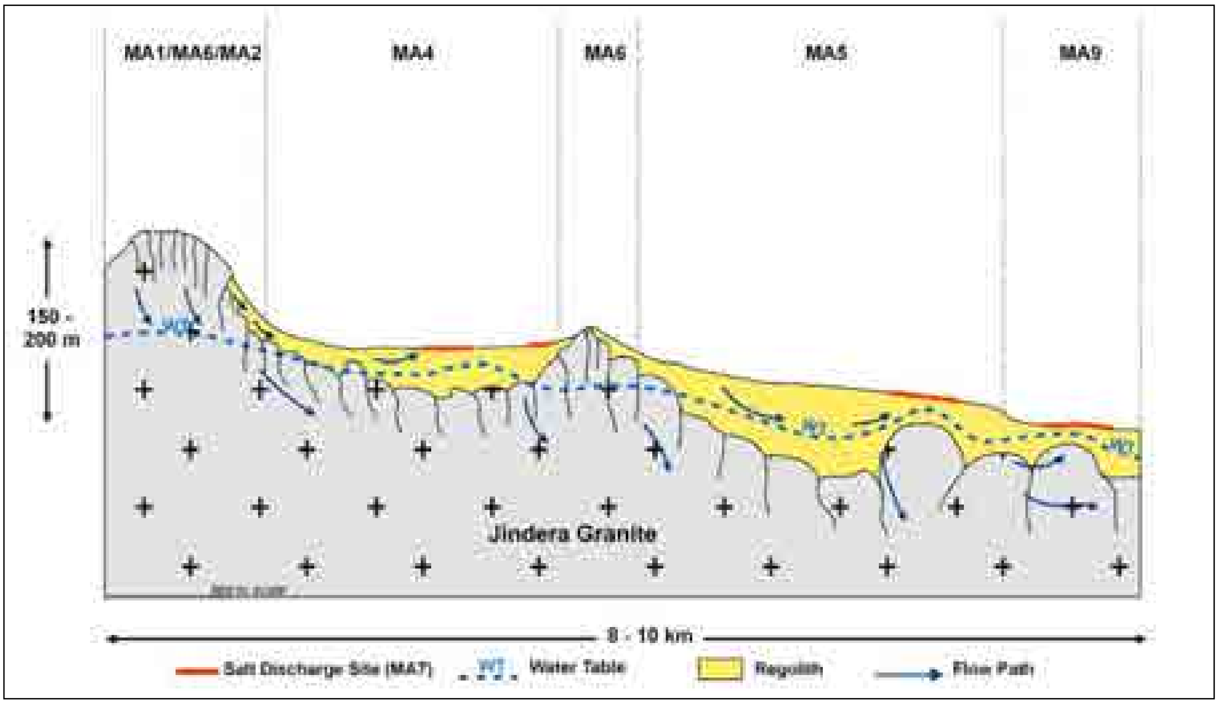


Figure 3: Management cross-section for Burrumbuttock HGL showing defined management areas.

Table 6: Specific management actions for management areas within the Burrumbuttock HGL.

Management Area (MA)	Action
MA1/MA2/MA6 (RIDGES)	**Vegetation for ecosystem function** Establish and manage trees to intercept lateral groundwater flow **(VE2).** Establish and manage blocks of trees to reduce recharge **(VE1).** **Vegetation for production** Establish and manage perennial pastures to intercept shallow lateral groundwater flow **(VP3).**
MA6 (RISES – ROCKY KNOBS)	**Vegetation for production** Establish and manage perennial pastures to manage recharge **(VP2).** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** **Farming Systems** Implement rotational cropping with a perennial pasture component to manage recharge **(FS3).** Implement pasture cropping with annual cereals in perennial pastures to manage recharge **(FS1).** Implement no-till farming systems to increase soil water storage, soil water use and to reduce recharge **(FS8).**
MA4 (MID-SLOPES)	**Vegetation for ecosystem function** Establish and manage trees to intercept lateral groundwater flow **(VE2).** **Vegetation for production** Adjacent to MA1, establish and manage perennial pastures to intercept shallow lateral groundwater flow **(VP3).** **Farming Systems** Implement rotational cropping with a perennial pasture component to manage recharge **(FS3).** Implement pasture cropping with annual cereals in perennial pastures to manage recharge **(FS1).** Implement no-till farming systems to increase soil water storage, soil water use and to reduce recharge **(FS8).**

Management Area (MA)	Action
MA5 (LOWER SLOPES – COLLUVIAL)	**Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Establish and manage perennial pastures to manage recharge **(VP2).** **Farming Systems** Implement pasture cropping with annual cereals in perennial pastures to manage recharge **(FS1).** Implement rotational cropping with a perennial pasture component to manage recharge **(FS3).**
MA9 (ALLUVIAL PLAIN)	**Vegetation for ecosystem service** Maintain and improve riparian native vegetation to reduce discharge to streams **(VE4).** **Vegetation for production** Establish and manage perennial pastures to manage recharge **(VP2).**
MA7 (SALINE SITES)	**Salt land rehabilitation** Fence and isolate salt land and discharge areas to promote revegetation **(SR1).** Establish and manage salt land pasture systems to improve productivity **(SR2).**

High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative impacts on salinity (Table 7).

Table 7: Management actions having negative salinity impacts in the Burrumbuttock HGL.

At Risk Management Areas	Action
MA1 (RIDGES)	Long fallows in farming systems **(DLU1).** Annual cropping with annual plants **(DLU3).**
MA6 (RISES – ROCKY KNOBS)	Long farming in cropping systems **(DLU1).** Annual cropping with annual plants **(DLU3).**
MA4 (MID-SLOPES)	Long fallows in farming systems **(DLU1).** Annual cropping with annual plants **(DLU3).**
MA5 (LOWER SLOPES – COLLUVIAL)	Long fallows in farming systems **(DLU1).** Annual cropping with annual plants **(DLU3).** Farm dams in flow lines **(DLU5).**
MA7 (SALINE SITES)	Long fallows in farming systems **(DLU1).** Annual cropping with annual plants **(DLU3).** Farm dams in flow lines **(DLU5).**

REFERENCES

DECCW, 2010, *Reconnaissance soil and land resources of the Murray CMA*, NSW Department of Environment, Climate Change and Water, Sydney

Geoscience Australia, 2011, *Australian stratigraphic units database*, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int

Keith, D. A. 2004, *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, Hurstville, NSW Department of Environment and Conservation

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, OEH Sydney, [Accessed: 10 November 2014] www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

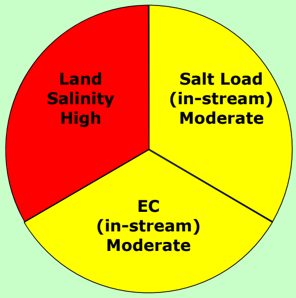
Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia

Stelling, F. 1998, *South west slopes revegetation guide (south of the Murrumbidgee River)*, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

Wooldridge, A., Nicholson, A., Muller R., Jenkins, B. R., Wilford, J. and Winkler, M. 2015, *Guidelines for managing salinity in rural areas*, NSW Office of Environment and Heritage, Sydney, NSW

10. Brocklesby Hydrogeological Landscape

LOCALITIES	**Brocklesby, Howlong Hill, Burrumbuttock Hill**
MAP SHEET	**Jerilderie 1:250 000**
CONFIDENCE LEVEL	**Medium**



OVERVIEW

The Brocklesby Hydrogeological Landscape (HGL) is west of Burrumbuttock, north of Howlong and south of Walbundrie (Figure 1). The HGL covers an area of 376 km^2 and receives 550 to 600 mm of rain per annum.

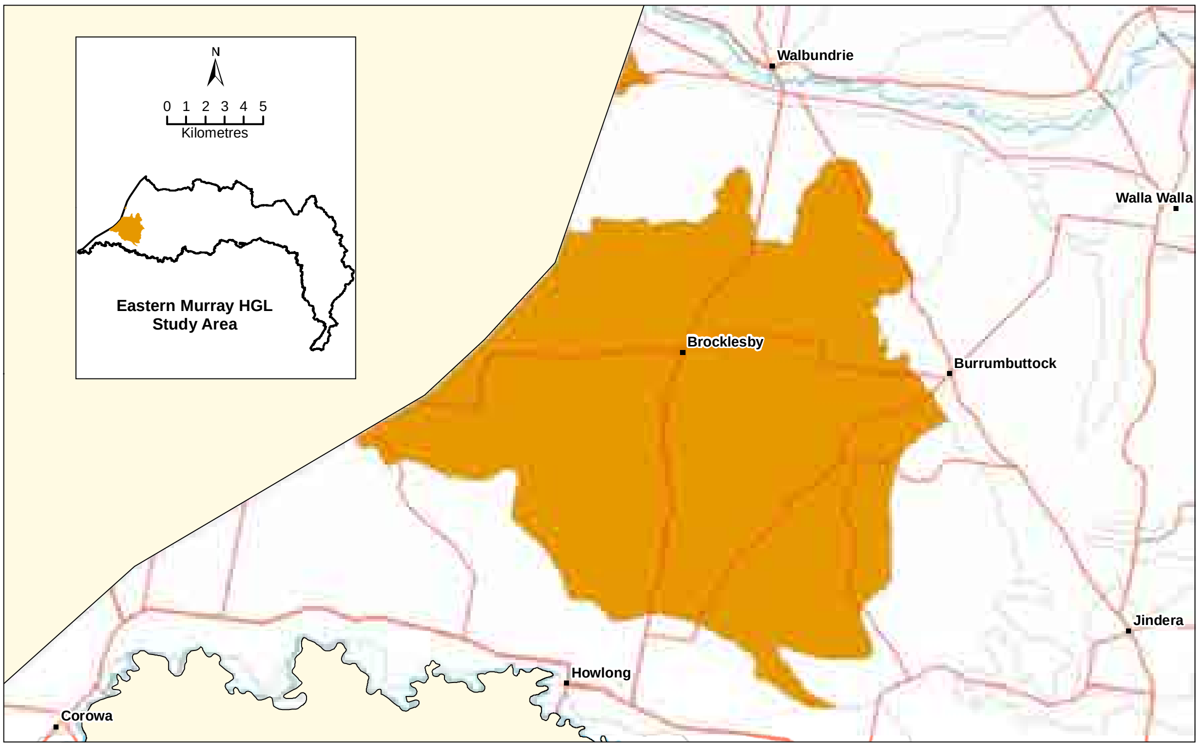


Figure 1: Brocklesby HGL distribution map.

The Brocklesby HGL is characterised by narrow to broad ridge crests; long, straight to waning slopes; broad drainage depressions; and widely spaced, narrow drainage lines (Figure 2). These form rolling low hills and undulating rises, and residual low hills and rises. Rock outcrop is variable. Processes are primarily erosional on steeper hills and rises, colluvial on the long slopes, with some transferral areas occurring along the drainage lines. This HGL includes rocks from the Ordovician Wagga Group. Unconsolidated colluvial and alluvial sediments derived from the surrounding rocks have been deposited on lower slopes and along streams that pass through. Soils depths are variable on crests, ridges and upper slopes; moderately deep on mid to lower slopes; and moderately deep and imperfectly drained in drainage lines. Sheet erosion is widespread on steeper slopes and has seen removal and translocation of much of the topsoil.

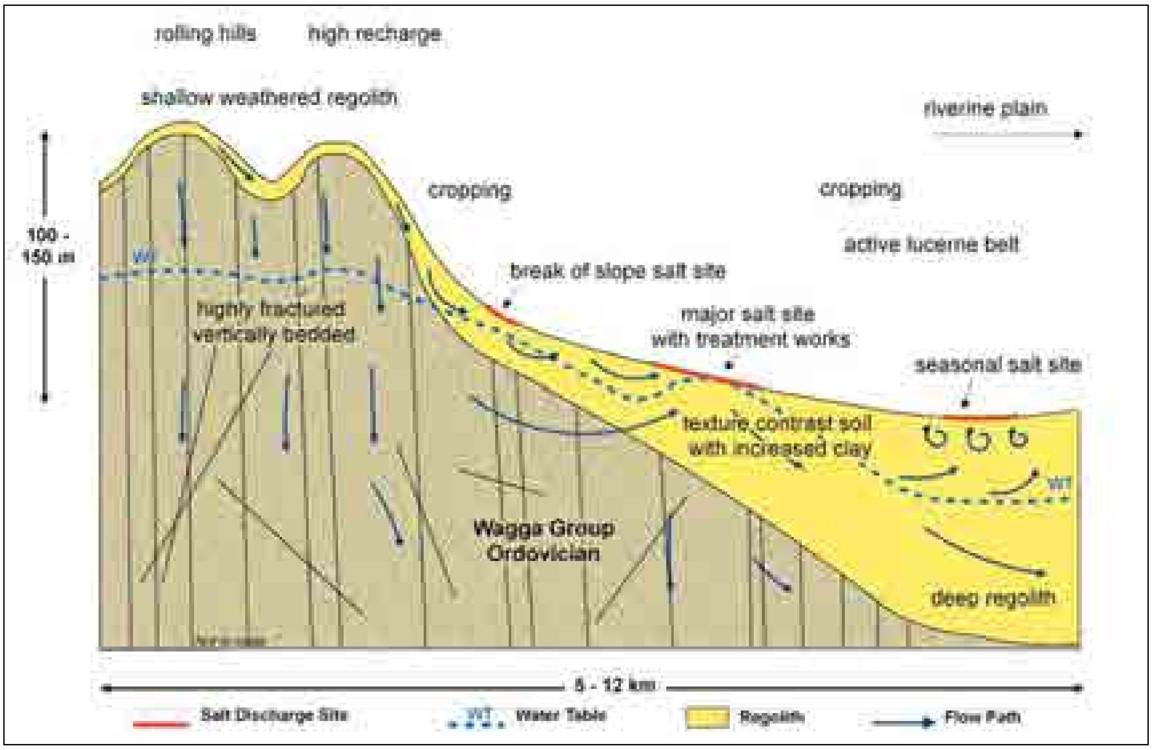


Figure 2: Conceptual cross-section for Brocklesby HGL showing the distribution of regolith and landforms, salt sites if present, and flow paths of water infiltrating the system.

Land salinity is common and is typically seen at gradient changes on the colluvial slopes and in flow lines. Moderate salt load and EC levels occur in this HGL (Table 1).

Table 1: Brocklesby HGL salinity expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	High occurrence of saline land (particularly at colluvial slope change) and commonly in flow lines
Salt Load (Export)	Moderate – intermittent creeks frequently observed to be flowing at >600 µS/cm
EC (Water Quality)	Moderate – occasional spikes of high salinity water up to 2000 µS/cm have been observed

Salt stored within the Brocklesby HGL has high mobility. There is a high salt store that has moderate availability (Table 2).

Table 2: Brocklesby HGL salt store and availability.

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

The overall salinity hazard in the Brocklesby HGL is moderate. This is due to the moderate likelihood that salinity issues will occur that have potentially significant impacts (Table 3).

Table 3: Likelihood of salinity occurrence, potential impact and overall hazard of salinity for the Brocklesby HGL.

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

LANDSCAPE FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 4.

Photo 1:Rolling low hills and broad drainage depression in the eastern part of the Brocklesby HGL (Photo: OEH/R Muller).

Photo 2: Rolling low hills and long, waning slopes in the Brocklesby HGL (Photo: OEH/R Muller).

Photo 3: Rolling low hills and long, waning slopes in the Brocklesby HGL (Photo: OEH/R Muller).

Photo 4: Large salt sites commonly occur at colluvial slope changes in the Brocklesby HGL (Photo: OEH/A Nicholson).

Photo 5: View across the rolling mid slope area of Brocklesby HGL (Photo: OEH/A Nicholson).

Photo 6: Large salt site at colluvial slope change which is managed with salt tolerant species (saltbush) and tree planting in the Brocklesby HGL (Photo: OEH/A Nicholson).

Photo 7: View to lower MA9 unit from the MA5 unit in Brocklesby HGL (Photo: OEH/A Nicholson).

Photo 8: Salt remediation site in Brocklesby HGL (Photo: OEH/A Nicholson).

Photo 9: Salt sites and waterlogging occur at slope changes and in flow lines in the Brocklesby HGL, often impacting on vegetation health (Photo: OEH/R Muller).

Photo 10: In the lower, flatter elements of the Brocklesby HGL, waterlogging is an issue during wet periods, often impacting on crop health (Photo: OEH/R Muller).

Table 4: Summary of information used to define the Brocklesby HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2011)*	This HGL comprises locally metamorphosed consolidated sedimentary rocks from the Ordovician period. These are overlain by unconsolidated Cenozoic fluvial sediments and unconsolidated Quaternary colluvium. Key lithologies include: • colluvium and/or residual deposits – boulders, gravel and sand; may include minor alluvial or sand plain deposits • Shepparton Formation – unconsolidated to poorly consolidated mottled variegated clay, silty clay with lenses of polymictic, coarse to fine sand and gravel; partly modified by pedogenesis • Wagga Group – quartzose siltstone, sandstone, quartz-mica schist, mudstone and chert. Minor quartzite, graphitic schist and hornfels.
Annual Rainfall	550–600 mm
Regolith and Landforms	The Brocklesby HGL is slightly to moderately weathered and is characterised by hills (90–150 m relief, >20% slope), low hills (30–90 m relief, 10–20% slope) and rises (9–30 m relief, 3–10% slope) with narrow to broad ridge crests and gently inclined colluvial slopes, formed on Ordovician metasedimentary bedrock. Rock outcrop on the crests and upper slopes ranges from 0–50%. Broad drainage depressions with widely spaced, narrow drainage lines form the low-lying parts of the landscape. Regolith materials are kaolinite-bearing quartzose clayey sands with minor gravels and some sandy clays. On ridge crests and upper slopes there are some angular tabular pebble and cobble-bearing coarse sandy gravels and gravelly sands with variable kaolinitic clay content.
Soil Landscapes *(DECCW 2010)*	This HGL corresponds closely to Pulletop soil landscape. Small patches of Livingstone soil landscape are also included. Soils are shallow to moderately deep (40–100 cm) Mesotrophic Red Chromosols (Red Podzolic Soils) and deep (1.0–1.5 m) to very deep (>1.5 m), moderately well-drained Brown Chromosols and Kurosols (Brown and Yellow Podzolic Soils) on crests, ridges and upper slopes. Moderately deep (80–150 cm) Bleached and Haplic Red Chromosols (Red Podzolic Soils) occur on mid to lower slopes. Moderately deep (80–150 cm) mottled Subnatric Brown Sodosols (Solodic Soils) and imperfectly drained Brown and Red Sodosols (Solodic Soils) are found in drainage lines. Sheet erosion is widespread on steeper slopes and has seen the removal and translocation of much of the topsoil. The changed drainage pattern caused by the removal of vegetation and topsoil from slopes, the sodic nature of the soils in drainage lines, and the texture contrast nature of soils have contributed to salt outbreaks that are often seasonal and occur at break of slopes and on foot-slopes.
Land and Soil Capability *(OEH 2012)*	Class 5

Land Use	Cropping, grazing
Key Land Degradation Issues	• acidity • waterlogging • structural problems.
Native Vegetation *(Stelling 1998; Keith 2004)*	Vegetation on the upper slopes and hills tends to be white box woodland, while lower slopes and plains it is more likely to be box – cypress pine woodland (yellow box and grey box) or yellow box and Blakely's red gum woodland. All communities in Brocklesby characteristically form on residual and colluvial deposits from underlying meta-sediments which form Red-brown earths. Tree species on the rises and hills can include *Eucalyptus albens* (white box) on fertile slopes and ridges, *E. blakelyi* (Blakely's red gum) on loamy soils, *E. dealbata* (tumbledown gum) and *E. goniocalyx* (long-leaf box) on well drained hills or dry rocky slopes, as well as *Allocasuarina verticillata* (drooping sheoak) on dry ridges and *Callitris glaucophylla* (white cypress pine). Species on mid-slopes may include *E. melliodora* (yellow box) where the soils are moderately fertile and well drained, *E. microcarpa* (grey box) on heavier soils, *Exocarpos cupressiformis* (native cherry) and *Acacia implexa* (hickory wattle). Understorey species may include a range of acacia species, *Bursaria spinosa* (sweet bursaria), *Daviesia latifolia* (hop bitter-pea) and *Indigofera adesmiifolia* (tick indigo). On lower slopes, additional species may include *Allocasuarina luehmannii* (bulloak), *E. bridgesiana* (apple box), *Acacia difformis* (drooping wattle) and *A. acinacea* (gold-dust wattle).

HYDROGEOLOGY

Aquifers within this landscape are unconfined to semi-confined with groundwater flow occurring primarily through fractures in bedrock and saprolite. Some flow occurs through colluvial and alluvial sediments on lower slopes and in flow lines. Hydraulic conductivity is low to moderate and transmissivity is low. Groundwater recharge rates are estimated to be moderate to high.

Groundwater systems are typically local to intermediate with short to intermediate flow lengths, and are loosely defined by topographic catchments. Water quality within these systems is marginal to brackish. Watertable depths are shallow to intermediate.

Medium to long residence times are typical. These landscapes have a medium response time to changes in land management.

Typical values for the hydrogeological parameters of this HGL are summarised in Table 5.

Table 5: Summary of values for typical hydrogeological parameters of the Brocklesby HGL.

Aquifer Type	Unconfined to semi-confined in fractured rock and saprolite Lateral flow through unconsolidated colluvial and alluvial sediments on lower slopes and in flow lines
Hydraulic Conductivity	Low to moderate Range: <10 m/day
Aquifer Transmissivity	Low Range: <2 m^2/day
Specific Yield	Low Range: <5%
Hydraulic Gradient	Gentle Range: <10%
Groundwater Salinity	Marginal to brackish Range: 800–4800 µS/cm
Depth to Watertable	Shallow to intermediate (locally artesian) Range: <8 m
Typical Sub-Catchment Size	Medium (100–1000 ha)
Scale (Flow Length)	Local to intermediate Flow length: <15 km (short to intermediate)
Recharge Estimate	Moderate to high (gravely hills)
Residence Time	Medium to long (years to decades)
Responsiveness to Change	Medium (years)

MANAGEMENT OPTIONS

Overarching salinity management strategies have specific biophysical outcomes. These are achieved by implementing a series of targeted land management actions that take into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape to impact on salinity. Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Salinity is driven by interactions between water-use capacity of vegetation, physical soil properties and hydrogeological processes within the HGL.

Actions that influence the way water is used by vegetation or stored in the soil profile will have impacts on recharge. The influence of both continual and episodic recharge and the impacts of extreme weather events need to be considered when deciding on appropriate

management actions. Short and long-term climate cycles also need to be considered as they have a bearing on salinity processes, particularly salt load and land salinity.

Landscape Functions – Brocklesby HGL

Functions this landscape provides within a catchment scale salinity context:

- **D.** The landscape generates salt loads which enter the streams and are redistributed in the catchment.
- **G.** The landscape contains important land assets (including infrastructure and high value agricultural land) on which salinity processes impact.

Landscape Management Strategies – Brocklesby HGL

Appropriate strategies pertinent to this landscape:

- **Buffer the salt store – keep it dry and immobile (1):** There are stores of salt in colluvial areas that vegetation can buffer, limiting the salinity impact. These areas are generally in the depositional elements of the lower landscape. These areas comprise a significant percentage of this HGL.
- **Discharge rehabilitation and management (4):** The saline and waterlogged sites are small to moderate in size. Discharge management will reduce salt discharge to streams when vegetation is matched to salt sites, and will also limit on-site land degradation.
- **Intercept shallow lateral flow and shallow groundwater (2):** Within this HGL it is possible to target shallow watertables that occur where bedrock is close to the surface. Rows of trees (8–30 rows) can be effective to intercept lateral flow. Rooting depth can intercept shallow groundwater if plantings are correctly targeted.
- **Dry out the landscape with diffuse actions over most of the landscape (6):** Encourage plant growth and increase plant water use in order to use excess soil moisture and shallow groundwater. Healthy, actively growing vegetation will also act as a buffer to groundwater accessions in wet seasonal conditions.

Key Management Focus – Brocklesby HGL

The focus for this landscape is farm scale recharge and discharge management. This landscape has short groundwater flow lengths which mean there will be quick response to management change. Many farms contain both recharge and discharge areas.

Specific Land Management Opportunities

Specific opportunities for this HGL:

- Soils are deep, fertile and have high cation exchange capacity (CEC).
- Local groundwater systems with relatively quick response to management changes.

Specific Land Management Constraints

Constraints for land management in this HGL include:

- Recharge is diffuse across the landscape. Changes to land management will have to take place across landscape to have the greatest impact.
- High recharge rates due to high gravel content in some soil types.
- High recharge rates due to gradational soil types which are well drained.
- High level of landscape understanding is required to successfully implement revegetation actions which aim to intercept shallow groundwater.

Specific Targeted Actions

Management areas for this HGL are illustrated in Figure 3. The specific management actions for these areas are described in Table 6.

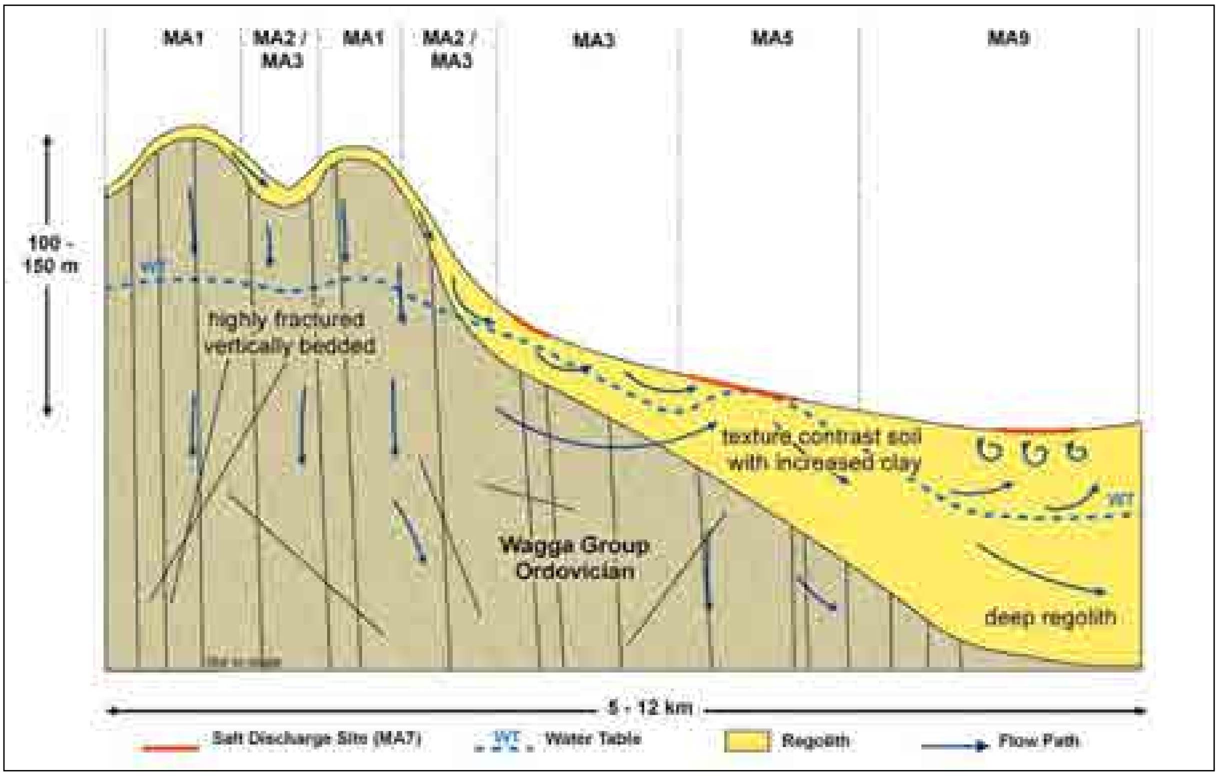


Figure 3: Management cross-section for Brocklesby HGL showing defined management areas.

Table 6: Specific management actions for management areas within the Brocklesby HGL.

Management Area (MA)	Action
MA1 (RIDGES)	**Vegetation for ecosystem function** Establish and manage blocks of trees to reduce recharge **(VE1).** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge (**VP1).** Establish and manage perennial pastures to manage recharge (**VP2).**
MA2/3 (UPPER SLOPES – EROSIONAL & COLLUVIAL)	**Vegetation for ecosystem function** Establish and manage blocks of trees to reduce recharge **(VE1).** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge (**VP1).** Establish and manage perennial pastures to manage recharge (**VP2).**
MA3 (UPPER SLOPES – COLLUVIAL)	**Farming Systems** Phase farming with perennial component – crop rotations to manage recharge **(FS3).** Pasture cropping with annual cereals into perennial pastures to manage recharge **(FS1).** **Vegetation for production** Establish and manage perennial pastures to manage recharge (**VP2).** Improve grazing management of existing perennial pastures to manage recharge (**VP1).**

Management Area (MA)	Action
MA5 (LOWER SLOPES – COLLUVIAL)	**Vegetation for production** Establish and manage perennial pastures to manage recharge (**VP2).** Improve grazing management of existing perennial pastures to manage recharge (**VP1).** **Farming Systems** Implement rotational cropping with a perennial pasture component to manage recharge **(FS3).** Implement pasture cropping with annual cereals in perennial pastures to manage recharge **(FS1).** Implement zero-till farming systems to increase soil water storage, soil water use and to reduce recharge **(FS6).** Implement controlled traffic farming systems to increase soil water storage, soil water use and to reduce recharge **(FS7).**
MA7 (SALINE SITES)	**Salt land rehabilitation** Fence and isolate salt land and discharge areas to promote revegetation **(SR1).** Establish and manage salt land pasture systems to improve productivity **(SR2).**
MA9 (ALLUVIAL PLAIN)	**Vegetation for ecosystem function** Maintain and improve riparian native vegetation to reduce discharge to streams **(VE4).**

High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative impacts on salinity (Table 7).

Table 7: Management actions having negative salinity impacts in the Brocklesby HGL.

At Risk Management Areas	Action
MA1 (RIDGES)	Poor management of grazing pastures **(DLU2).** Annual cropping with annual plants **(DLU3).**
MA2 (UPPER SLOPES – EROSIONAL)	Annual cropping with annual plants **(DLU3).** Long fallows in farming systems **(DLU1).** Poor management of grazing pastures **(DLU2).**
MA3 (UPPER SLOPES – COLLUVIAL)	Annual cropping with annual plants **(DLU3).** Long fallows in farming systems **(DLU1).** Poor management of grazing pastures **(DLU2).**
MA5 (LOWER SLOPES – COLLUVIAL)	Annual cropping with annual plants **(DLU3).** Long fallows in farming systems **(DLU1).** Poor management of grazing pastures **(DLU2).**
MA7 (SALINE SITES)	Farm dams in flow lines **(DLU5).**
MA9 (ALLUVIAL PLAIN)	Farm dams in flow lines **(DLU5).**

REFERENCES

DECCW, 2010, *Reconnaissance soil and land resources of the Murray CMA*, NSW Department of Environment, Climate Change and Water, Sydney

Geoscience Australia, 2011, *Australian stratigraphic units database*, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int

Keith, D. A. 2004, *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, Hurstville, NSW Department of Environment and Conservation

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, Office of Environment and Heritage, Sydney, [Accessed: 10 November 2014] www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia

Stelling, F. 1998, *South west slopes revegetation guide (south of the Murrumbidgee River)*, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

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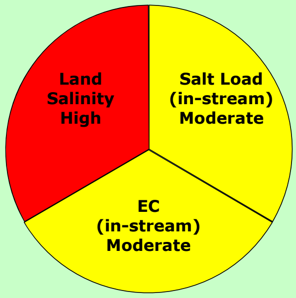
11. Nail Can-Bungowannah Hydrogeological Landscape

LOCALITIES	**Lavington**
MAP SHEET	**Jerilderie 1:250 000** **Wangaratta 1:250 000**
CONFIDENCE LEVEL	**Low**



OVERVIEW

The Nail Can-Bungowannah Hydrogeological Landscape (HGL) is north-west of Albury and south of Burrumbuttock (Figure 1). The HGL covers an area of 188 km^2 and receives 600 to 800 mm of rain per annum.

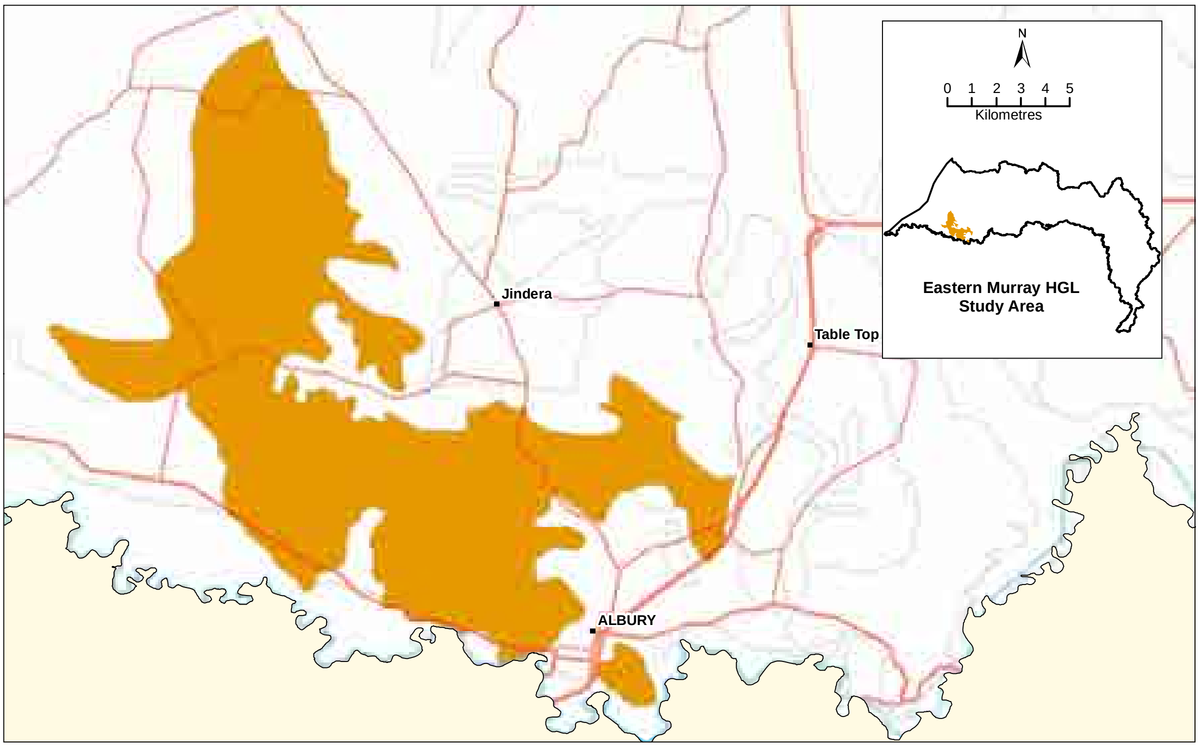


Figure 1: Nail Can-Bungowannah HGL distribution map.

The Nail Can-Bungowannah HGL is characterised by narrow ridge crests and upper slopes; long, straight to waning middle and lower slopes; and narrow drainage lines (Figure 2). Processes are primarily erosional on the ridge crests and upper slopes; colluvial on the long slopes; with minor transferral areas occurring along the drainage lines. This HGL includes rocks from the Ordovician Wagga Group. Unconsolidated colluvial and alluvial sediments derived from the surrounding rocks have been deposited on lower slopes and along streams that pass through. Lacustrine sediments occur adjacent to the riverine plain. Soils are shallow on crests, ridges and upper slopes; moderately deep on mid to lower slopes; and very deep in drainage lines. Topsoils are fragile with structural decline and loss by wind erosion common. Sheet erosion is widespread and has seen removal and translocation of much of the topsoil.

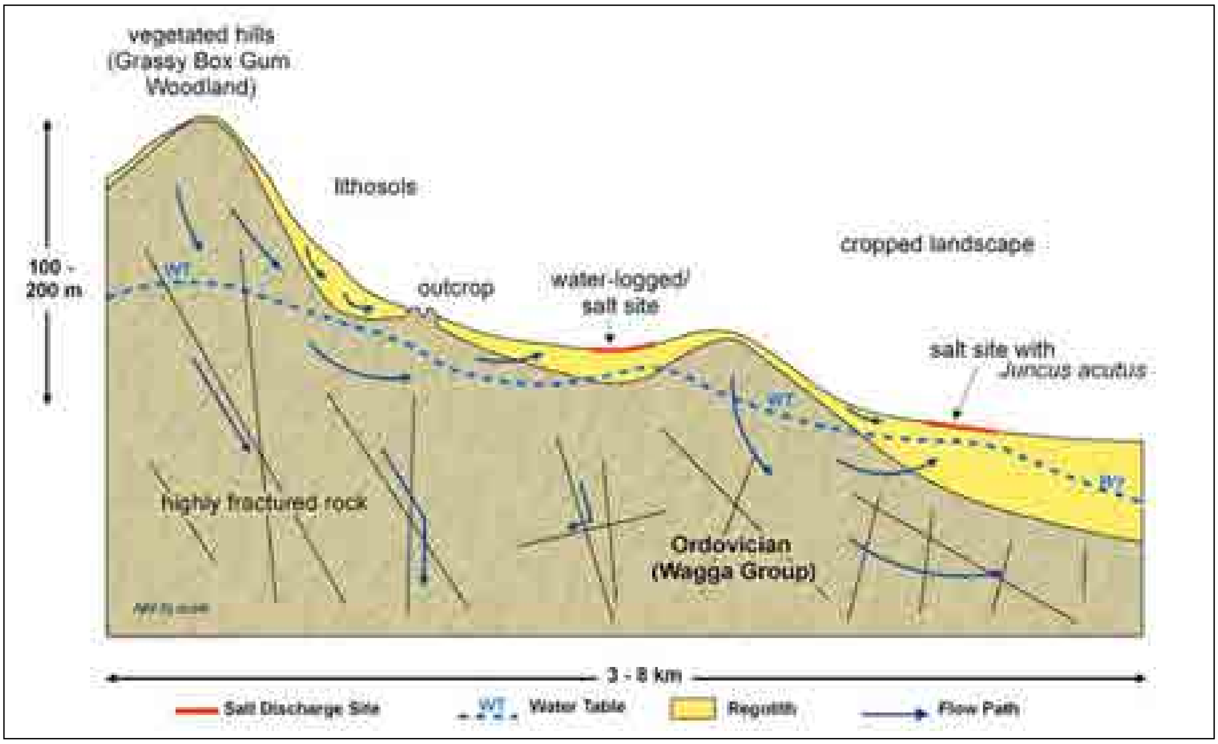


Figure 2: Conceptual cross-section for Nail Can-Bungowannah HGL showing the distribution of regolith and landforms, salt sites if present, and flow paths of water infiltrating the system.

Land salinity is commonly observed, mapped along flow lines and in waterlogged depressions in this HGL. Moderate levels of salt load and EC are present (Table 1).

Table 1: Nail Can-Bungowannah HGL salinity expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	High – salt land commonly observed and mapped along flow lines
Salt Load (Export)	Moderate – perennial creeks observed generating salt load export
EC (Water Quality)	Moderate – water in streams has been observed to be above 600 µS/cm

Salt stored within the Nail Can-Bungowannah HGL has moderate mobility. There is a moderate salt store that has moderate availability (Table 2).

Table 2: Nail Can-Bungowannah HGL salt store and availability.

SALT MOBILITY			
	Low availability	**Moderate** availability	**High** availability
High salt store			
Moderate salt store		**Nail Can-Bungowannah**	
Low salt store			

The overall salinity hazard in the Nail Can-Bungowannah HGL is moderate. This is due to the moderate likelihood that salinity issues will occur that have potentially significant impacts (Table 3).

Table 3: Likelihood of salinity occurrence, potential impact and overall hazard of salinity for the Nail Can-Bungowannah HGL.

OVERALL SALINITY HAZARD			
	Limited potential impact	**Significant** potential impact	**Severe** potential impact
High likelihood of occurrence			
Moderate likelihood of occurrence		**Nail Can-Bungowannah**	
Low likelihood of occurrence			

LANDSCAPE FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 4.

Photo 1: Slightly weathered metamorphic rocks with skeletal soils in the Nail Can-Bungowannah HGL host important box-gum grassy woodlands (Photo: OEH/R Muller).

Photo 2: Slightly weathered metamorphic rocks with skeletal soils in the Nail Can-Bungowannah HGL are increasingly being exposed to urban development (Photo: OEH/R Muller).

Photo 3: Rolling low hills with narrow drainage lines are common in the Nail Can-Bungowannah HGL (Photo: OEH/R Muller).

Photo 4: Relatively broad drainage depressions in the lower parts of the Nail Can-Bungowannah HGL show signs of waterlogging (Photo: OEH/R Muller).

Photo 5: *Juncus acutus* is a common indicator species on moderately sized salt sites in the Nail Can-Bungowannah HGL (Photo: OEH/A Nicholson).

Photo 6: Poor soil structure and sodicity in drainage lines within the Nail Can-Bungowannah HGL can result in significant gully erosion (Photo: OEH/A Nicholson).

Photo 7: Small areas of exposed sub-soil are licked by stock in the Nail Can-Bungowannah HGL and are susceptible to erosion (Photo: OEH/A Nicholson).

Photo 8: Nail Can-Bungowannah HGL landscape view indicating steep slopes and acute landforms (Photo: OEH/A Nicholson).

Table 4: Summary of information used to define the Nail Can-Bungowannah HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2011)*	This HGL comprises locally metamorphosed consolidated sedimentary rocks from the Ordovician period. These are overlain by unconsolidated Quaternary colluvium and lake deposits. Key lithologies include: • colluvium and/or residual deposits – boulders, gravel and sand; may include minor alluvial or sand plain deposits • Wagga Group – quartzose siltstone, sandstone, quartz-mica schist, mudstone and chert. Minor quartzite, graphitic schist and hornfels.
Annual Rainfall	600–800 mm
Regolith and Landforms	The Nail Can-Bungowannah HGL is slightly to moderately weathered and is characterised by hills (90–200 m relief, >20% slope), low hills (30–90 m relief, <20% slope) and rises (9-30 m relief) with narrow ridge crests, moderate to long colluvial slopes and narrow drainage lines, formed on Ordovician metasedimentary bedrock. Regolith materials are kaolinite-bearing quartzose clayey sands with minor gravels and some sandy clays. On ridge crests and upper slopes there are angular tabular pebble and cobble-bearing coarse sandy gravels and gravelly sands with variable kaolinitic clay content.
Soil Landscapes *(DECCW 2010)*	This HGL corresponds closely to Livingstone soil landscape. Small patches of Wait-a-while soil landscape occur on areas of stagnant alluvial plain. Soils are: shallow (<50 cm) Mesotrophic Paralithic Leptic Rudosols (Lithosols) on crests, ridges and upper slopes; moderately deep (50–100 cm) Mesotrophic Red Chromosols and Eutrophic Brown Kurosols (Red and Brown Podzolic Soils) on mid lower slopes; moderately deep (50–100 cm) Mesotrophic Brown Kandosols (Brown Earths) on lower slopes; and, very deep Grey and Brown Self-mulching and Red and Brown Sub-plastic Chromosols and Sodosols (Red-brown Earths/transitional Red-brown Earths) and Epipedal Vertosols (Cracking Grey and Brown Clays) in drainage lines. Topsoils are fragile with structural decline and loss by wind erosion common. Sheet erosion is widespread and has seen the removal and translocation of much of the topsoil. The changed drainage pattern caused by the removal of vegetation and topsoil; the sodic nature of the soils in drainage lines; and the texture contrast nature of soils have contributed to scalding.
Land and Soil Capability *(OEH 2012)*	Class 6
Land Use	Mainly grazing on volunteer, naturalised, native or improved pastures. Areas of native forest exist immediately north and west of Albury. Urban and peri-urban areas are significant

Key Land Degradation Issues	• sheet erosion • minor to moderate gully erosion (up to 1.5m deep – most to bedrock).
Native Vegetation *(Stelling 1998; Keith 2004)*	Vegetation on the upper slopes tends to be white box woodland and red gum woodland, with white box on rises and upper slopes, and yellow box and Blakely's red gum woodland along drainage lines on lower slopes. Tree species can include *Eucalyptus albens* (white box) on relatively fertile, well drained soils on slopes and ridges, *E. polyanthemos* (red box), *E. macrorhyncha* (red stringybark) and *E. dealbata* (tumbledown gum) on shallow to skeletal soils on well drained hills and slopes, *E. goniocalyx* (long-leaf box) on dry rocky slopes and *E. blakelyi* (Blakely's red gum) on compact loamy soils. Other tree species may be *Acacia dealbata* (silver wattle), *A. implexa* (hickory wattle), *Allocasuarina verticillata* (drooping sheoak) on dry ridges, *Brachychiton populneus* (kurrajong) and *Callitris glaucophylla* (white cypress pine). Understorey species may include *Acacia paradoxa* (kangaroo thorn), *A. deanei* ssp. *paucijuga* (Deane's wattle), *A. pycnantha* (golden wattle), *Bursaria spinosa* (sweet bursaria) and *Indigofera adesmiifolia* (tick indigo) on rocky, well drained soils. On lower slopes where the soils are moderately fertile and well drained, additional species may include *E. melliodora* (yellow box) and *E. bridgesiana* (apple box), with *Leptospermum continentale* (prickly tea-tree) in poorly drained sites and soaks on lower slopes.

HYDROGEOLOGY

Aquifers within this landscape are unconfined to semi-confined with groundwater flow occurring primarily through fractures in bedrock and saprolite. Some flow occurs through colluvial and alluvial sediments on lower slopes and in flow lines. Hydraulic conductivity is low to moderate. Transmissivity is low. Groundwater recharge rates are estimated to be moderate to high.

Groundwater systems are typically local with short flow lengths, and are loosely defined by topographic catchments. Water quality within these systems is marginal. Watertable depths are intermediate, with some perching in adjacent to the riverine plain.

Medium residence times are typical. These landscapes have a medium to fast response time to changes in land management.

Typical values for the hydrogeological parameters of this HGL are summarised in Table 5.

Table 5: Summary of values for typical hydrogeological parameters of the Nail Can-Bungowannah HGL.

Aquifer Type	Unconfined to semi-confined in fractured rock and saprolite Lateral flow through unconsolidated colluvial and alluvial sediments on lower slopes and in flow lines Some perching of watertables occurs in lacustrine deposits adjacent to the riverine plain
Hydraulic Conductivity	Low to moderate Range: <10 m/day
Aquifer Transmissivity	Low Range: <2 m^2/day
Specific Yield	Low Range: <5%
Hydraulic Gradient	Moderate Range: 10–30%
Groundwater Salinity	Marginal Range: 800–1600 µS/cm
Depth to Watertable	Intermediate (localised perching) Range: 2–8 m
Typical Sub-Catchment Size	Medium (10 –1000 ha)
Scale (Flow Length)	Local Flow length: <5 km (short)
Recharge Estimate	Moderate to high
Residence Time	Medium (years)
Responsiveness to Change	Fast to medium (months to years)

MANAGEMENT OPTIONS

Overarching salinity management strategies have specific biophysical outcomes. These are achieved by implementing a series of targeted land management actions that take into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape to impact on salinity. Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Salinity is driven by interactions between water-use capacity of vegetation, physical soil properties and hydrogeological processes within the HGL.

Actions that influence the way water is used by vegetation or stored in the soil profile will have impacts on recharge. The influence of both continual and episodic recharge and the

impacts of extreme weather events need to be considered when deciding on appropriate management actions. Short and long-term climate cycles also need to be considered as they have a bearing on salinity processes, particularly salt load and land salinity.

Landscape Functions – Nail Can-Bungowannah HGL

Functions this landscape provides within a catchment scale salinity context:

- **D.** The landscape generates salt loads which enter the streams and are redistributed in the catchment
- **G.** The landscape contains important land assets (including infrastructure and high value agricultural land) on which salinity processes impact
- **B.** The landscape provides fresh water runoff as an important dilution flow source.

Landscape Management Strategies – Nail Can-Bungowannah HGL

Appropriate strategies pertinent to this landscape:

- **Buffer the salt store – keep it dry and immobile (1):** There are stores of salt in colluvial areas that vegetation can buffer, limiting the salinity impact. They are generally in the depositional elements of the lower landscape.
- **Discharge rehabilitation and management (4):** The saline and waterlogged sites are small to moderate in size. Discharge management will improve on-site and off-site salinity outcomes when vegetation is matched to salt sites.
- **Dry out the landscape with diffuse actions over most of the landscape (6):** Encourage plant growth and increase plant water use in order to use excess soil moisture and shallow groundwater. Healthy, actively growing vegetation will also act as a buffer to groundwater accessions in wet seasonal conditions.

Key Management Focus – Nail Can-Bungowannah HGL

In areas under agricultural land use, the focus should be on farm water efficiency through grazing management within mixed farming.

In areas under urban, peri-urban or future urban development, salinity should be an important consideration for planning civil and civic engineering projects.

Specific Land Management Opportunities

Specific opportunities for this HGL:

- High watertables exist in low areas of the landscape. These offer potential for pasture based grazing systems based on pastures that have salt and waterlogging tolerance.
- High recharge areas are frequently covered with native vegetation. These offer the opportunity to maintain and improve native vegetation.
- Changing management in saline areas, especially grazing management will improve on-site and off-site salinity outcomes.
- Remnant native vegetation exists in the landscape. Maintaining and improving remnant vegetation is an important component of catchment salinity management.

Specific Land Management Constraints

Constraints for land management in this HGL include:

- Urban encroachment is both a victim of and contributor to salinity processes in this landscape.
- Climatic limitations will influence the ability of pasture systems to reduce recharge and manage discharge.
- Soil constraints will restrict pasture growth, particularly high gravel content, soil acidity and low CEC.

Specific Targeted Actions

Management areas for this HGL are illustrated in Figure 3. The specific management actions for these areas are described in Table 6.

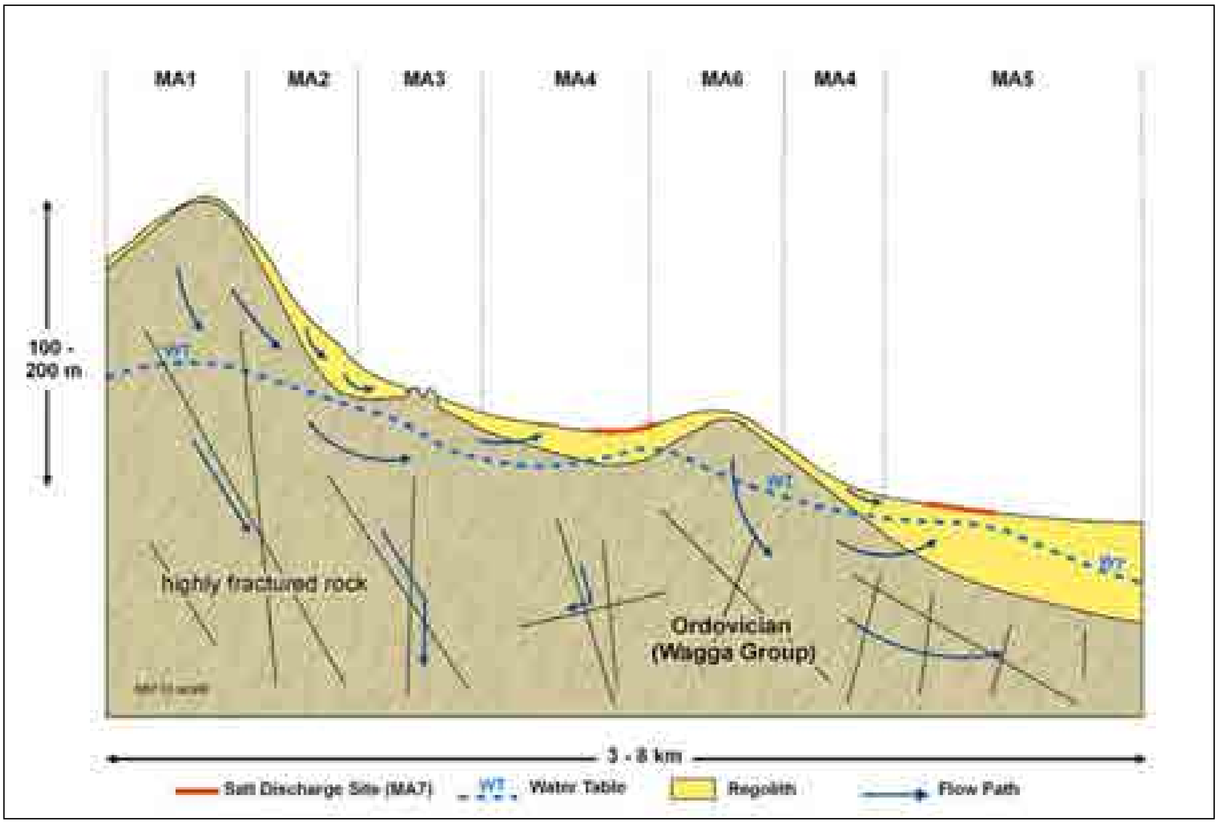


Figure 3: Management cross-section for Nail Can-Bungowannah HGL showing defined management areas.

Table 6: Specific management actions for management areas within the Nail Can-Bungowannah HGL.

Management Area (MA)	Action
MA1 (RIDGES)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** Revegetate non-agricultural land with native species to manage recharge **(VE6).**
MA2 (UPPER SLOPES – EROSIONAL)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** Revegetate non-agricultural land with native species to manage recharge **(VE6).**
MA3 (UPPER SLOPES – COLLUVIAL)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** Revegetate non-agricultural land with native species to manage recharge **(VE6).**
MA4 (MID-SLOPES)	**Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge (**VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** **Farming Systems** Implement rotational cropping with a perennial pasture component to manage recharge **(FS3).** Implement pasture cropping with annual cereals in perennial pastures to manage recharge **(FS1).** Implement zero-till farming systems to increase soil water storage, soil water use and to reduce recharge **(FS6).**

Management Area (MA)	Action
MA5 (LOWER SLOPES – COLLUVIAL)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** Maintain and improve riparian native vegetation to reduce discharge to streams **(VE4).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge (**VP1).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).** **Farming Systems** Implement rotational cropping with a perennial pasture component to manage recharge **(FS3).** Implement pasture cropping with annual cereals in perennial pastures to manage recharge **(FS1).** Implement zero-till farming systems to increase soil water storage, soil water use and to reduce recharge **(FS6).**
MA6 (RISES)	**Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge (**VP1).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).** Establish and manage perennial pastures to manage recharge (**VP2).**
MA7 (SALINE SITES)	**Salt land rehabilitation** Fence and isolate salt land and discharge areas to promote revegetation **(SR1).** Establish and manage salt land pasture systems to improve productivity **(SR2).** Mulch sites using tactical animal impact **(SR9).**

High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative impacts on salinity (Table 7).

Table 7: Management actions having negative salinity impacts in the Nail Can-Bungowannah HGL.

At Risk Management Areas	Action
MA1 (RIDGES)	Clearing and poor management of native vegetation **(DLU4).** Poor management of grazing pastures **(DLU2).**
MA2 (UPPER SLOPES – EROSIONAL)	Clearing and poor management of native vegetation **(DLU4).** Poor management of grazing pastures **(DLU2).**
MA3 (UPPER SLOPES – COLLUVIAL)	Annual cropping with annual plants **(DLU3).** Poor management of grazing pastures **(DLU2).**
MA4 (MID-SLOPES)	Annual cropping with annual plants **(DLU3).** Poor management of grazing pastures **(DLU2).**
MA5 (LOWER SLOPES – COLLUVIAL)	Clearing and poor management of native vegetation **(DLU4).** Farm dams in flow lines **(DLU5).** Locating infrastructure on discharge areas **(DLU7).** Annual cropping with annual plants **(DLU3).** Long fallows in farming systems **(DLU1).**
MA6 (RISES)	Annual cropping with annual plants **(DLU3).** Poor management of grazing pastures **(DLU2).**
MA7 (SALINE SITES)	Farm dams in flow lines **(DLU5).** Poor management of grazing pastures **(DLU2).**

REFERENCES

DECCW, 2010, *Reconnaissance soil and land resources of the Murray CMA*, NSW Department of Environment, Climate Change and Water, Sydney

Geoscience Australia, 2011, *Australian stratigraphic units database*, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int

Keith, D. A. 2004, *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, Hurstville, NSW Department of Environment and Conservation

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, OEH Sydney, [Accessed: 10 November 2014] www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

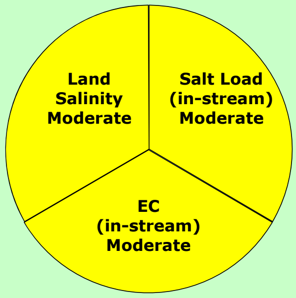
Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia

Stelling, F. 1998, *South west slopes revegetation guide (south of the Murrumbidgee River)*, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

Wooldridge, A., Nicholson, A., Muller R., Jenkins, B. R., Wilford, J. and Winkler, M. 2015, *Guidelines for managing salinity in rural areas*, NSW Office of Environment and Heritage, Sydney, NSW

12. Yambla Hydrogeological Landscape

LOCALITIES	**Yambla Ridge, Clay Hill**
MAP SHEET	**Jerilderie 1:250 000** **Wagga Wagga 1:250 000**
CONFIDENCE LEVEL	**Low**



OVERVIEW

The Yambla Hydrogeological Landscape (HGL) extends from north of Table Top to south of Culcairn and is dominated by the Great Yambla Ridge to the east of Gerogery (Figure 1). The HGL covers an area of 138 km^2 and receives 650 to 900 mm of rain per annum.

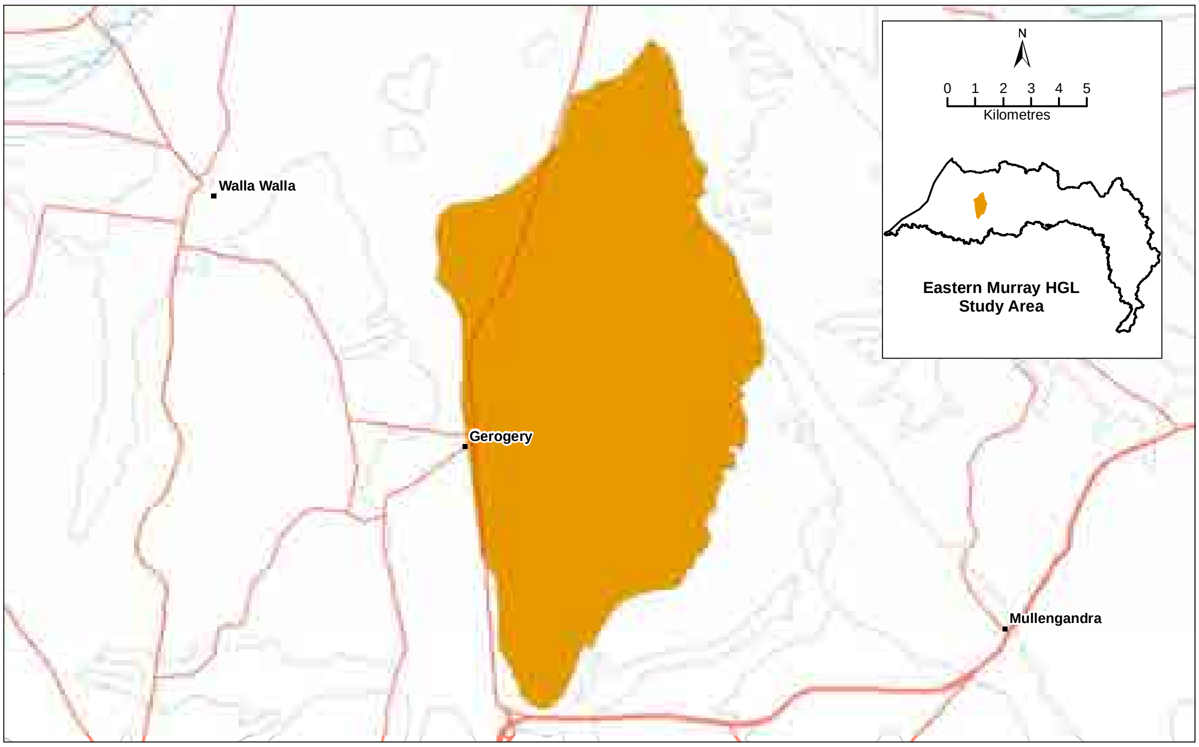


Figure 1: Yambla HGL distribution map.

The Yambla HGL is moderately weathered and is characterised by a gently inclined long westerly sloping plain, rolling hills, undulating foot-slopes, undulating plateaus and cliffs and steep slopes (Figure 2). Moderately spaced, shallow drainage lines often cut to bedrock. Rock outcrop occurs on crests, on the edges of flat crests, and on mid to lower slopes. This HGL includes consolidated Devonian sedimentary rocks and associated unconsolidated colluvial material. In lower parts of the landscape, these are overlain by unconsolidated

Cenozoic fluvial sediments. Soils are shallow and well-drained on crests, ridges and on flatter upper slopes; shallow, moderately well-drained on upper and mid-slopes associated with rock outcrop; deep and moderately well-drained on lower slopes; and deep and poorly drained in drainage lines. Significant waterlogging occurs on lower slopes. Gully and tunnel erosion is evident in drainage depressions. Mass movement (rockfall) occurs on scarp slopes, with sheet erosion on steep slopes.

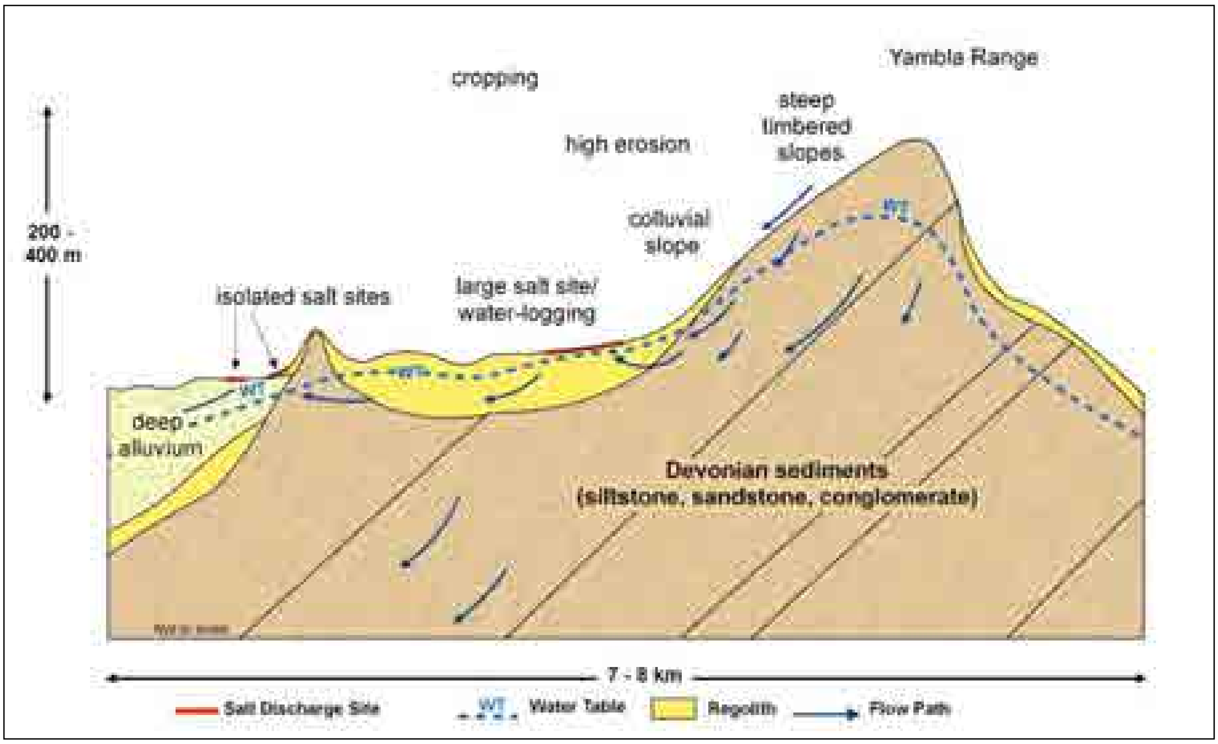


Figure 2: Conceptual cross-section for Yambla HGL showing the distribution of regolith and landforms, salt sites if present, and flow paths of water infiltrating the system.

Large salt sites occur at base of main range slope, and isolated sites occur adjacent to the low ridge to the west of the HGL. This HGL generates moderate salt load and EC (Table 1).

Table 1: Yambla HGL salinity expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	Moderate – large salt sites occur at the base of the Great Yambla Ridge slope, and isolated sites are present adjacent to low ridge to the west of the ridge
Salt Load (Export)	Moderate – significant salt load exported during wet periods
EC (Water Quality)	Moderate EC observed during wet periods with occasional high spikes

Salt stored within the Yambla HGL has moderate mobility. There is a moderate salt store that has moderate availability (Table 2).

Table 2: Yambla HGL salt store and availability.

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

The overall salinity hazard in the Yambla HGL is moderate. This is due to the moderate likelihood that salinity issues will occur that have potentially significant impacts (Table 3).

Table 3: Likelihood of salinity occurrence, potential impact and overall hazard of salinity for the Yambla HGL.

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

LANDSCAPE ATTRIBUTES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 4.

Photo 1: Steep cliffs and slopes of the Great Yambla Ridge are characteristic of the eastern side of the Yambla HGL (Photo: OEH/R Muller).

Photo 2: Undulating foot-slopes and a long, gently inclined, westerly sloping plain are characteristic of the western side of the Great Yambla Ridge in the Yambla HGL (Photo: OEH/A Nicholson).

Photo 3: Waterlogging and tree decline in the lower slopes of the western side of the Great Yambla Ridge in the Yambla HGL (Photo: OEH/A Nicholson).

Photo 4: Photo indicating abrupt slope change from the westerly sloping plain to the very steep upper slopes (Photo: OEH/A Nicholson).

Photo 5: A low, north-south trending ridge occurs between Gerogery and the Great Yambla Ridge in the Yambla HGL (Photo: OEH/R Muller).

Photo 6: A low, north-south trending ridge occurs between Gerogery and the Great Yambla Ridge in the Yambla HGL (Photo: OEH/R Muller).

Photo 7: In the Yambla HGL, waterlogging is common on the eastern side of the low ridge, where it meets the long, westerly sloping plain coming from the Great Yambla Ridge (Photo: OEH/R Muller).

Photo 8: Undulating foot-slopes and a long, gently inclined, westerly sloping plain are characteristic of the western side of the Great Yambla Ridge in the Yambla HGL (Photo: OEH/R Muller).

Table 4: Summary of information used to define the Yambla HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2011)*	This HGL comprises consolidated Devonian sedimentary rocks and associated unconsolidated colluvial material. In lower parts of the landscape, these are overlain by unconsolidated Cenozoic fluvial sediments. Key lithologies include: • Shepparton Formation – unconsolidated to poorly consolidated mottled variegated clay, silty clay with lenses of polymictic, coarse to fine sand and gravel; partly modified by pedogenesis • unnamed sandstone, conglomerate, siltstone, shale and quartzite; often ferruginous.
Annual Rainfall	650–900 mm.
Regolith and Landforms	The Yambla HGL is slightly to moderately weathered and is characterised by steep to precipitous mountains (300–400 m relief), hills (90–300m relief), and low hills 30–90 m relief) with broad flat crests forming an undulating plateau, on Devonian sedimentary bedrock. Outcrop (30–75%) occurs on crests and mid to lower slopes. Rises (9–30 m relief) and gently inclined westerly sloping alluvial plains (<9 m relief) flank the higher landscape elements. The low-lying part of the landscape is formed on Quaternary Shepparton Formation alluvial sediments. Slopes range from 2–75% with local relief of 10–400 m, and this HGL is between 200–650 m elevation. Moderately spaced shallow drainage lines often incise through to bedrock. The parent rock is highly resistant and regolith is poorly developed. Regolith materials are kaolinite-bearing quartzose clayey sands with gravels. On ridge crests and upper slopes there are angular tabular pebble and cobble-bearing coarse sandy gravels and gravelly sands.
Soil Landscapes *(DECCW 2010)*	This HGL contains a suite of soil landscapes on sandstones and conglomerates. They are distinguished by relief and slope. Great Yambla Ridge soil landscape occupies undulating plateau, The Rock Uplifted westerly-dipping plateau, Hell Hole rolling hills, Morven Lane undulating low hills and rises and Gerogery very gently inclined plain and foot-slopes. Soils include: shallow (<50 cm), well-drained Clastic Rudosols (Lithosols) on crests, and ridges on flatter upper slopes; shallow (<0.5 m), moderately well-drained Leptic Tenosols and Lutic Rudosols (Lithosols) on upper and mid-slopes associated with rock outcrop; deep (1.0–1.5 m), moderately well-drained Red and Brown Chromosols and Kurosols (Red Podzolic Soils) on lower slopes; deep (1.0–1.5 m), and poorly drained Brown, Grey, and Red Sodosols (Soloths) and Grey Kurosols (Grey Podzolic Soils) in drainage lines; and, Stratic Rudosols (Alluvial Soils) occur along current and ancient channels.
Land and Soil Capability *(OEH 2012)*	Class 5

Land Use	Predominantly grazing country with areas of Nature Reserve and National Park on the Ridge. Small areas of cropping occur on the flat country to the west
Key Land Degradation Issues	• moderate sheet erosion on steep slopes • moderate gully erosion • tunnel erosion in drainage depressions • significant waterlogging on lower slopes • sodicity (localised) • salinity (localised) • acidity (localised) • aluminium toxicity (localised) • manganese toxicity (localised)
Native Vegetation *(Stelling 1998; Keith 2004)*	Vegetation on the upper and lower slopes tends to be white box and grey box woodland dominant, with some Blakely's red gum woodland. white box woodland also occurs on the flats and gentle rises. Vegetation on the rocky outcrops tends to be Dwyer's red gum woodland with currawang and long-leaf box, as well as red stringybark dry forest on the drier slopes with south-easterly aspect. Tree species in the rocky outcrops include *Acacia doratoxylon* (currawang), *A. implexa* (hickory wattle), *Allocasuarina verticillata* (drooping sheoak) on dry ridges, *Eucalyptus goniocalyx* (long-leaf box) on dry rocky slopes with shallow soil, *Brachychiton populneus* (kurrajong), *E. polyanthemos* (red box) and *E. dwyeri* (Dwyer's red gum) on well drained sites with shallow soils, *E. albens* (white box) on more fertile slopes and ridges, *E. blakelyi* (Blakely's red gum) on compact loamy soils, *Callitris glaucophylla* (white cypress pine), and *C. endlicheri* (black cypress pine). Understorey species include *Acacia rubida* (red-stemmed wattle), *A. verniciflua* (varnish wattle), *Dillwynia* spp. (parrot pea), *Dodonaea viscosa* ssp. *angustissima* (narrow-leaf hop-bush), *Indigofera australis* (austral indigo) and *Pultenaea cunninghamii* (grey bush-pea). Tree species on the upper and lower slopes may also include *Acacia dealbata* (silver wattle), *Eucalyptus dealbata* (tumbledown gum), *E. melliodora* (yellow box) and *E. microcarpa* (grey box). Understorey species on the slopes may include *Bursaria spinosa* (sweet bursaria), *Daviesia ulicifolia* (gorse bitter pea) and *Indigofera adesmiifolia* (tick indigo).

HYDROGEOLOGY

Aquifers within this landscape are unconfined to semi-confined with groundwater flow occurring primarily through fractures in bedrock and saprolite. Significant flow also occurs through colluvial and alluvial sediments on lower slopes and in flow lines. Hydraulic conductivity is moderate to high and transmissivity is low to moderate. Groundwater recharge rates are estimated to be moderate to high.

Groundwater systems are typically local with short flow lengths, and are loosely defined by topographic catchments. Water quality within these systems is marginal. Watertable depths are shallow to intermediate. Localised perching of watertables occurs above clay lenses during wetter periods.

Short to medium residence times are typical. These landscapes have a medium to fast response time to changes in land management.

Typical values for the hydrogeological parameters of this HGL are summarised in Table 5.

Table 5: Summary of values for typical hydrogeological parameters of the Yambla HGL.

Aquifer Type	Unconfined to semi-confined in fractured rock and saprolite Lateral flow through unconsolidated colluvial and alluvial sediments on lower slopes and in flow lines Some perching of watertables occurs in flatter parts of the landscape
Hydraulic Conductivity	Moderate to high Range: 10^{-2}–>10 m/day
Aquifer Transmissivity	Low to moderate Range: <50 m^2/day
Specific Yield	Moderate to high Range: 5–>15%
Hydraulic Gradient	Moderate to steep Range: 10–>30%
Groundwater Salinity	Marginal Range: 800–1600 µS/cm
Depth to Watertable	Shallow to intermediate (localised perching) Range: <8 m
Typical Sub-Catchment Size	Small (<100 ha)
Scale (Flow Length)	Local Flow length: <5 km (short)
Recharge Estimate	Moderate to high
Residence Time	Short to medium (months to years)
Responsiveness to Change	Fast to medium (months to years)

MANAGEMENT OPTIONS

Overarching salinity management strategies have specific biophysical outcomes. These are achieved by implementing a series of targeted land management actions that take into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape to impact on salinity. Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Salinity is driven by interactions between water-use capacity of vegetation, physical soil properties and hydrogeological processes within the HGL.

Actions that influence the way water is used by vegetation or stored in the soil profile will have impacts on recharge. The influence of both continual and episodic recharge and the impacts of extreme weather events need to be considered when deciding on appropriate management actions. Short and long-term climate cycles also need to be considered as they have a bearing on salinity processes, particularly salt load and land salinity.

Landscape Salinity Functions – Yambla HGL

Functions this landscape provides within a catchment scale salinity context:

- **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
- **D.** The landscape generates salt loads which enter the streams and are redistributed in the catchment.

Management Strategy Objectives – Yambla HGL

Appropriate strategies pertinent to this landscape:

- **Buffer the salt store – keep it dry and immobile (1):** This HGL contributes significant fresh water as dilution flow to the local stream system. The fresh runoff mitigates the salt load, stream salinity and EC concentration of the local streams.
- **Discharge rehabilitation and management (4):** Discharge management will improve on-site and off-site salinity outcomes.
- **Maintain or maximise runoff (10):** There are stores of salt in colluvial areas that vegetation can buffer, limiting the salinity impact. These areas are generally in the depositional elements of the lower landscape.

Key Management Focus – Yambla HGL

This HGL is a net dilution landscape in the context of local streams. There are salt land outbreaks. This landscape should have a focus on discharge management. There are also large areas of native vegetation in this landscape.

Specific Land Management Opportunities

Specific opportunities for this HGL:

- Remnant native vegetation exists in the landscape. Maintaining and improving this is an important component of catchment salinity management action.

Specific Land Management Constraints

Constraints for land management in this HGL include:

- Saline soils in the colluvial parts of this landscape
- Seasonal waterlogging occurs during low growth periods of the year
- Low CEC soils with low water holding capacity and low fertility.

Specific Targeted Actions

Management areas for this HGL are illustrated in Figure 3. The specific management actions for these areas are described in Table 6.

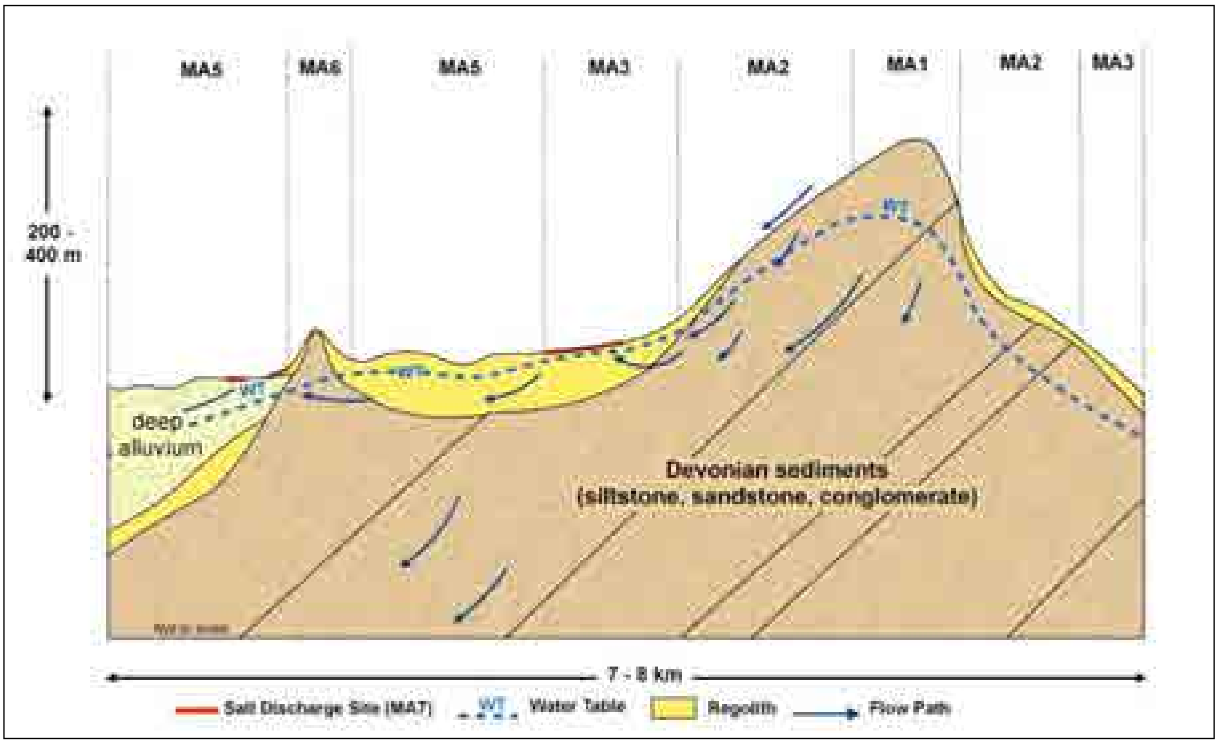


Figure 3: Management cross-section for Yambla HGL showing defined management areas.

Table 6: Specific management actions for management areas within the Yambla HGL.

Management Area (MA)	Action
MA1 (RIDGES)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).**
MA2 (UPPER SLOPES – EROSIONAL)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).**

Management Area (MA)	Action
MA3 (UPPER SLOPES – COLLUVIAL)	**Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge (**VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).** **Farming Systems** Implement pasture cropping with annual cereals in perennial pastures to manage recharge **(FS1).** Implement rotational cropping with a perennial pasture component to manage recharge **(FS3).**
MA6 (RISE)	**Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge (**VP1).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).** **Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).**
MA5 (LOWER SLOPES – COLLUVIAL)	**Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge (**VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).** **Farming Systems** Implement pasture cropping with annual cereals in perennial pastures to manage recharge **(FS1).** Implement rotational cropping with a perennial pasture component to manage recharge **(FS3).**

Management Area (MA)	Action
MA7 (SALINE SITES)	**Salt land rehabilitation** Fence and isolate salt land and discharge areas to promote revegetation **(SR1).** Establish and manage salt land pasture systems to improve productivity **(SR2).** Undertake rehabilitation to ameliorate land salinity processes and reduce land degradation **(SR4).** Mulch sites to reduce evaporation and promote pasture growth **(SR8).** Mulch sites using tactical animal impact **(SR9).**

High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative impacts on salinity (Table 7).

Table 7: Management actions having negative salinity impacts in the Yambla HGL.

At Risk Management Areas	Action
MA1/MA6 (RIDGES & RISES)	Clearing and poor management of native vegetation **(DLU4).**
MA2 (UPPER SLOPES – EROSIONAL)	Clearing and poor management of native vegetation **(DLU4).**
MA3 (UPPER SLOPES – COLLUVIAL	Annual cropping with annual plants **(DLU3).**
MA5 (LOWER SLOPES – COLLUVIAL)	Long fallows in farming systems **(DLU1).** Annual cropping with annual plants **(DLU3).**

REFERENCES

DECCW, 2010, *Reconnaissance soil and land resources of the Murray CMA*, NSW Department of Environment, Climate Change and Water, Sydney

Geoscience Australia, 2011, *Australian stratigraphic units database*, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int

Keith, D. A. 2004, *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, Hurstville, NSW Department of Environment and Conservation

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, OEH Sydney, [Accessed: 10 November 2014] www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

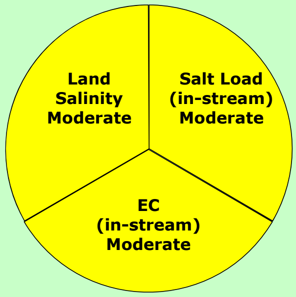
Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia

Stelling, F. 1998, *South west slopes revegetation guide (south of the Murrumbidgee River)*, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

Wooldridge, A., Nicholson, A., Muller R., Jenkins, B. R., Wilford, J. and Winkler, M. 2015, *Guidelines for managing salinity in rural areas*, NSW Office of Environment and Heritage, Sydney, NSW

13. Table Top Hydrogeological Landscape

LOCALITIES	**Table Top, Ettamogah, Thurgoona**
MAP SHEET	**Jerilderie 1:250 000** **Tallangatta 1:250 000** **Wagga Wagga 1:250 000** **Wangaratta 1:250 000**
CONFIDENCE LEVEL	**Low**



OVERVIEW

The Table Top Hydrogeological Landscape (HGL) extends from Thurgoona to Table Top north-east of Albury (Figure 1). The HGL covers an area of 121 km^2 and receives 700 to 900 mm of rain per annum.

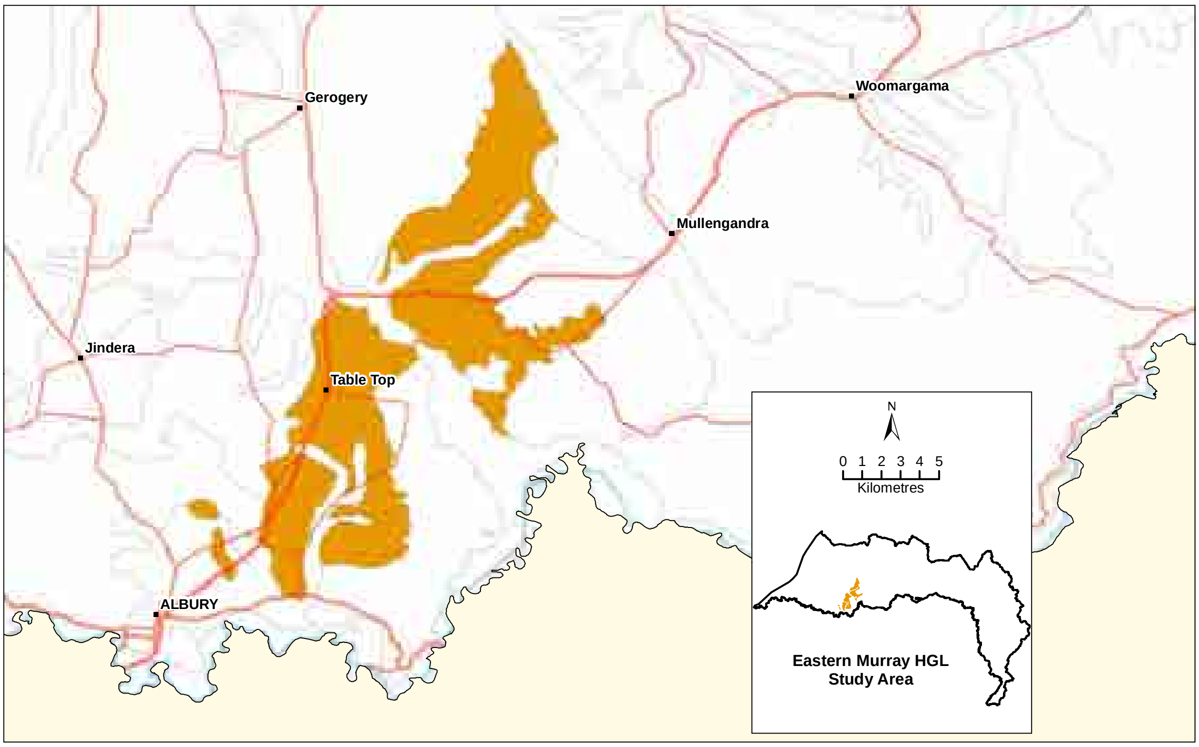


Figure 1: Table Top HGL distribution map.

The Table Top HGL is moderately to deeply weathered with undulating low hills and rises having rounded crests and long gently inclined foot-slopes (Figure 2). Undulating plains and fans are also present. Slopes are gentle and waxing. Drainage lines are widely spaced and poorly defined. This HGL includes consolidated intrusive and metamorphosed rocks from the Ordovician period and volcanic rocks from the Silurian-Devonian periods. Unconsolidated colluvial and alluvial sediments associated with the surrounding rocks have been deposited on lower slopes and along flow lines that pass through. Soils on the more extensive subdued terrain are well-drained on crests; and deep and moderately well-drained on slopes. Foot-slopes and drainage lines consist of deep, poorly drained soils. Soils on the more rugged terrain are shallow and well-drained on crests and steep upper and mid-slopes; and well drained on the lower slopes. Degradation is generally linked to topography with sheet erosion and mass movement on the steepest slopes. In the drainage lines sodic soils are fragile and readily erode. The sodic soils tend to seal and waterlog. This interaction contributes to salinity within this HGL.

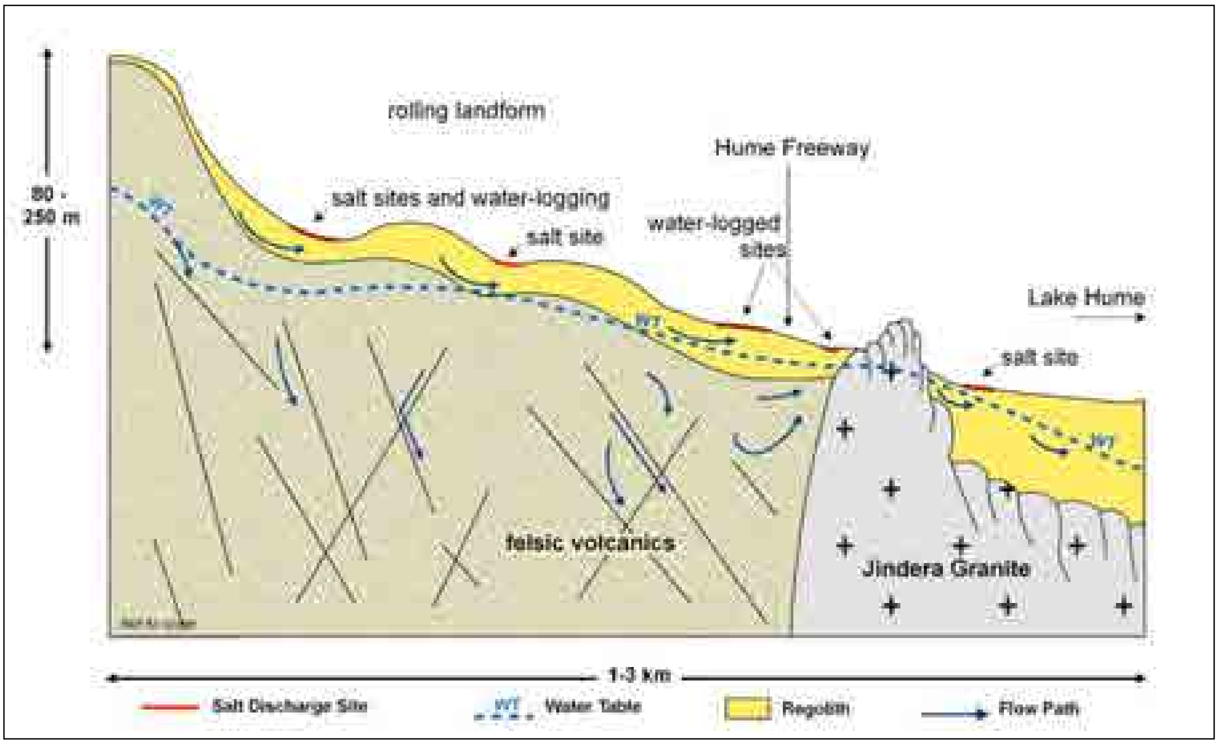


Figure 2: Conceptual cross-section for Table Top HGL showing the distribution of regolith and landforms, salt sites if present, and flow paths of water infiltrating the system.

Salt sites are common and visible across the landscape in topographic depressions and associated with texture changes. Salt load and EC in this HGL are moderate (Table 1).

Table 1: Table Top HGL salinity expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	Moderate – common salt sites visible across the landscape in topographic depressions and associated with texture changes
Salt Load (Export)	Moderate – streams are mostly perennial and export most of the year
EC (Water Quality)	Moderate – salinity levels observed at a range of sites are moderate

Salt stored within the Table Top HGL has moderate mobility. There is a moderate salt store that has moderate availability (Table 2).

Table 2: Table Top HGL salt store and availability.

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

The overall salinity hazard in the Table Top HGL is high. This is due to the high likelihood that salinity issues will occur that have potentially significant impacts (Table 3).

Table 3: Likelihood of salinity occurrence, potential impact and overall hazard of salinity for the Table Top HGL.

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

LANDSCAPE FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 4.

Photo 1: The undulating hills and rises running down to undulation plains seen in the Table Top area are typical of the Table Top HGL (Photo: OEH/R Muller).

Photo 2: The undulating hills and rises running down to undulation plains seen in the Table Top area are common features of the Table Top HGL (Photo: OEH/R Muller).

Photo 3: A common feature of the Table Top HGL is granitic hills that rise out of the undulating plain (Photo: OEH/R Muller).

Photo 4: Undulating hills and rises with rounded crests seen in the Table Top area (Photo: OEH/R Muller).

Photo 5: Relief in the northern end of the Table Top HGL is greater with steeper hill-slopes (Photo: OEH/R Muller).

Photo 6: Relief in the northern end of the Table Top HGL is greater with steeper hill-slopes running down to a broad plain (Photo: OEH/R Muller).

Table 4: Summary of information used to define the Table Top HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2011)*	This HGL comprises consolidated intrusive and metamorphosed rocks from the Ordovician period and volcanic rocks from the Silurian-Devonian periods. Unconsolidated colluvial and alluvial sediments associated with the surrounding rocks have been deposited on lower slopes and along flow lines that pass through. The key lithologies are: • unnamed felsic volcanics and volcaniclastics – pale to intermediate coloured volcanic and volcaniclastic rocks rich in quartz and feldspar • Bethanga Gneiss – gneiss • Felsic intrusives – granite, granodiorite, gneissic granite.
Annual Rainfall	700–900 mm
Regolith and Landforms	The Table Top HGL is slightly to moderately weathered and is characterised by an undulating landscape of low hills (30–90 m relief) and rises (9–30 m relief) with rounded crests and an area of steeper hills (90–250 m relief) in the north, formed on indurated Ordovician metamorphic (gneiss) and Siluro-Devonian felsic volcanic bedrock. Slopes are typically <10%, local relief is up to 250 m, and this HGL is between 200–500 m elevation. Long gently inclined colluvial slopes are common, and transition into alluvial plains with widely spaced and poorly defined drainage lines. Regolith materials are quartzose clayey sands with gravels. On ridge crests and upper slopes there are angular pebble and cobble-bearing coarse sandy gravels and gravelly sands.
Soil Landscapes *(DECCW 2010)*	Ettamogah is the most commonly occurring soil landscape found within this HGL. Minor occurrences of many other soil landscapes including Pulletop, Cookardinia, Big Budginigi Hill, Knox Road, Soldiers hill, Hell Hole and The Rock. Soils on the more extensive subdued terrain include: well-drained Red Chromosols and Kurosols (Red Podzolic Soils) occur on crests; deep (1.0–1.5 m), moderately well-drained Yellow Chromosols (Yellow Podzolic Soils) on slopes of the more extensive subdued terrain. Foot-slopes and drainage lines consist of deep (1.0–1.5 m), poorly drained Yellow Sodosols (Brown and Yellow Soloths and Solodic Soils). Soils on the more rugged terrain include: shallow (<50 cm), well-drained Clastic Rudosols or Leptic Tenosols (Lithosols) on crests, steep upper and mid-slopes; and, well drained Red and Brown Kandosols (Red and Brown Earths) on the lower slopes. Degradation is generally linked to topography with sheet erosion and mass movement on the steepest slopes. In the drainage lines sodic soils (Sodosols and Kurosols) are fragile and readily erode. The sodic soils tend to seal and waterlog. This interaction contributes to salinity within this HGL.
Land and Soil Capability *(OEH 2012)*	Class 5

Land Use	Dominantly grazing land with areas of softwood plantation, vegetation reserves and minor irrigated cropping. Peri-urban development
Key Land Degradation Issues	• moderate sheet and rill erosion (upper slopes) • moderate wind erosion • moderate gully erosion (localised) • seasonal waterlogging (localised) • salinity (localised).
Native Vegetation *(Stelling 1998; Keith 2004)*	Vegetation on the hills south of the highway tends to be white box woodland and red gum woodland (including Blakely's and tumbledown red gum), while vegetation north of the highway (where Table Top HGL occurs on the eastern slopes of Yambla Range only) tends to be red stringybark dry sclerophyll forest. Tree species on the hilly country can include *Eucalyptus dealbata* (tumbledown gum) and *E. goniocalyx* (long-leaf box) on well drained, north and north-west facing dry rocky slopes, or *E. macrorhyncha* (red stringybark) on south and south-eastern slopes, as well as *Allocasuarina verticillata* (drooping sheoak) on dry ridges, *E. albens* (white box) on fertile slopes and ridges, *E. blakelyi* (Blakely's red gum) on loamy soils, *E. polyanthemos* (red box), *Brachychiton populneus* (kurrajong), *Exocarpos cupressiformis* (native cherry), *Acacia dealbata* (silver wattle) and *Callitris glaucophylla* (white cypress pine). Understorey species on hilly country may include *Acacia rubida* (red-stemmed wattle), *A. verniciflua* (varnish wattle) and *A. paradoxa* (kangaroo thorn), as well as *Bursaria spinosa* (sweet bursaria), *Daviesia latifolia* (hop bitter-pea), *Grevillea alpina* (cat's claws), *Platylobium formosum* (handsome flat-pea), *Pultenaea largiflorens* (twiggy bush-pea) and *Indigofera adesmiifolia* (tick indigo). *Cassinia aculeata* (common cassinia) is prolific on the Tabletop HGL slopes. Tree species on the south-eastern facing slopes of the Yambla Range may include *E. macrorhyncha* (red stringybark) more prolifically, as well as *E. dwyeri* (Dwyer's red gum) and *Acacia doratoxylon* (currawang) on well drained rocky soils. *Callitris endlicheri* (black cypress pine) is present but uncommon. Understorey species may include *A. pycnantha* (golden wattle) and *A. verniciflua* (varnish wattle). Species on the lower slopes south of the highway may include *E. melliodora* (yellow box) where the soils are moderately fertile and well drained, and *E. bridgesiana* (apple box) where soils are heavier.

HYDROGEOLOGY

Aquifers within this landscape are unconfined to semi-confined with groundwater flow primarily through fractures in bedrock and saprolite. Some flow occurs through colluvial and alluvial sediments on lower slopes and in flow lines. Hydraulic conductivity is low to moderate and transmissivity is low. Groundwater recharge rates are estimated to be moderate.

Groundwater systems are typically local with short flow lengths and are loosely defined by topographic catchments. Water quality within these systems is marginal. Watertable depths are shallow to intermediate.

Medium to long residence times are typical. These landscapes have a medium response time to changes in land management.

Typical values for the hydrogeological parameters of this HGL are summarised in Table 5.

Table 5: Summary of values for typical hydrogeological parameters of the Table Top HGL.

Aquifer Type	Unconfined to semi-confined in fractured rock and saprolite Lateral flow through unconsolidated colluvial and alluvial sediments on lower slopes and in flow lines
Hydraulic Conductivity	Low to moderate Range: <10^{-2}–10 m/day
Aquifer Transmissivity	Low Range: <2 m^2/day
Specific Yield	Low to moderate Range: <5–15%
Hydraulic Gradient	Moderate Range: 10–30%
Groundwater Salinity	Marginal Range: 800–1600 µS/cm
Depth to Watertable	Shallow to intermediate Range: <2–8 m
Typical Sub-Catchment Size	Small (<100 ha)
Scale (Flow Length)	Local Flow length: <5 km (short)
Recharge Estimate	Moderate
Residence Time	Medium to long (years to decades)
Responsiveness to Change	Medium (years)

MANAGEMENT OPTIONS

Overarching salinity management strategies have specific biophysical outcomes. These are achieved by implementing a series of targeted land management actions that take into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape to impact on salinity. Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Salinity is driven by interactions between water-use capacity of vegetation, physical soil properties and hydrogeological processes within the HGL.

Actions that influence the way water is used by vegetation or stored in the soil profile will have impacts on recharge. The influence of both continual and episodic recharge and the impacts of extreme weather events need to be considered when deciding on appropriate management actions. Short and long-term climate cycles also need to be considered as they have a bearing on salinity processes, particularly salt load and land salinity.

Landscape Salinity Functions – Table Top HGL

Functions this landscape provides within a catchment scale salinity context:

- **D.** The landscape generates salt loads which enter the streams and are redistributed in the catchment.
- **G.** The landscape contains important land assets (including infrastructure and high value agricultural land) on which salinity processes impact.

Management Strategy Objectives – Table Top HGL

Appropriate strategies pertinent to this landscape:

- **Buffer the salt store – keep it dry and immobile (1):** There are stores of salt in this landscape that vegetation can buffer, limiting the salinity impact. These areas are generally in the depositional elements of the rolling landscape and close to changes in underlying geology.
- **Discharge rehabilitation and management (4):** The saline sites are medium to large in size with considerable waterlogging evident. Discharge management is important in this landscape due to impacts on major infrastructure (Hume Highway). Discharge management will also limit on-site land degradation.
- **Dry out the landscape with diffuse actions over most of the landscape (6):** Encourage plant growth and increase plant water use in order to use excess soil moisture and shallow groundwater. This landscape is seen as being dominated by annual vegetation systems. Perennial vegetation will act as a buffer to groundwater accessions in wet seasonal conditions.

Key Management Focus–Table Top HGL

The focus of this HGL is small sub-catchment based water management throughout the whole landscape. The most effective management actions should focus on perennial pasture management and targeted tree planting.

Peri-urban development is likely to be impacted by and cause salinity through impediment to groundwater flow and constriction to the salinity processes. The lower landform units (saline and waterlogged areas) in this landscape will be at higher risk to urban salinity.

Future urban development will need to consider urban water management.

Specific Land Management Opportunities

Specific opportunities for this HGL:

- Opportunity for sound urban planning to be implemented prior to development.
- Local water system enables management to be effective.
- Improving grazing management of existing native pastures particularly on areas which are seasonally waterlogged.
- Grazing management on and around discharge sites.

Specific Land Management Constraints

Constraints for land management in this HGL include:

- Grazing management on and around discharge sites.
- Rural residential holdings dominate the landscape.
- Many salt sites throughout the landscape.
- Impacts of infrastructure – particularly major highway.

Specific Targeted Actions

Management areas for this HGL are illustrated in Figure 3. The specific management actions for these areas are described in Table 6.

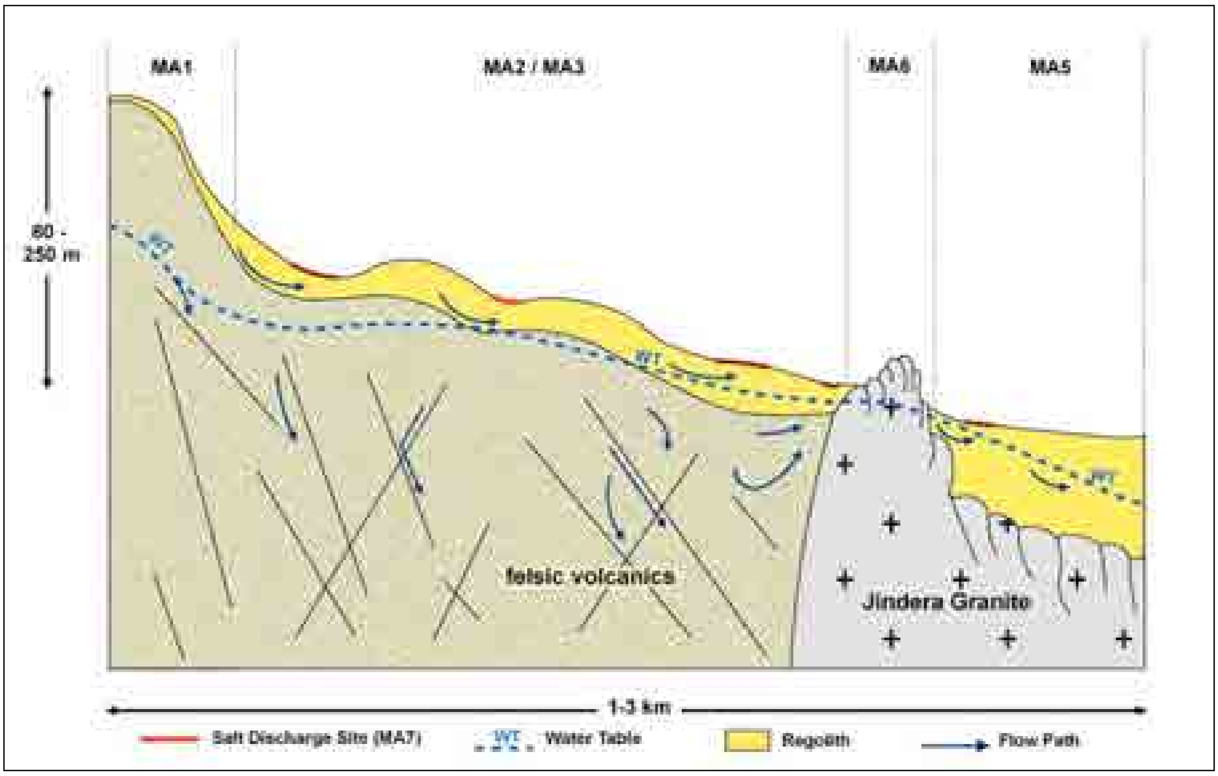


Figure 3: Management cross-section for Table Top HGL showing defined management areas.

Table 6: Specific management actions for management areas within the Table Top HGL.

Management Area (MA)	Action
MA1 (RIDGES)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** Establish and manage trees that are integrated into farming logistics to reduce recharge **(VE5).**
MA2/3 (UPPER SLOPES – EROSIONAL & COLLUVIAL)	**Vegetation for ecosystem function** Establish and manage trees to intercept lateral groundwater flow **(VE2).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).** Establish commercial forestry to manage recharge **(VP7).**

Management Area (MA)	Action
MA5 (LOWER SLOPES – COLLUVIAL)	**Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**
MA6 (RISES)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** **Vegetation for production** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**
MA7 (SALINE SITES)	**Salt land rehabilitation** Fence and isolate salt land and discharge areas to promote revegetation **(SR1).** Establish and manage salt land pasture systems to improve productivity **(SR2).** Establish forestry systems on salt land to improve productivity **(SR3).**

High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative impacts on salinity (Table 7).

Table 7: Management actions having negative salinity impacts in the Table Top HGL.

At Risk Management Areas	Action
MA1/6 (RIDGES)	Clearing and poor management of native vegetation **(DLU4).**
MA2/3 & MA5 (UPPER SLOPES – EROSIONAL & COLLUVIAL) (LOWER SLOPES – COLLUVIAL)	Poor management of grazing pastures **(DLU2).** Annual cropping with annual plants **(DLU3).** Locating infrastructure on discharge areas **(DLU7).**
MA7 (SALINE SITES)	Locating infrastructure on discharge areas **(DLU7).**

REFERENCES

DECCW, 2010, *Reconnaissance soil and land resources of the Murray CMA*, NSW Department of Environment, Climate Change and Water, Sydney

Geoscience Australia, 2011, *Australian stratigraphic units database*, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int

Keith, D. A. 2004, *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, Hurstville, NSW Department of Environment and Conservation

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, OEH Sydney, [Accessed: 10 November 2014] www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia

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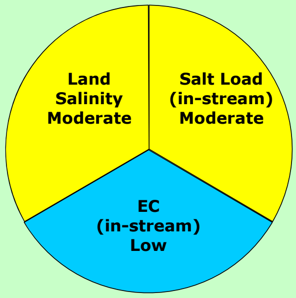
14. Thurgoona Hydrogeological Landscape

LOCALITIES	**Thurgoona, Hume Dam Village**
MAP SHEET	**Tallangatta 1:250 000** **Wagga Wagga 1:250 000** **Wangaratta 1:250 000**
CONFIDENCE LEVEL	**Low**



OVERVIEW

The Thurgoona Hydrogeological Landscape (HGL) extends from Lake Hume Village to the top of the Bowna arm of Lake Hume (Figure 1). The HGL covers an area of 52 km^2 and receives approximately 700 mm of rain per annum.

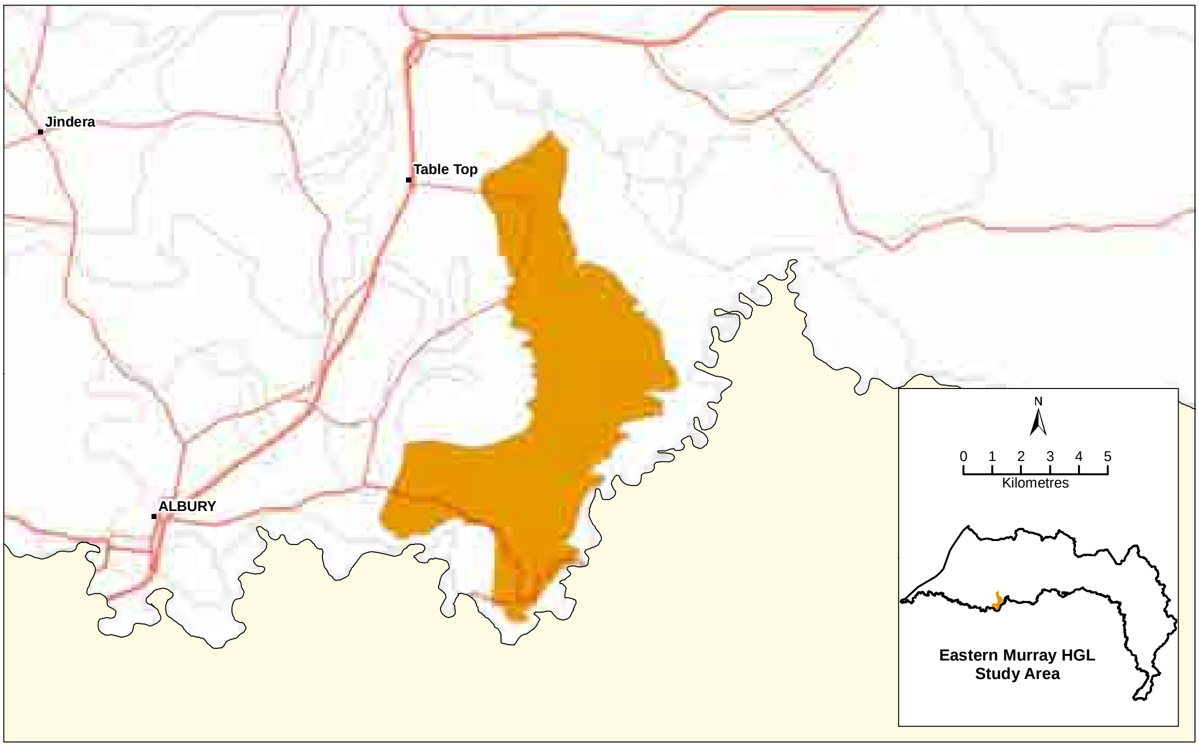


Figure 1: Thurgoona HGL distribution map.

The Thurgoona HGL is moderately to highly weathered and is characterised by undulating hills, rolling hills, low hills, rises and gently inclined foot-slopes and fans. Broad crests and ridges are typical, with long straight slopes and widely spaced drainage lines (Figure 2). There are small areas of rock outcrop and large areas of residual and colluvial deposits derived from the underlying geology. This HGL includes metamorphosed consolidated rocks from the Ordovician and Silurian periods that have been intruded by granitic rocks from the

Silurian. Unconsolidated Quaternary alluvium occurs along river valleys. Soils are deep and poorly drained on crests; very deep and imperfectly drained on slopes; deep and imperfectly drained on the upper and mid-slopes of the foot-slopes; moderately deep and poorly drained on lower foot-slopes; moderately well-drained on fans; deep and poorly drained in higher energy drainage lines; and, rapidly drained in major drainage lines. A thick ferromanganiferous hardpan commonly occurs on crests and upper slopes. Some soils on fans contain iron and manganese nodules which are occasionally cemented into a hardpan. Moderate to severe gully erosion is an issue along drainage lines and on lower slopes.

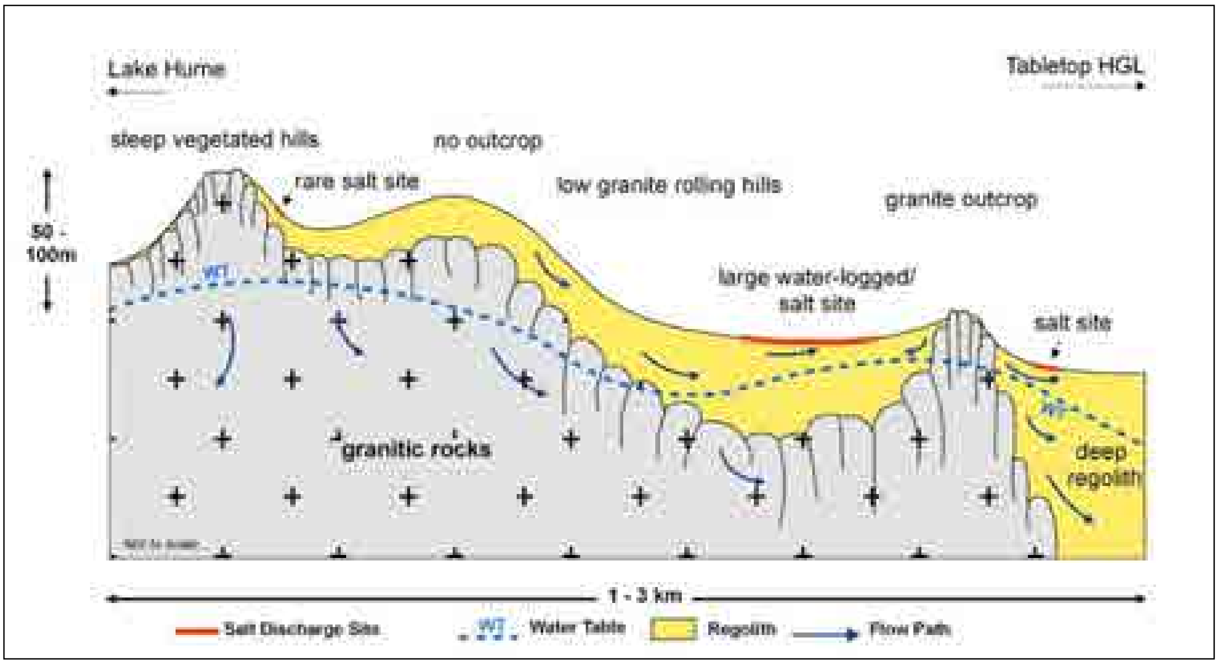


Figure 2: Conceptual cross-section for Thurgoona HGL showing the distribution of regolith and landforms, salt sites if present, and flow paths of water infiltrating the system.

Land salinity is generally moderate with some sites observed, mainly as waterlogging. Saltload is moderate and EC is low in this HGL (Table 1).

Table 1: Thurgoona HGL salinity expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	Moderate – some observed salinity sites at break of slope. Mainly waterlogging
Salt Load (Export)	Moderate – Intermittent streams which can carry >400 µS/cm water
EC (Water Quality)	Low – with occasional spikes >400 µS/cm

Salt stored within the Thurgoona HGL has moderate mobility. There is a moderate salt store that has moderate availability (Table 2).

Table 2: Thurgoona HGL salt store and availability.

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

The overall salinity hazard in the Thurgoona HGL is moderate. This is due to the low likelihood that salinity issues will occur that have potentially significant impacts (Table 3).

Table 3: Likelihood of salinity occurrence, potential impact and overall hazard of salinity for the Thurgoona HGL.

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

LANDSCAPE FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 4.

Photo 1: Rocky granitic outcrops occur on the north-western margin of the Thurgoona HGL. These are surrounded by long colluvial slopes (Photo: OEH/R Muller).

Photo 2: Low rolling hills with shorter colluvial slopes are common in the central northern area of the Thurgoona HGL (Photo: OEH/R Muller).

Photo 3: Steeper hills with long colluvial slopes occur on the eastern margin of the Thurgoona HGL, where the rocks have undergone a higher grade of metamorphism and are more resistant to weathering (Photo: OEH/R Muller).

Photo 4: The steeper hills and long colluvial slopes of the Thurgoona HGL grade into the flat colluvial/alluvial plain of the Table Top HGL in the foreground (Photo: OEH/R Muller).

Photo 5: The steep eastern margin of the Thurgoona HGL is defined by Lake Hume (Photo: OEH/R Muller).

Photo 6: The hills on the eastern margin of the Thurgoona HGL were a source of rock during the construction of the Hume Dam wall (Photo: OEH/R Muller).

Table 4: Summary of information used to define the Thurgoona HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2011)*	This HGL comprises metamorphosed consolidated rocks from the Ordovician and Silurian periods that have been intruded by granitic rocks from the Silurian. Unconsolidated Quaternary alluvium occurs along river valleys. Key lithologies include: • channel and flood plain alluvium – gravel, sand, silt and clay • Hawksview Granite –felsic, unfractionated granite • Bethanga Gneiss – gneiss.
Annual Rainfall	700 mm
Regolith and Landforms	The Thurgoona HGL is moderately to highly weathered and is characterised by undulating hills (90–100 m relief), low hills (30–90 m relief), and rises (9–30 m relief) with broad crests and ridges and gently inclined colluvial slopes, formed on Ordovician metamorphic (gneiss) and Silurian granitic bedrock. Alluvial plains with widely spaced drainage lines form the low-lying parts of the landscape. Slopes are typically 3–15%, local relief is 10–100 m and this HGL is between 170–450 m elevation. Regolith materials are quartzose clayey sands and sandy clays with gravels. On ridge crests and upper slopes there are clayey sands and localised areas of ferruginous duricrust.
Soil Landscapes *(DECCW 2010)*	This HGL fits with a couple of discreet suites of soil landscapes. Tipperary and Bowna soil landscapes are hilly and provide the topographically highest points within the HGL. Pleasure Point and Bowna are the most commonly occurring soil landscapes. There are minor occurrences of Yarra Yarra, Wagra, Cookardinia and Tipperary soil landscapes. Soils include: deep (1.0–1.5 m), poorly drained Red Dermosols (Red Earths) and Chromosols (Red Podzolic Soils) on crests; very deep (>1.5 m), imperfectly drained Brown and Yellow Chromosols (Yellow Podzolic Soils) and Dermosols (Yellow Earths) on slopes; deep (1.0–1.5 m), imperfectly drained Yellow and Brown Chromosols and Dermosols (Yellow Podzolic Soils) on the upper and mid-slopes of the foot-slopes; moderately deep (0.5–1.0 m), poorly drained Yellow Sodosols (Soloths) on lower foot-slopes; moderately well-drained Red and Brown Kandosols (Red Earths) on fans; deep (1.0–1.5 m), poorly drained Yellow Chromosols (Yellow Podzolic Soils) in higher energy drainage lines; and, rapidly drained sandy Stratic Rudosols (Alluvial Soils) in major drainage lines. Some sites have source bordering fine aeolian sand inclusions in the A horizon (from Hume Dam). A thick ferromanganiferous hardpan commonly occurs on crests and upper slopes. The Red and Brown Kandosols (Red Earths) that occur on fans often contain iron and manganese nodules which are occasionally cemented into a hardpan. Moderate to severe gully erosion is an issue along drainage lines and on lower slopes. Localised areas of minor sheet and rill erosion occur on upper slopes of fans. Localised waterlogging can be an issue during wet periods and may lead to salinisation.

Land and Soil Capability *(OEH 2012)*	Class 5
Land Use	Land use is typically grazing on volunteer, naturalised, native or improved pastures. East of Thurgoona, there is some land used by Department of Defence, and the eastern margin of this HGL is defined by Lake Hume. Peri-urban development is an emerging land use in this area
Key Land Degradation Issues	• minor sheet and rill erosion (localised on upper slopes) • moderate gully erosion • stream-bank erosion within drainage depressions • localised soil compaction • hard-setting surfaces (widespread) • sodic soils (widespread) • waterlogging (seasonal) • salinity (related to waterlogging).
Native Vegetation *(Stelling 1998; Keith 2004)*	Vegetation on the hills and ranges tends to be white box woodland and red gum woodland (including Blakely's and tumbledown red gum) on western slopes and red stringybark on eastern slopes. Vegetation on the low, gently undulating country tends to be yellow box and apple box woodlands and river red gum woodland. Tree species on the hilly country can include *Eucalyptus albens* (white box) on fertile slopes and ridges, *E. blakelyi* (Blakely's red gum) on loamy soils, *E. polyanthemos* (red box); *E. dealbata* (tumbledown gum); and *E. goniocalyx* (long-leaf box) on well drained or dry rocky slopes (particularly north and north-west facing slopes); or *E. macrorhyncha* (red stringybark) on south and south-eastern slopes. Other tree species can include *Allocasuarina verticillata* (drooping sheoak) on dry ridges, *Brachychiton populneus* (kurrajong), *Exocarpos cupressiformis* (native cherry), *Acacia dealbata* (silver wattle) and *Callitris glaucophylla* (white cypress pine). Understorey species on hilly country may include *Acacia pycnantha* (kangaroo thorn) and *A. verniciflua* (varnish wattle), as well as *Bursaria spinosa* (sweet bursaria), *Daviesia latifolia* (hop bitter-pea), *Platylobium formosum* (handsome flat-pea), *Pultenaea largiflorens* (twiggy bush-pea) and *Indigofera australis* (austral indigo). Vegetation on the low gently undulating country can include *E. melliodora* (yellow box) where the soils are moderately fertile and well drained, and *E. bridgesiana* (apple box) where soils are heavier. Riparian zones and low lying areas subject to occasional flooding can support *E. camaldulensis* (river red gun), *Callistemon sieberi* (river bottlebrush) and a variety of sedges, rushes and reeds.

HYDROGEOLOGY

Aquifers within this landscape are unconfined to semi-confined, with groundwater flow occurring primarily through fractures in bedrock and saprolite. Some flow occurs through colluvial and alluvial sediments on lower slopes and in flow lines. Hydraulic conductivity and transmissivity are moderate. Groundwater recharge rates are estimated to be moderate.

Groundwater systems are typically local with short flow lengths and are loosely defined by topographic catchments. Water quality within these systems is fresh to marginal. Watertable depths are shallow to intermediate.

Medium residence times are typical. These landscapes have a medium response time to changes in land management.

Typical values for the hydrogeological parameters of this HGL are summarised in Table 5.

Table 5: Summary of values for typical hydrogeological parameters of the Thurgoona HGL.

Aquifer Type	Unconfined to semi-confined in fractured rock and saprolite Lateral flow through unconsolidated colluvial and alluvial sediments on lower slopes and in flow lines
Hydraulic Conductivity	Moderate Range: <10^{-2}–10 m/day
Aquifer Transmissivity	Moderate Range: 2–50 m^2/day
Specific Yield	Low to moderate Range: <15%
Hydraulic Gradient	Moderate to steep Range: >10%
Groundwater Salinity	Fresh to marginal Range: <1600 µS/cm
Depth to Watertable	Shallow to intermediate Range: <8 m
Typical Sub-Catchment Size	Small (<100 ha)
Scale (Flow Length)	Local Flow length: <5 km (short)
Recharge Estimate	Moderate
Residence Time	Medium (years)
Responsiveness to Change	Medium (years)

MANAGEMENT OPTIONS

Overarching salinity management strategies have specific biophysical outcomes. These are achieved by implementing a series of targeted land management actions that take into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape to impact on salinity. Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Salinity is driven by interactions between water-use capacity of vegetation, physical soil properties and hydrogeological processes within the HGL.

Actions that influence the way water is used by vegetation or stored in the soil profile will have impacts on recharge. The influence of both continual and episodic recharge and the impacts of extreme weather events need to be considered when deciding on appropriate management actions. Short and long-term climate cycles also need to be considered as they have a bearing on salinity processes, particularly salt load and land salinity.

Landscape Functions – Thurgoona HGL

Functions this landscape provides within a catchment scale salinity context:

- **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
- **D.** The landscape generates salt loads which enter the streams and are redistributed in the catchment
- **G.** The landscape contains important land assets (including infrastructure and high value agricultural land) on which salinity processes impact.

Landscape Management Strategies – Thurgoona HGL

Appropriate strategies pertinent to this landscape:

- **Maintain or maximise runoff (10):** This HGL contributes significant fresh water as dilution flow to the local stream system. The fresh runoff mitigates the salt load, stream salinity and EC concentration of the local streams.
- **Discharge rehabilitation and management (4):** The saline and waterlogged sites are small in size. Discharge management will reduce salt discharge to streams when vegetation is matched to salt sites.
- **Buffer the salt store – keep it dry and immobile (1):** There are stores of salt in colluvial areas that vegetation can buffer, limiting the salinity impact. They are generally in the depositional elements of the middle to lower landscape. They comprise a significant percentage of this HGL.

Key Management Focus – Thurgoona HGL

The focus of this HGL is localised water management throughout the whole landscape. Future urban development will need to consider urban water management and salinity in particular.

Specific Land Management Opportunities

Specific opportunities for this HGL:

- Good perennial pasture base from which to build effective pastures.
- Some areas of land are not used for agriculture production – production vs. protection issues less likely to be encountered.
- Implementation of good salinity planning in urban developing areas.

Specific Land Management Constraints

Constraints for land management in this HGL include:

- Climatic limitations will influence the ability of pasture systems to reduce recharge and manage discharge.
- Major road infrastructure and peri-urban development are both victims of, and contributors to salinity processes in this landscape.

Specific Targeted Actions

Management areas for this HGL are illustrated in Figure 3. The specific management actions for these areas are described in Table 6.

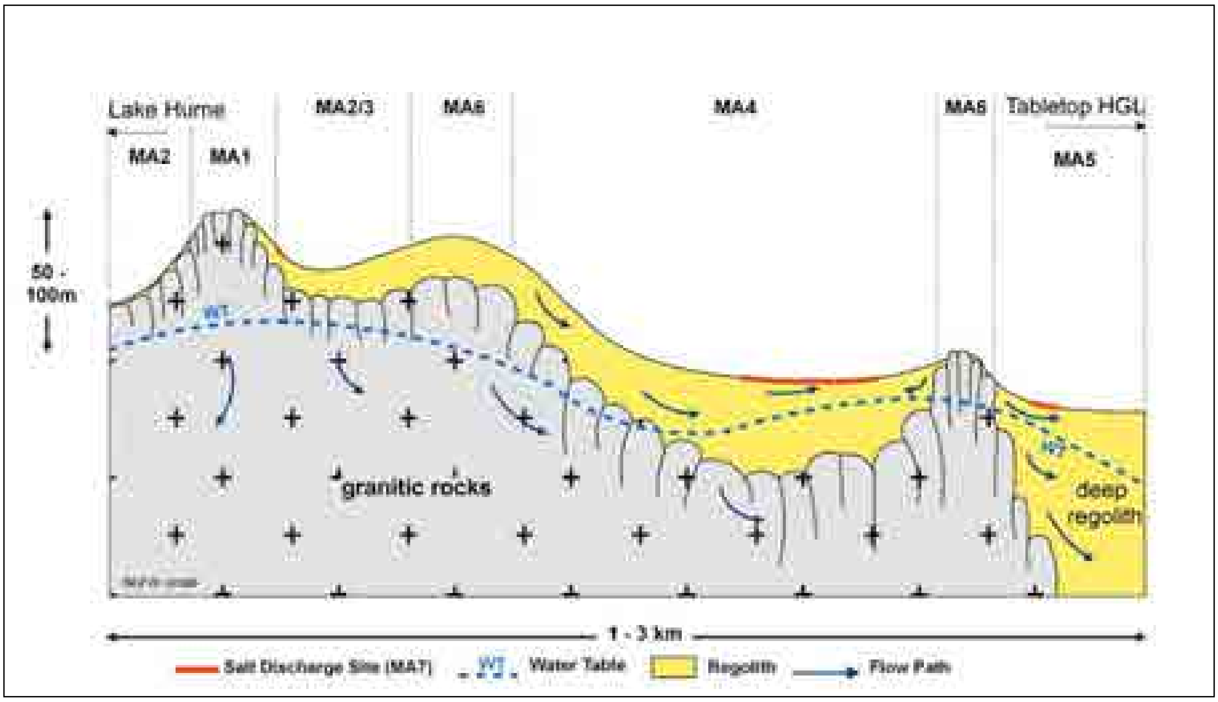


Figure 3: Management cross-section for Thurgoona HGL showing defined management areas.

Table 6: Specific management actions for management areas within the Thurgoona HGL.

Management Area (MA)	Action
MA1 (RIDGES)	**Vegetation for ecosystem function** Establish and manage trees that are integrated into farming logistics to reduce recharge **(VE5).** Revegetate non-agricultural land with native species to manage recharge **(VE6).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge (**VP1).** Establishment and management of perennial pastures (**VP2).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**
MA2/3 (UPPER SLOPES – EROSIONAL & COLLUVIAL)	**Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge (**VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**
MA4 (MID SLOPES)	**Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge (**VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**
MA5 (LOWER SLOPES – COLLUVIAL)	**Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge (**VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**
MA6 (RISES)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** Revegetate non-agricultural land with native species to manage recharge **(VE6).**

Management Area (MA)	Action
MA7 (SALINE SITES)	**Salt land rehabilitation** Fence and isolate salt land and discharge areas to promote revegetation **(SR1).** Establish and manage salt land pasture systems to improve productivity **(SR2).** Mulch sites using tactical animal impact **(SR9).**

High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative impacts on salinity (Table 7).

Table 7: Management actions having negative salinity impacts in the Thurgoona HGL.

At Risk Management Areas	Action
MA1 & MA6 (RIDGES AND RISES)	Poor management of grazing pastures **(DLU2).** Clearing and poor management of native vegetation **(DLU4).**
MA2 (UPPER SLOPES – EROSIONAL)	Poor management of grazing pastures **(DLU2).** Clearing and poor management of native vegetation **(DLU4).**
MA4 (MID-SLOPE)	Locating infrastructure on discharge areas **(DLU7).** Farm dams in flow lines **(DLU5).** Poor management of grazing pastures **(DLU2).**
MA5 (LOWER SLOPES – COLLUVIAL)	Farm dams in flow lines **(DLU5).** Poor management of grazing pastures **(DLU2).**
MA7 (SALINE SITES)	Locating infrastructure on discharge areas **(DLU7).**

REFERENCES

DECCW, 2010, *Reconnaissance soil and land resources of the Murray CMA*, NSW Department of Environment, Climate Change and Water, Sydney

Geoscience Australia, 2011, *Australian stratigraphic units database*, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int

Keith, D. A. 2004, *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, Hurstville, NSW Department of Environment and Conservation

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, Office of Environment and Heritage, Sydney, [Accessed: 10 November 2014] www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

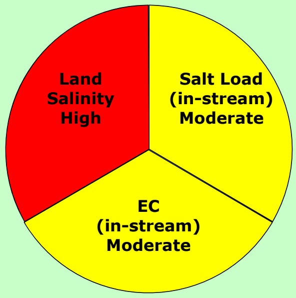
Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia

Stelling, F. 1998, *South west slopes revegetation guide (south of the Murrumbidgee River)*, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

Wooldridge, A., Nicholson, A., Muller R., Jenkins, B. R., Wilford, J. and Winkler, M. 2015, *Guidelines for managing salinity in rural areas*, NSW Office of Environment and Heritage, Sydney, NSW

15. Hume Hydrogeological Landscape

LOCALITIES	**Bowna**
MAP SHEET	**Wagga Wagga 1:250 000**
CONFIDENCE LEVEL	**Low**



OVERVIEW

The Hume Hydrogeological Landscape (HGL) extends northwards from Lake Hume at Bowna to north of the Hume freeway (Figure 1). The HGL covers an area of 75 km^2 and receives 700 to 850 mm of rain per annum.

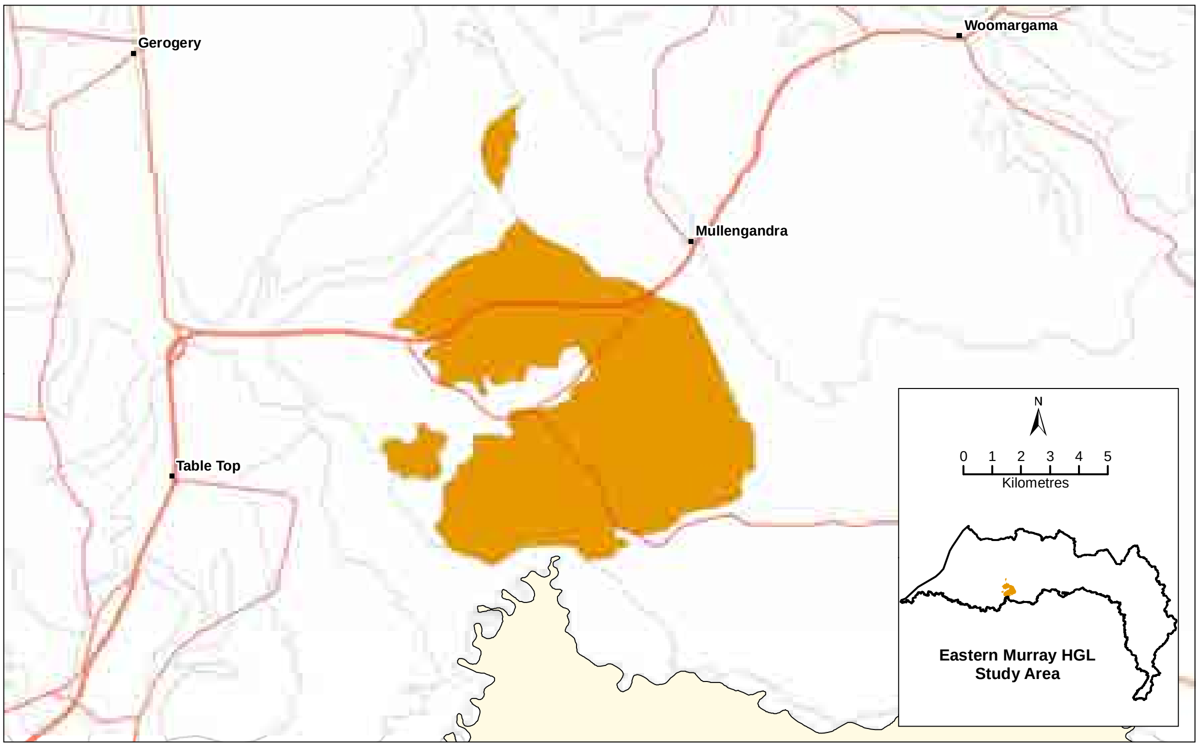


Figure 1: Hume HGL distribution map.

The Hume HGL is variably weathered, characterised by broad ridge crests; long, straight to waning slopes; short, rolling fans; and narrow drainage lines (Figure 2). Rock outcrop is minor and isolated to ridge crests. Processes are primarily erosional on steeper hills; colluvial on the long slopes; with some transferral areas occurring along the drainage lines. Regolith is composed of quartzose, clayey sands and gravels. This HGL includes rocks from the Ordovician and Silurian periods and associated colluvial material. Unconsolidated

Quaternary alluvium occurs along river valleys. Soils are shallow and variably drained on crests; very deep and imperfectly drained on slopes; deep and imperfectly drained on the upper and mid-slopes of the foot-slopes; moderately deep and poorly drained on lower foot-slopes; moderately well-drained on fans; moderately well-drained on terraces; and deep and poorly drained in higher energy drainage lines. Very deep and moderately well-drained soils occur on the confined floodplain; and, rapidly drained sandy soils occur in major drainage lines. Some sites have source bordering fine aeolian sand inclusions in the A horizon (from Hume Dam). A thick ferromanganiferous hardpan commonly occurs on crests and upper slopes. Some soils that occur on fans often contain iron and manganese nodules that are occasionally cemented into a hardpan. Minor to moderate gully erosion occurs along drainage lines on lower slopes.

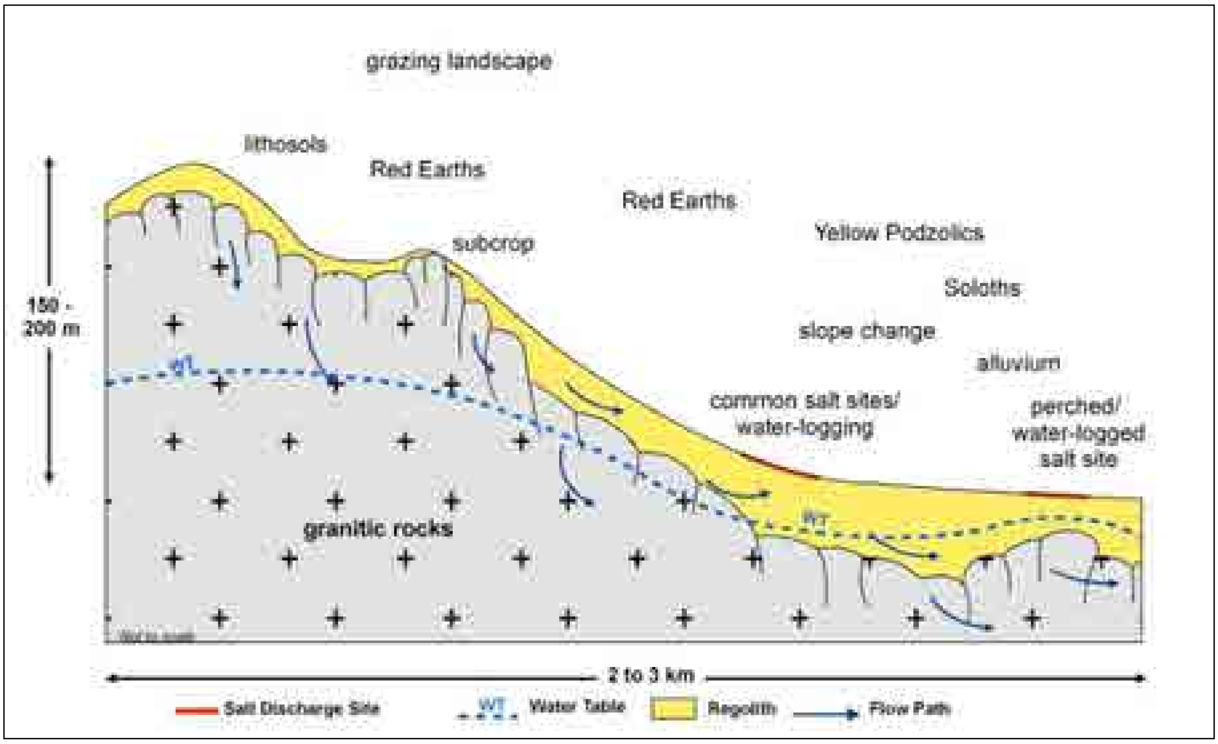


Figure 2: Conceptual cross-section for Hume HGL showing the distribution of regolith and landforms, salt sites if present, and flow paths of water infiltrating the system.

Land salinity is common, particularly at colluvial foot-slopes and in drainage lines. Moderate salt load and EC levels are present (Table 1).

Table 1: Hume HGL salinity expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	High – salt sites commonly occur at colluvial foot-slopes and in drainage lines
Salt Load (Export)	Moderate – perennial streams carry continuous salt loads
EC (Water Quality)	Moderate – streams measured around 600 µS/cm and occasional spikes to 1100 µS/cm

Salt stored within the Hume HGL has high mobility. There is a high salt store that has moderate availability (Table 2).

Table 2: Hume HGL salt store and availability.

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

The overall salinity hazard in the Hume HGL is moderate. This is due to the moderate likelihood that salinity issues will occur that have potentially significant impacts (Table 3).

Table 3: Likelihood of salinity occurrence, potential impact and overall hazard of salinity for the Hume HGL.

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

LANDSCAPE FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 4.

Photo 1: High hills occur on the north-western margin of the Hume HGL. These grade down through long colluvial slopes into flatter drainage lines (Photo: OEH/R Muller).

Photo 2: Low rolling hills with shorter colluvial slopes are seen in the central northern area of the Hume HGL (Photo: OEH/R Muller).

Photo 3: The steeper hills and long colluvial slopes of the Hume HGL grade into the flat colluvial/alluvial plain of the Table Top HGL in the foreground (Photo: OEH/R Muller).

Photo 4: In the central part of the Hume HGL, rolling hills with short colluvial slopes grade into the flat colluvial/alluvial plain of the Table Top HGL in the foreground. The high range in the background is the eastern margin of the Yambla HGL (Photo: OEH/R Muller).

Photo 5: Steeper rolling hills and colluvial slopes in the central part of the Hume HGL grade into the flat colluvial/alluvial plain of the Table Top HGL in the foreground (Photo: OEH/R Muller).

Photo 6: Rolling hills and colluvial slopes in the central part of the Hume HGL grade into the flat colluvial/alluvial plain of the Table Top HGL in the foreground (Photo: OEH/R Muller).

Table 4: Summary of information used to define the Hume HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2011)*	This HGL comprises granitic rocks from the Ordovician and Silurian periods and associated colluvial material. Unconsolidated Quaternary alluvium occurs along river valleys. Key lithologies include: • channel and flood plain alluvium – gravel, sand, silt and clay • Koetong Granite – nonmagnetic, bluish grey, two mica cordierite granite; coarse grained biotite muscovite granite; mostly equigranular but centre is porphyritic and parts of margins are fine grained; locally abundant enclaves • unnamed felsic intrusives – granite, granodiorite, gneissic granite.
Annual Rainfall	700–850 mm
Regolith and Landforms	The Hume HGL is slightly to moderately weathered and is characterised by hills (90–250 m relief), low hills (30–90 m relief), and rises (9–30 m relief) with broad ridge crests; long colluvial slopes and narrow drainage lines, formed on Ordovician and Silurian granitic rocks. Rock outcrop is minor and isolated to ridge crests. Regolith materials are quartzose clayey sands and sandy clays with gravels.
Soil Landscapes *(DECCW 2010)*	This HGL contains a suite of soil landscapes on granite and biotite gneiss. They are distinguished by relief and slope. Cumberoona Road soil landscape occupies rolling to steep hills; Bowna soil landscape occupies undulating to rolling hills and low hills; Pleasure Point soil landscape occupies foot-slopes and fans; and Mullengandra soil landscape occupies the floodplain. Yarra Yarra, Dora Dora and Wagra soil landscapes are also present. Soils include: shallow Orthic Tenosols (Lithosols), very shallow (<50 cm), rapidly drained Clastic Rudosols (Lithosols), deep (1.0–1.5 m), poorly drained Red Dermosols (Red Earths) and Chromosols (Red Podzolic Soils) on crests; very deep (>1.5 m), imperfectly drained Brown and Yellow Chromosols (Yellow Podzolic Soils) and Dermosols (Yellow Earths) on slopes; deep (1.0–1.5 m), imperfectly drained Yellow and Brown Chromosols and Dermosols (Yellow Podzolic Soils) on the upper and mid-slopes of the foot-slopes; moderately deep (0.5–1.0 m), poorly drained Yellow Sodosols (Soloths) on lower foot-slopes; moderately well-drained Red and Brown Kandosols (Red Earths) on fans; moderately well-drained Red and Brown Sodosols (Solodic Soils) on terraces; deep (1.0–1.5 m), poorly drained Yellow Chromosols (Yellow Podzolic Soils) in higher energy drainage lines; Very deep (>1.5 m), moderately well-drained Brown and Grey Dermosols (Brown Podzolic Soils) occur on the confined floodplain; and rapidly drained sandy Stratic Rudosols (Alluvial Soils) in major drainage lines. Some sites have source bordering fine aeolian sand inclusions in the A horizon (from Hume Dam). A thick ferromanganiferous hardpan commonly occurs on

	crests and upper slopes. The Red and Brown Kandosols (Red Earths) that occur on fans often contain iron and manganese nodules which are occasionally cemented into a hardpan. Minor to moderate gully erosion occurs along drainage lines on lower slopes. Localised waterlogging and salinity are evident, as are localised areas of minor sheet and rill erosion.
Land and Soil Capability *(OEH 2012)*	Class 6
Land Use	Grazing on volunteer, naturalised, native or improved pastures
Key Land Degradation Issues	• moderate gully erosion along drainage lines (lower slopes) • waterlogging (localised) • salinity (localised) • minor sheet and rill erosion (localised on upper slopes of fans) • trees show evidence of dieback.
Native Vegetation *(Stelling 1998; Keith 2004)*	Vegetation on upper slopes and hills tends to be red box and white box woodland, hill red gum woodland and red stringybark dry forest. These communities have developed on the granite and gneiss typical of this HGL. Tree species can include *Eucalyptus blakelyi* (Blakely's red gum) on loamy soils, *E. dwyeri* (Dwyer's red gum) and *E. polyanthemos* (red box) on well drained soils, *E. albens* (white box) on fertile slopes and ridges, *E. goniocalyx* (long-leaf box) on dry rocky slopes, *E. melliodora* (yellow box), *Allocasuarina verticillata* (drooping sheoak), *Acacia dealbata* (silver wattle), *A. implexa* (hickory wattle), *Brachychiton populneus* (kurrajong), *Callitris glaucophylla* (white cypress pine) and *Exocarpos cupressiformis* (native cherry). *Eucalyptus macrorhyncha* (red stringybark) occurs on slopes with a southerly or south-eastern aspect. Understorey shrub species may include *Acacia paradoxa* (kangaroo thorn), *Bursaria spinosa* (sweet bursaria), *Cassinia* sp., *Dodonaea viscosa* ssp. *angustissima* (narrow-leaf hop-bush) and *Daviesia latifolia* (hop bitter-pea). *Leptospermum continentale* (prickly tea-tree) occurs in poorly drained sites and soaks on lower slopes. Vegetation on the lower slopes additionally may include *E. melliodora* (yellow box) on lower slopes and *E. bridgesiana* (apple box) where the soils are heavy but well drained.

HYDROGEOLOGY

Aquifers within this landscape are unconfined to semi-confined with groundwater flow occurring primarily through fractures in bedrock and saprolite. Some flow occurs through colluvial and alluvial sediments on lower slopes and in flow lines. Hydraulic conductivity is low to moderate and transmissivity is low. Groundwater recharge rates are estimated to be low to moderate.

Groundwater systems are typically local with short flow lengths and are loosely defined by topographic catchments. Water quality within these systems is marginal. Watertable depths are shallow to intermediate.

Medium residence times are typical. These landscapes have a medium response time to changes in land management.

Typical values for the hydrogeological parameters of this HGL are summarised in Table 5.

Table 5: Summary of values for typical hydrogeological parameters of the Hume HGL.

Aquifer Type	Unconfined to semi-confined in fractured rock and saprolite Lateral flow through unconsolidated colluvial and alluvial sediments on lower slopes and in flow lines
Hydraulic Conductivity	Low to moderate Range: <10 m/day
Aquifer Transmissivity	Low Range: <2 m^2/day
Specific Yield	Low to moderate Range: <15%
Hydraulic Gradient	Moderate to steep Range: >10%
Groundwater Salinity	Marginal Range: 800–1600 µS/cm
Depth to Watertable	Shallow to intermediate Range: <8 m
Typical Sub-Catchment Size	Small (<100 ha)
Scale (Flow Length)	Local Flow length: <5 km (short)
Recharge Estimate	Low to moderate
Residence Time	Medium (years)
Responsiveness to Change	Medium (years)

MANAGEMENT OPTIONS

Overarching salinity management strategies have specific biophysical outcomes. These are achieved by implementing a series of targeted land management actions that take into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape to impact on salinity. Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Salinity is driven by interactions between water-use capacity of vegetation, physical soil properties and hydrogeological processes within the HGL.

Actions that influence the way water is used by vegetation or stored in the soil profile will have impacts on recharge. The influence of both continual and episodic recharge and the impacts of extreme weather events need to be considered when deciding on appropriate management actions. Short and long-term climate cycles also need to be considered as they have a bearing on salinity processes, particularly salt load and land salinity.

Landscape Functions – Hume HGL

Functions this landscape provides within a catchment scale salinity context:

- **D.** The landscape generates salt loads which enter the streams and are redistributed in the catchment.
- **F.** The landscape generates high salinity concentration water.
- **G.** The landscape contains important land assets (including infrastructure and high value agricultural land) on which salinity processes impact.

Landscape Management Strategies – Hume HGL

Appropriate strategies pertinent to this landscape:

- **Buffer the salt store – keep it dry and immobile (1):** There are stores of salt in particular parts of the landscape that can be buffered by vegetation, limiting the salinity impact. They are generally in the depositional elements of the middle to lower landscape. They comprise a significant percentage of this HGL.
- **Discharge rehabilitation and management (4):** Discharge sites appear in the landscape through wet climate cycles. Improved management of these saline areas can reduce the impact of salinisation and prevent large negative impacts during wet cycles. Discharge management will also limit on site land degradation.
- **Dry out the landscape with diffuse actions over most of the landscape (6):** Encourage plant growth and increase plant water use in order to use excess soil moisture and shallow groundwater. Healthy, actively growing vegetation will also act as a buffer to groundwater accessions in wet seasonal conditions.

Key Management Focus – Hume HGL

This landscape is seen as dominated by production systems based on annual plants. The key management focus should be to introduce perennial components into the landscape and the farming systems.

Specific Land Management Opportunities

Specific opportunities for this HGL:

- Good perennial pasture base from which to build effective pastures.
- Some areas of land are not used for agriculture production – production vs. protection issues less likely to be encountered.

Specific Land Management Constraints

Constraints for land management in this HGL include:

- Climatic limitations will influence the ability of pasture systems to reduce recharge and manage discharge.
- Major road infrastructure is a victim of, and contributor to salinity processes in this landscape.
- Gully erosion is present close to or as part of many salt sites.

Specific Targeted Actions

Management areas for this HGL are illustrated in Figure 3. The specific management actions for these areas are described in Table 6.

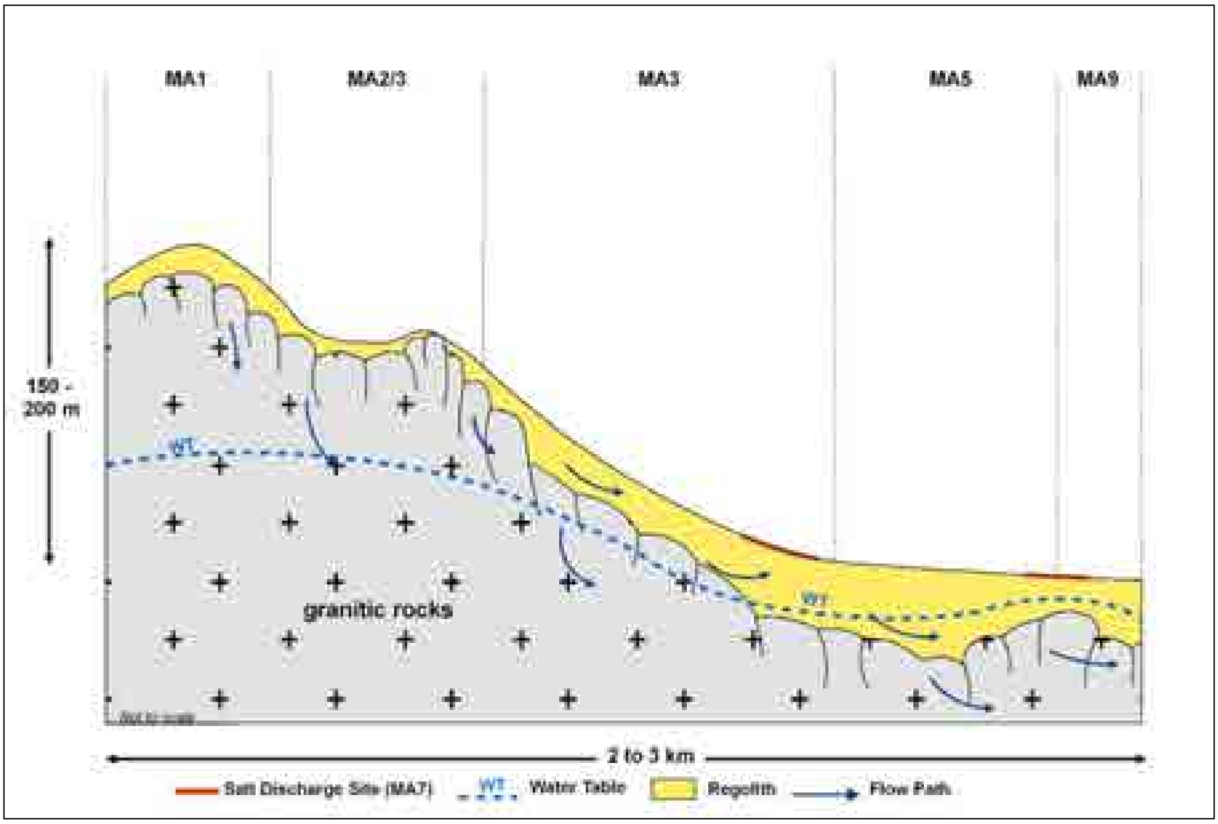


Figure 3: Management cross-section for Hume HGL showing defined management areas.

Table 6: Specific management actions for management areas within the Hume HGL.

Management Area (MA)	Action
MA1 (RIDGES)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge (**VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**
MA2/3 (UPPER SLOPES – EROSIONAL & COLLUVIAL)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge (**VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5)**.
MA3 (UPPER SLOPES – COLLUVIAL)	**Vegetation for ecosystem function** Interception planting of native woody species to target shallow groundwater **(VE2).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge (**VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** Establish and manage perennial pastures to intercept shallow lateral groundwater flow **(VP3).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**

Management Area (MA)	Action
MA5 (LOWER SLOPES – COLLUVIAL)	**Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge (**VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**
MA7 (SALINE SITES)	**Salt land rehabilitation** Fence and isolate salt land and discharge areas to promote revegetation **(SR1).** Establish and manage salt land pasture systems to improve productivity **(SR2).** Undertake rehabilitation to ameliorate land salinity processes and reduce land degradation **(SR4).** Mulch sites to reduce evaporation and promote pasture growth **(SR8).**
MA9 (ALLUVIAL PLAIN)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** Maintain and improve riparian native vegetation to reduce discharge to streams **(VE4).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge (**VP1).**

High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative impacts on salinity (Table 7).

Table 7: Management actions having negative salinity impacts in the Hume HGL.

At Risk Management Areas	Action
MA1 (RIDGES)	Poor management of grazing pastures **(DLU2).** Clearing and poor management of native vegetation **(DLU4).**
MA2/3 (UPPER SLOPES – EROSIONAL & COLLUVIAL)	Poor management of grazing pastures **(DLU2).** Clearing and poor management of native vegetation **(DLU4).**
MA3 (UPPER SLOPES – COLLUVIAL)	Poor management of grazing pastures **(DLU2).** Annual cropping with annual plants **(DLU3).** Locating infrastructure on discharge areas **(DLU7).**
MA5 (LOWER SLOPES – COLLUVIAL)	Annual cropping with annual plants **(DLU3).** Locating infrastructure on discharge areas **(DLU7).**
MA9 ALLUVIAL FLOODPLAIN	Clearing and poor management of native vegetation **(DLU4).** Poor management of grazing pastures **(DLU2).**

REFERENCES

DECCW, 2010, *Reconnaissance soil and land resources of the Murray CMA*, NSW Department of Environment, Climate Change and Water, Sydney

Geoscience Australia, 2011, *Australian stratigraphic units database*, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int

Keith, D. A. 2004, *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, Hurstville, NSW Department of Environment and Conservation

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, OEH Sydney, [Accessed: 10 November 2014] www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

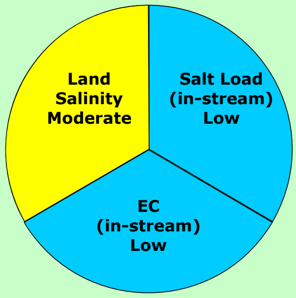
Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia

Stelling, F. 1998, *South west slopes revegetation guide (south of the Murrumbidgee River)*, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

Wooldridge, A., Nicholson, A., Muller R., Jenkins, B. R., Wilford, J. and Winkler, M. 2015, *Guidelines for managing salinity in rural areas*, NSW Office of Environment and Heritage, Sydney, NSW

16. Soldiers Hill Hydrogeological Landscape

LOCALITIES	**Soldiers Hill**
MAP SHEET	**Wagga Wagga 1:250 000**
CONFIDENCE LEVEL	**Low**



OVERVIEW

The Soldiers Hill Hydrogeological Landscape (HGL) is north-west of Morven, north-east of Culcairn and south of Majors Creek (Figure 1). The HGL covers an area of 55 km^2 and receives 600 to 650 mm of rain per annum.

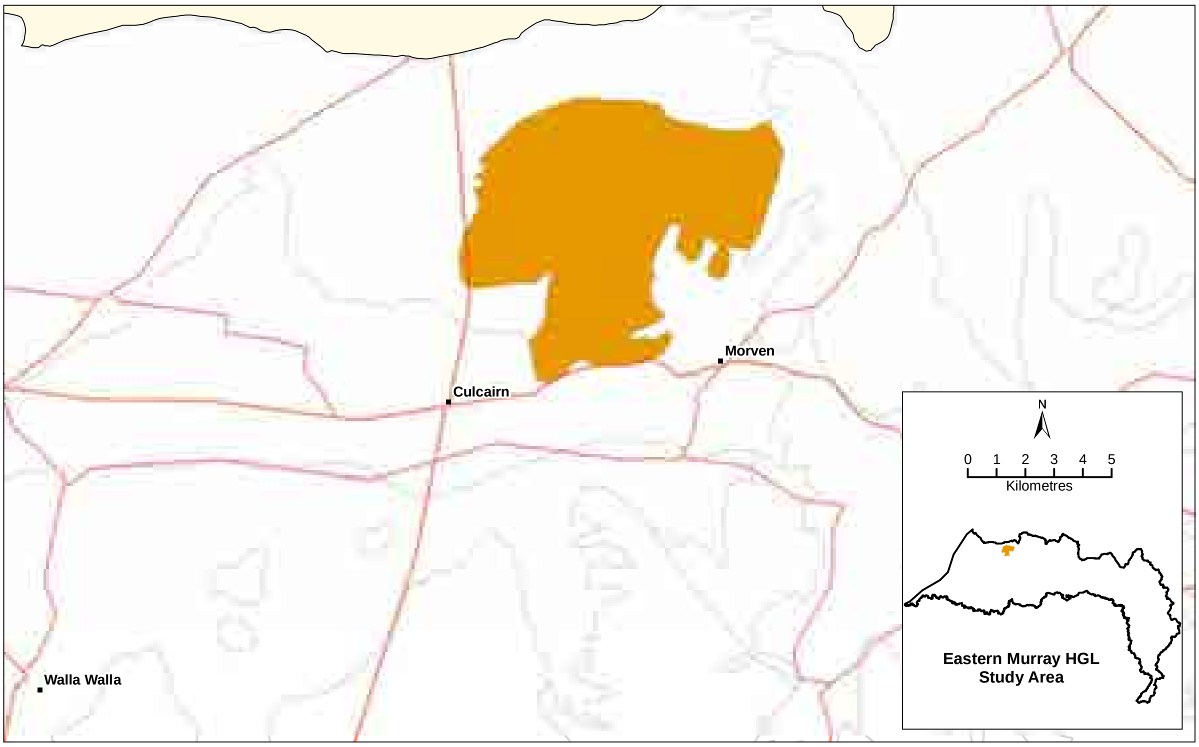


Figure 1: Soldiers Hill HGL distribution map.

The Soldiers Hill HGL is variably weathered and is characterised by undulating hills, low hills and rises with rounded crests and long gently inclined foot-slopes with some rock outcrop, and undulating plains (Figure 2). Slopes are gentle and waxing. Some hills have steep crests with steep straight slopes and significant rock outcrop. Drainage lines are widely spaced and moderately defined. This HGL includes consolidated volcanic rocks from the Silurian and Devonian periods. Soils are moderately deep and well-drained on rocky crests; deep and moderately well-drained on less rocky crests and slopes; shallow around rock outcrops; and deep and poorly drained on lower slopes and in drainage lines. The landscape shape and texture contrast soils accommodate widespread sheet erosion, gully erosion along drainage lines and localised saline outbreaks. Tree dieback has been identified as an issue in this HGL.

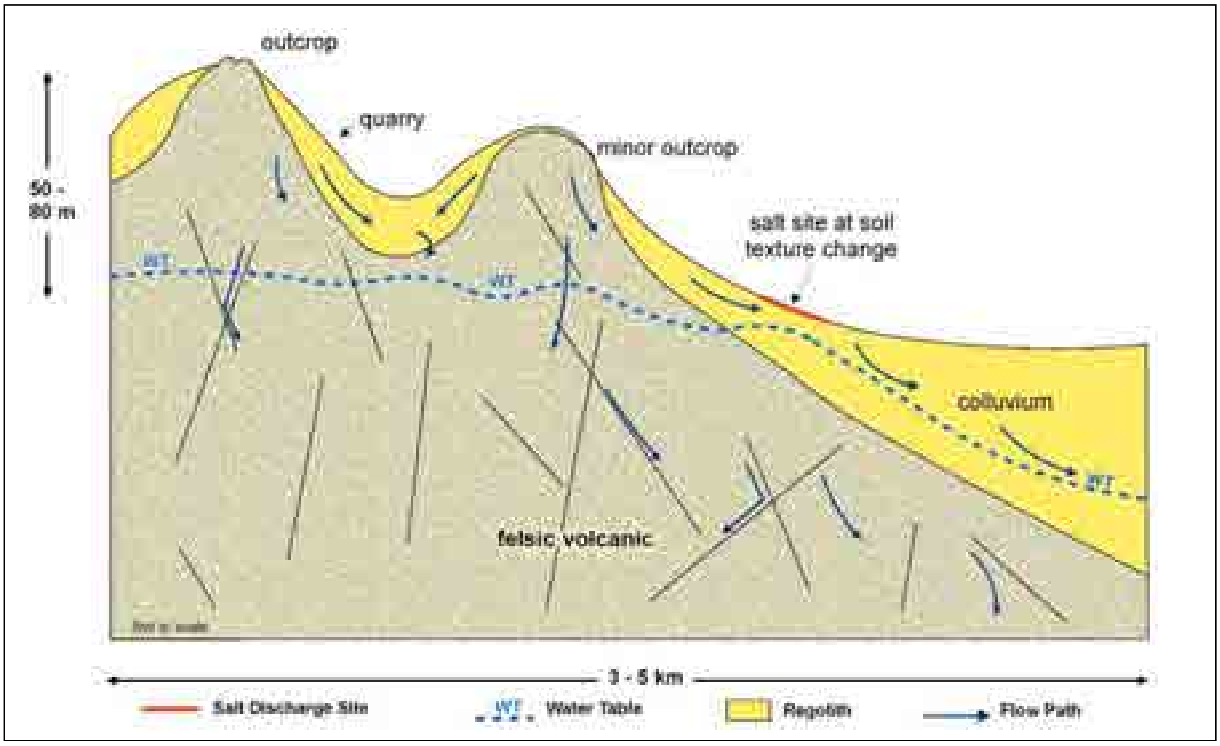


Figure 2: Conceptual cross-section for Soldiers Hill HGL showing the distribution of regolith and landforms, salt sites if present, and flow paths of water infiltrating the system.

Land salinity occurs on the lower colluvial slopes and are associated with soil texture changes. Salt load and EC levels in this HGL are low (Table 1).

Table 1: Soldiers Hill HGL salinity expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	Moderate – salt sites present on lower colluvial slopes related to soil texture change
Salt Load (Export)	Low – surface water not observed, therefore load considered to be low
EC (Water Quality)	Low – water quality is fresh

Salt stored within the Soldiers Hill HGL has low mobility. There is a low salt store that has low availability (Table 2).

Table 2: Soldiers Hill HGL salt store and availability.

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

The overall salinity hazard in the Soldiers Hill HGL is low. This is due to the moderate likelihood that salinity issues will occur that have potentially limited impacts (Table 3).

Table 3: Likelihood of salinity occurrence, potential impact and overall hazard of salinity for the Soldiers Hill HGL.

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

LANDSCAPE FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 4.

Photo 1: Salt efflorescence can be observed on lower slopes and in flow lines in the Soldiers Hill HGL (Photo: University of Canberra/K Harvey).

Photo 2: Regolith development on the hills of the Soldiers Hill HGL is weak and rocky outcrop is common (Photo: University of Canberra/A Price).

Photo 3: The rocky hills of the Soldiers Hill HGL grade down into long, gently inclined foot-slopes with deeper soil development (Photo: OEH/R Muller).

Photo 4: The deeper soils on the gently inclined slopes of the Soldiers Hill HGL are generally used for cropping (Photo: OEH/R Muller).

Photo 5: The northern part of the Soldiers Hill HGL has better soil development on the rolling hills and rises with less rocky outcrop present (Photo: OEH/R Muller).

Table 4: Summary of information used to define the Soldiers Hill HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2011)*	This HGL comprises consolidated volcanic rocks from the Silurian and Devonian periods. Unconsolidated Quaternary colluvium occurs on lower slopes. Key lithologies include: • colluvium and/or residual deposits – boulders, gravel and sand • unnamed felsic volcanics and volcaniclastics – felsic to intermediate volcanic and volcaniclastic rocks.
Annual Rainfall	600–650 mm
Regolith and Landforms	The Soldiers Hill HGL is variably weathered and is characterised by undulating low hills (30–80 m relief) and rises (9–30 m relief) with rounded crests and long colluvial slopes, developed on Siluro-Devonian felsic volcanic bedrock, and undulating alluvial plains (<9 m relief) with widely spaced shallow drainage lines. Slopes are typically 3–15%, local relief is 10–80 m and this HGL is between 220–340 m elevation. Some hills have steep crests with rock outcrop. Regolith materials are quartzose clayey sands and sandy clays with gravels. On ridge crests and upper slopes there are angular pebble and cobble-bearing coarse sandy gravels and gravelly sands.

Soil Landscapes *(DECCW 2010)*	This HGL includes Knox Road and Ettamogah soil landscapes with minor Soldiers Hill soil landscape on steeper hills. Soils include: moderately deep (0.5–1.0 m), well-drained Leptic Tenosols (Lithosols) on rocky (30–50% rock outcrop) crests; deep and moderately well-drained Red and Brown Chromosols and Kurosols (Red and Brown Podzolic Soils) on less rocky crests and slopes; shallow (<0.5 m) Bleached Leptic Tenosols (Lithosols) occurring around rock outcrops; and deep (1.0–1.5 m), poorly drained Yellow Dermosols (Yellow Earths) and Yellow Sodosols (Brown and Yellow Soloths and Solodic Soils) on lower slopes and in drainage lines. The landscape shape and texture contrast soils accommodate widespread sheet erosion and localised saline outbreaks.
Land and Soil Capability *(OEH 2012)*	Class 6
Land Use	Continuous or rotation cropping with some grazing on volunteer, naturalised, native or improved pasture
Key Land Degradation Issues	• minor sheet erosion • gully erosion along drainage lines • localised saline outbreaks • tree dieback.
Native Vegetation *(Stelling 1998; Keith 2004)*	Vegetation within the Soldiers Hill HGL tends to be yellow box woodland and grey box woodland, while white box woodland and Blakely's red gum woodland may also occur towards Boorook HGL. Tree species can include *Eucalyptus melliodora* (yellow box) and *E. bridgesiana* (apple box) where the soils are moderately fertile and well drained, *E. microcarpa* (grey box) on heavier soils, *E. polyanthemos* (red box) on well drained or dry rocky slopes and *E. camaldulensis* (river red gum) and *Allocasuarina luehmannii* (bulloak) along Billabong Creek. Other tree species may include *E. albens* (white box), *E. blakelyi* (Blakely's red gum), *Callitris glaucophylla* (white cypress pine) and *Brachychiton populneus* (kurrajong). Understorey species may include *Acacia acinacea* (gold-dust wattle), *A. paradoxa* (kangaroo thorn), *A. pycnantha* (golden wattle) and *Bursaria spinosa* (sweet bursaria).

HYDROGEOLOGY

Aquifers within this landscape are unconfined to semi-confined with groundwater flow occurring primarily through fractures in bedrock and saprolite. Some flow occurs through colluvial and alluvial sediments on lower slopes and in flow lines. Hydraulic conductivity and transmissivity are low to moderate. Groundwater recharge rates are estimated to be moderate to high.

Groundwater systems are typically local with short flow lengths and are loosely defined by topographic catchments. Water quality within these systems is fresh. Watertable depths are intermediate.

Medium residence times are typical. These landscapes have a medium to fast response time to changes in land management.

Typical values for the hydrogeological parameters of this HGL are summarised in Table 5.

Table 5: Summary of values for typical hydrogeological parameters of the Soldiers Hill HGL.

Aquifer Type	Unconfined to semi-confined in fractured rock and saprolite Lateral flow through unconsolidated colluvial and alluvial sediments on lower slopes and in flow lines
Hydraulic Conductivity	Low to moderate Range: <10^{-2}–10 m/day
Aquifer Transmissivity	Low to moderate Range: <2–50 m^2/day
Specific Yield	Low to moderate Range: <5–15%
Hydraulic Gradient	Gentle to moderate Range: <10–30%
Groundwater Salinity	Fresh Range: <800 µS/cm
Depth to Watertable	Intermediate Range: 2–8 m
Typical Sub-Catchment Size	Small (<100 ha)
Scale (Flow Length)	Local Flow length: <5 km (short)
Recharge Estimate	Moderate to high
Residence Time	Medium (years)
Responsiveness to Change	Fast to medium (months to years)

MANAGEMENT OPTIONS

Overarching salinity management strategies have specific biophysical outcomes. These are achieved by implementing a series of targeted land management actions that take into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape to impact on salinity. Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Salinity is driven by interactions between water-use capacity of vegetation, physical soil properties and hydrogeological processes within the HGL.

Actions that influence the way water is used by vegetation or stored in the soil profile will have impacts on recharge. The influence of both continual and episodic recharge and the impacts of extreme weather events need to be considered when deciding on appropriate management actions. Short and long-term climate cycles also need to be considered as they have a bearing on salinity processes, particularly salt load and land salinity.

Landscape Salinity Functions – Soldiers Hill HGL

Functions this landscape provides within a catchment scale salinity context:

- **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
- **G.** The landscape contains important land assets (including infrastructure and high value agricultural land) on which salinity processes impact.

Management Strategy Objectives – Soldiers Hill HGL

Appropriate strategies pertinent to this landscape:

- **Buffer the salt store – keep it dry and immobile (1):** There are stores of salt in discrete upper colluvial areas which can be targeted for salinity management actions. Vegetation can buffer salt stores and limit the salinity impact.
- **Discharge rehabilitation and management (4):** Discharge management will improve on-site and off-site salinity outcomes. Salt sites in this HGL are numerous but minor in size, and are usually associated with waterlogging or erosion.
- **Maintain or maximise runoff (10):** This HGL contributes significant fresh water as dilution flow to the local stream system. The fresh runoff mitigates the salt load, stream salinity and EC concentration of the local streams.

Key Management Focus – Soldiers Hill HGL

The soils and landscape characteristics of this landscape mean that it is prone to high levels of groundwater recharge. Management should focus on actions which reduce the risk of excess recharge. This will mean improving management of perennial pastures within mixed farming systems.

Specific Land Management Opportunities

Specific opportunities for this HGL:

- This landscape contains significant areas of native grass pastures. These provide an excellent base to build better management of native pastures into the future.
- Improving grazing management of existing native pastures particularly on areas which are seasonally waterlogged.
- Grazing management on and around discharge sites.
- Local groundwater systems with relatively quick response to management changes.
- Salt land sites are small and exhibit minor symptoms.

Specific Land Management Constraints

Constraints for land management in this HGL include:

- Seasonal waterlogging occurs during low growth periods of the year.
- Land use is observed as high percentage of annual cropping.

Specific Targeted Actions

Management areas for this HGL are illustrated in Figure 3. The specific management actions for these areas are described in Table 6.

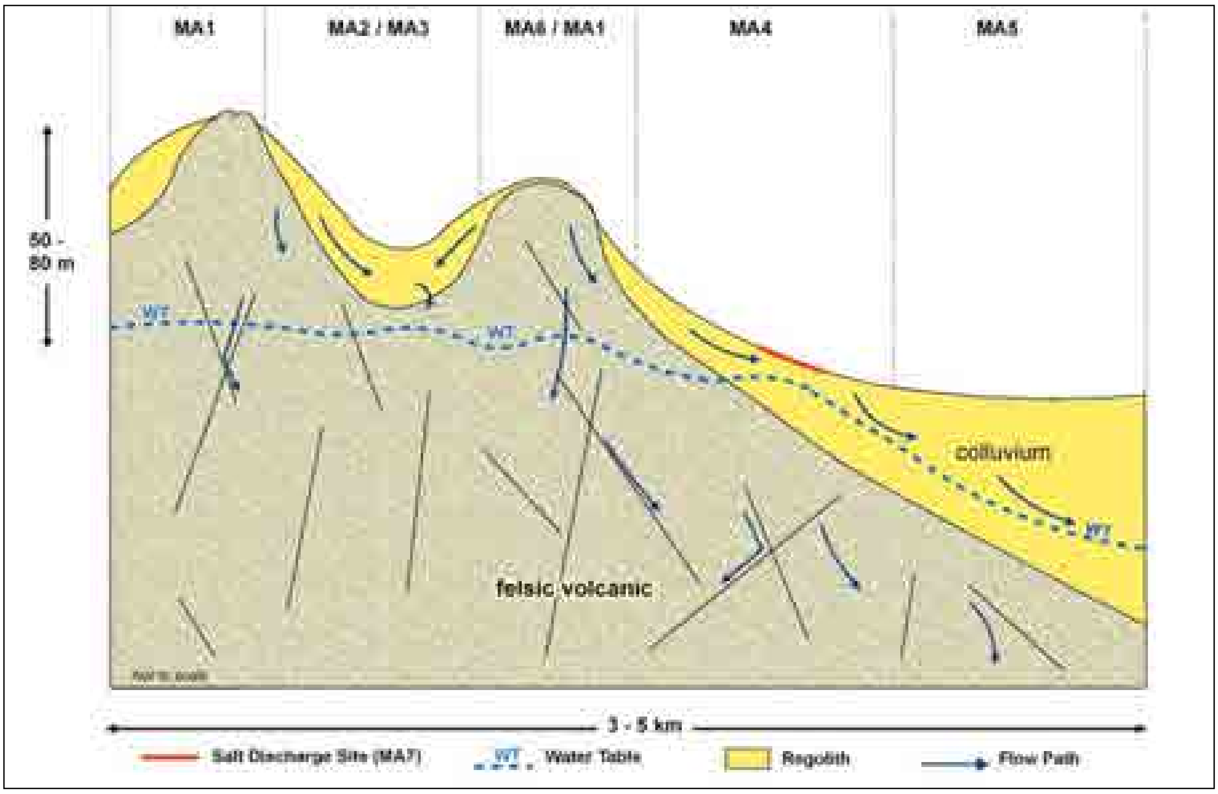


Figure 3: Management cross-section for Soldiers Hill HGL showing defined management areas.

Table 6: Specific management actions for management areas within the Soldiers Hill HGL.

Management Area (MA)	Action
MA1 & MA6 (RIDGES & RISES)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**
MA2/3 (UPPER SLOPES – EROSIONAL & COLLUVIAL)	**Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** **Farming Systems** Implement pasture cropping with annual cereals in perennial pastures to manage recharge **(FS1).** Implement rotational cropping with a perennial pasture component to manage recharge **(FS3).**
MA4 (MID-SLOPES)	**Vegetation for ecosystem function** Interception planting of native woody species to target shallow groundwater **(VE2).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** Establish and manage perennial pastures to intercept shallow lateral groundwater flow **(VP3).** **Farming Systems** Implement pasture cropping with annual cereals in perennial pastures to manage recharge **(FS1).** Implement rotational cropping with a perennial pasture component to manage recharge **(FS3).**

Management Area (MA)	Action
MA5 (LOWER SLOPES – COLLUVIAL)	**Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** Establish and manage perennial pastures to intercept shallow lateral groundwater flow **(VP3).** **Farming Systems** Implement pasture cropping with annual cereals in perennial pastures to manage recharge **(FS1).** Implement rotational cropping with a perennial pasture component to manage recharge **(FS3).**
MA7 (SALINE SITES)	Fence and isolate salt land and discharge areas to promote revegetation **(SR1).** Establish and manage salt land pasture systems to improve productivity **(SR2).** Establish forestry systems on salt land to improve productivity **(SR3).** Mulch sites using tactical animal impact **(SR9).**

High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative impacts on salinity (Table 7).

Table 7: Management actions having negative salinity impacts in the Soldiers Hill HGL.

At Risk Management Areas	Action
MA1 & MA6 (RIDGES & RISES)	Annual cropping with annual plants **(DLU3).** Clearing and poor management of native vegetation **(DLU4).**
MA2/3, MA4 & MA5 (UPPER SLOPES – EROSIONAL & COLLUVIAL) (MID-SLOPES) (LOWER SLOPES – COLLUVIAL)	Long fallows in farming systems **(DLU1).** Annual cropping with annual plants **(DLU3).**

REFERENCES

DECCW, 2010, *Reconnaissance soil and land resources of the Murray CMA*, NSW Department of Environment, Climate Change and Water, Sydney

Geoscience Australia, 2011, *Australian stratigraphic units database*, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int

Keith, D. A. 2004, *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, Hurstville, NSW Department of Environment and Conservation

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, Office of Environment and Heritage, Sydney, [Accessed: 10 November 2014] www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

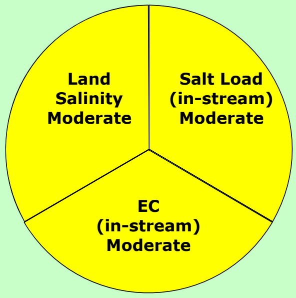
Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia

Stelling, F. 1998, *South west slopes revegetation guide (south of the Murrumbidgee River)*, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

Wooldridge, A., Nicholson, A., Muller R., Jenkins, B. R., Wilford, J. and Winkler, M. 2015, *Guidelines for managing salinity in rural areas*, NSW Office of Environment and Heritage, Sydney, NSW

17. Boorook Hydrogeological Landscape

LOCALITIES	**'Boorook'**
MAP SHEET	**Wagga Wagga 1:250 000**
CONFIDENCE LEVEL	**Low**



OVERVIEW

The Boorook Hydrogeological Landscape (HGL) runs north-east from Ralvona to Majors Creek (Figure 1). The HGL covers an area of 57 km^2 and receives approximately 700 mm of rain per annum.

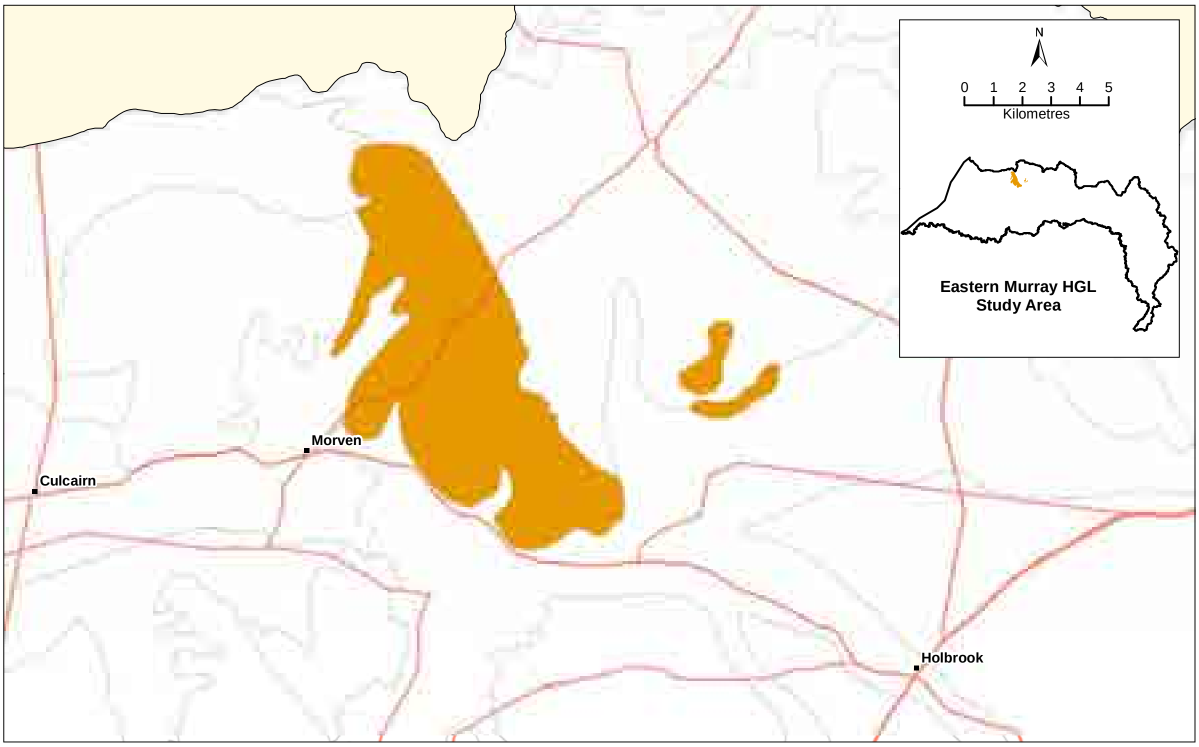


Figure 1: Boorook HGL distribution map.

The Boorook HGL is variably weathered, characterised by extensive rolling low hills and hills with broad crests and ridges; long waning mid to lower slopes; and broad drainage depressions (Figure 2). Relatively thick colluvial and slope-wash sediments occur on lower slopes and in drainage depressions. Rock outcrop is rare. This HGL includes locally metamorphosed consolidated sedimentary rocks from the Ordovician period. Soils are typically shallow and moderately well-drained on some crests, ridges and upper slopes; deep and imperfectly drained on other crests and upper slopes; moderately deep and moderately well-drained on mid to lower slopes; and moderately deep and imperfectly drained in drainage lines and on lower slopes. There are localised areas of sodic subsoils, often associated with areas of salinity. Moderate to severe sheet and rill erosion are common and widespread with most top-soils degraded to some extent.

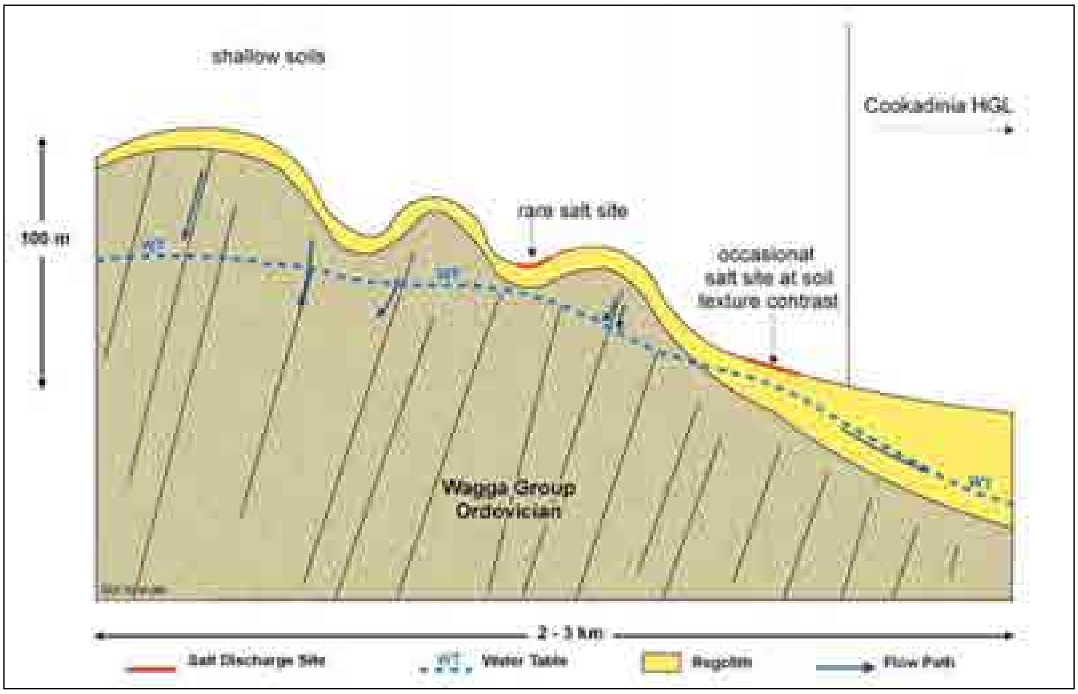


Figure 2: Conceptual cross-section for Boorook HGL showing the distribution of regolith and landforms, salt sites if present, and flow paths of water infiltrating the system.

Land salinity is common but localised and tends to occur on colluvial slopes at the break of slope. Moderate salt load and EC levels are present (Table 1).

Table 1: Boorook HGL salinity expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	Moderate – Localised salt sites on colluvial slopes and at break of slope
Salt Load (Export)	Moderate – no flow observed during study but geology suggests that load would be moderate
EC (Water Quality)	Moderate – no flow measured during study

Salt stored within the Boorook HGL has moderate mobility. There is a moderate salt store that has moderate availability (Table 2).

Table 2: Boorook HGL salt store and availability.

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

The overall salinity hazard in the Boorook HGL is low. This is due to the moderate likelihood that salinity issues will occur that have potentially limited impacts (Table 3).

Table 3: Likelihood of salinity occurrence, potential impact and overall hazard of salinity for the Boorook HGL.

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

LANDSCAPE FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 4.

Photo 1: The weathered metamorphosed sedimentary rocks that make up the Boorook HGL can be seen exposed in road cuttings. Soil development is shallow on the crests of hills (Photo: University of Canberra/A Price).

Photo 2: Hills in the Boorook HGL have broad crests and ridges; long mid to lower slopes; and broad drainage depressions (Photo: University of Canberra/K Harvey).

Photo 3: Rocky outcrop on hills is rare in the Boorook HGL, but where it does occur, it is generally associated with metamorphosed sandstone (Photo: OEH/R Muller).

Photo 4: Rolling low hills in the Boorook HGL run down to broad drainage depressions (Photo: OEH/R Muller).

Photo 5: Rolling low hills in the Boorook HGL have long, gently inclined slopes (Photo: OEH/R Muller).

Photo 6: Rolling low hills in the Boorook HGL have broad crests with gently inclined slopes and generally have no rocky outcrop (Photo: OEH/R Muller).

Table 4: Summary of information used to define the Boorook HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2011)*	This HGL comprises locally metamorphosed consolidated sedimentary rocks from the Ordovician period. Minor unconsolidated Quaternary colluvium and alluvium occur on lower slopes and in river valleys. Key lithologies include: • channel and flood plain alluvium – gravel, sand, silt and clay • colluvium and/or residual deposits – boulders, gravel and sand • Wagga Group – quartzose siltstone, sandstone, quartz-mica schist, mudstone and chert. Minor quartzite, graphitic schist and hornfels.
Annual Rainfall	700 mm
Regolith and Landforms	The Boorook HGL is slightly to moderately weathered and is characterised by rolling hills (90–100 m relief), low hills (30–90 m relief) and rises (9–30 m relief) with broad crests and ridges, long colluvial slopes and broad drainage depressions, on Ordovician metasedimentary bedrock. Rock outcrop is up to 50% and usually associated with sites underlain by sandstone. Slopes are typically 10–20%, local relief is 30–100 m and this HGL is between 200–720 m elevation. Regolith materials are kaolinite-bearing quartzose clayey sands with minor gravels and some sandy clays. On some ridge crests and upper slopes there are angular tabular pebble and cobble-bearing coarse sandy gravels and gravelly sands with variable kaolinitic clay content.
Soil Landscapes *(DECCW 2010)*	Lloyd is the main soil landscape found within this HGL. Minor occurrences of Pulletop and Four Mile Creek occur on relatively subdued terrain. Soils are typically: shallow (<0.5 m), moderately well-drained Paralithic Leptic Rudosols (Lithosols) on some crests, ridges and upper slopes; deep (1.0–1.5 m), imperfectly drained Red Kurosols (Red Podzolic Soils) on other crests and upper slopes; moderately deep (0.5–1.0 m), moderately well-drained Red Chromosols and Kurosols (Red Podzolic Soils) on mid to lower slopes; and, moderately deep (0.5–1.0 m), imperfectly drained Brown and Red Sodosols (Solodic Soils), and Yellow and Grey Sodosols (Soloths) and Brown Kurosols (Yellow Podzolic Soils) in drainage lines and on lower slopes. Sheet and rill erosion are common and widespread with most topsoils degraded to some extent. Gully erosion is locally common. Saline outbreaks are locally common and can be severe at the boundary between colluvium and alluvium. There are localised areas of sodic subsoils often associated with areas of salinity.
Land and Soil Capability *(OEH 2012)*	Class 5
Land Use	Predominantly grazing of volunteer, naturalise, native or improved pastures. Some continuous or rotation cropping also occurs

Key Land Degradation Issues	• moderate to severe sheet and rill erosion (upper slopes; cultivated lower slopes) • minor gully erosion (drainage lines) • localised saline outbreaks (lower change of slopes) • acidity (localised) and associated aluminium toxicity.
Native Vegetation *(Stelling 1998; Keith 2004)*	Vegetation tends to be white box woodland and Blakely's red gum woodland. Tree species in the hills include *Eucalyptus albens* (white box) on fertile slopes and ridges, *E. blakelyi* (Blakely's red gum) on loamy soils, *E. goniocalyx* (long-leaf box) on well drained hills or dry rocky slopes, *E. macrorhyncha* (red stringybark) on south-eastern facing slopes, *Callitris glaucophylla* (white cypress pine), *Allocasuarina verticillata* (drooping sheoak), *Brachychiton populneus* (kurrajong) and *Acacia implexa* (hickory wattle/lightwood). Characteristic understorey species may include *Acacia acinacea* (gold-dust wattle), *A. paradoxa* (kangaroo thorn), *A. pycnantha* (golden wattle), *Bursaria spinosa* (sweet bursaria), *Cassinia aculeate* (common cassinia) and *Dillwynia phylicoides* spp. complex (small-leaf parrot-pea).

HYDROGEOLOGY

Aquifers within this landscape are unconfined to semi-confined with groundwater flow occurring primarily through fractures in bedrock and saprolite. Some flow occurs through colluvial and alluvial sediments on lower slopes and in flow lines. Hydraulic conductivity and transmissivity are low. Groundwater recharge rates are estimated to be low to moderate.

Groundwater systems are typically local with short flow lengths, and are loosely defined by topographic catchments. Water quality within these systems is fresh to marginal. Watertable depths are intermediate to deep.

Medium to long residence times are typical. These landscapes have a medium to fast response time to changes in land management.

Typical values for the hydrogeological parameters of this HGL are summarised in Table 5.

Table 5: Summary of values for typical hydrogeological parameters of the Boorook HGL.

Aquifer Type	Unconfined to semi-confined in fractured rock and saprolite Lateral flow through unconsolidated colluvial and alluvial sediments on lower slopes and in flow lines
Hydraulic Conductivity	Low Range: <10^{-2} m/day
Aquifer Transmissivity	Low Range: <2 m^2/day
Specific Yield	Low Range: <5%
Hydraulic Gradient	Moderate to steep Range: 10–>30%
Groundwater Salinity	Fresh to marginal Range: <800–1600 µS/cm
Depth to Watertable	Intermediate to deep Range: 2–>8 m
Typical Sub-Catchment Size	Small (<100 ha)
Scale (Flow Length)	Local Flow length: <5 km (short)
Recharge Estimate	Low to moderate
Residence Time	Medium (years)
Responsiveness to Change	Fast to medium (months to years)

MANAGEMENT OPTIONS

Overarching salinity management strategies have specific biophysical outcomes. These are achieved by implementing a series of targeted land management actions that take into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape to impact on salinity. Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Salinity is driven by interactions between water-use capacity of vegetation, physical soil properties and hydrogeological processes within the HGL.

Actions that influence the way water is used by vegetation or stored in the soil profile will have impacts on recharge. The influence of both continual and episodic recharge and the impacts of extreme weather events need to be considered when deciding on appropriate

management actions. Short and long-term climate cycles also need to be considered as they have a bearing on salinity processes, particularly salt load and land salinity.

Landscape Salinity Functions – Boorook HGL

Functions this landscape provides within a catchment scale salinity context:

- **D.** The landscape generates salt loads which enter the streams and are redistributed in the catchment.
- **G.** The landscape contains important land assets (including infrastructure and high value agricultural land) on which salinity processes impact.

Management Strategy Objectives – Boorook HGL

Appropriate strategies pertinent to this landscape:

- **Buffer the salt store – keep it dry and immobile (1):** There are stores of salt in particular parts of this landscapes that can be buffered by vegetation, limiting the salinity impact. They are generally in the depositional elements of the middle to lower landscape.
- **Discharge rehabilitation and management (4):** Salt sites are small, exhibit minor salinity and are frequently waterlogged. Discharge management will improve on-site and off-site salinity outcomes.
- **Dry out the landscape with diffuse actions over most of the landscape (6):** Encourage plant growth and increase plant water use in order to use excess soil moisture and shallow groundwater. This landscape is seen as dominated by annual vegetation systems. Perennial vegetation will act as a buffer to groundwater accessions in wet seasonal conditions.

Key Management Focus – Boorook HGL

Grazing management is the key focus for this unit. This includes introduction and management of pasture systems based on perennial plants with a high relevance on cropping of winter cereals. Grazing management of perennial pastures will have major positive benefits on both discharge areas and the wider recharging landscape. Grazing infrastructure and management should consider saline and sodic sites as sensitive areas.

Specific Land Management Opportunities

Specific opportunities for this HGL:

- This landscape contains significant areas of native grass pastures. These provide an excellent base to build better management of native pastures into the future.
- This landscape has a local groundwater system with most farms having both recharge and discharge areas.

Specific Land Management Constraints

Constraints for land management in this HGL include:

- Soil aluminium toxicity associated with acidity.
- Shallow soils with high gravel content.

Specific Targeted Actions

Management areas for this HGL are illustrated in Figure 3. The specific management actions for these areas are described in Table 6.

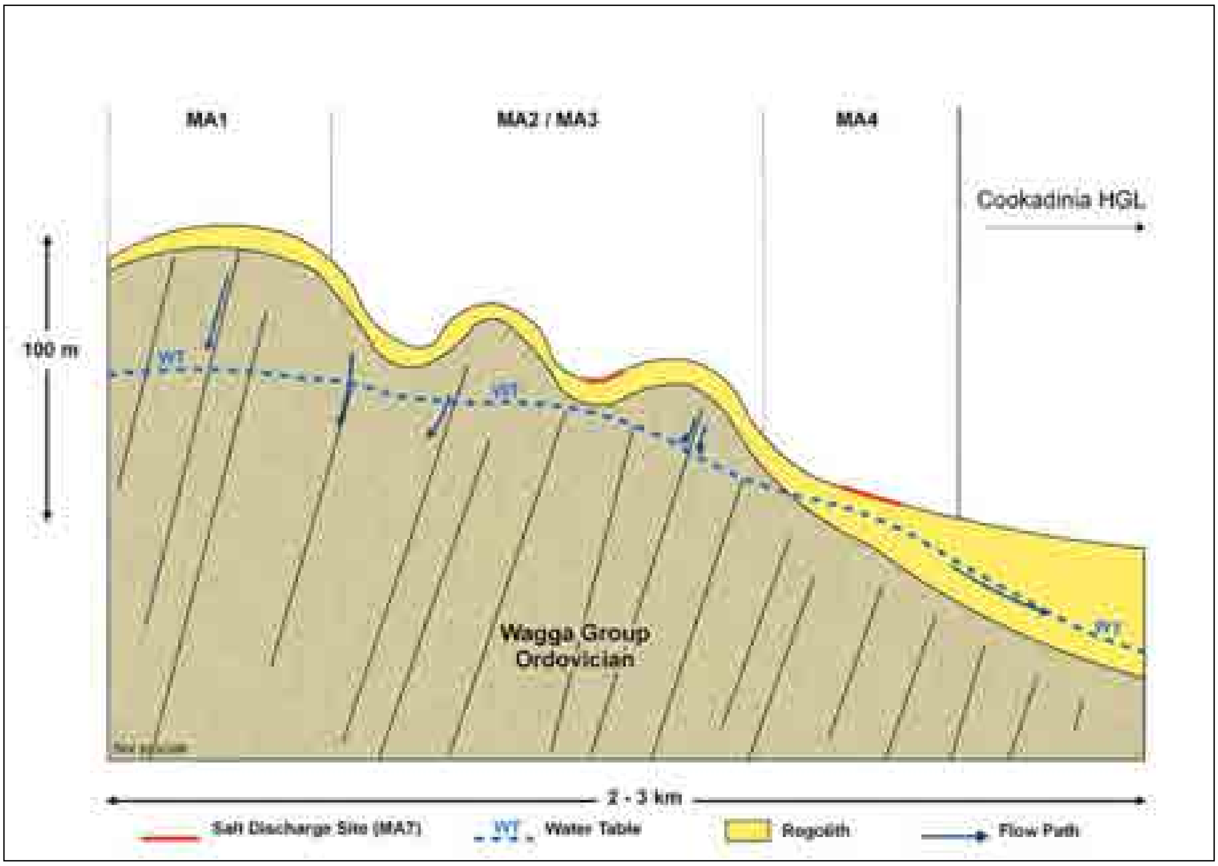


Figure 3: Management cross-section for Boorook HGL showing defined management areas.

Table 6: Specific management actions for management areas within the Boorook HGL.

Management Area (MA)	Action
MA1 (RIDGES)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**

Management Area (MA)	Action
MA2/3 (UPPER SLOPES – EROSIONAL & COLLUVIAL)	**Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** **Farming Systems** Implement pasture cropping with annual cereals in perennial pastures to manage recharge **(FS1).** Implement rotational cropping with a perennial pasture component to manage recharge **(FS3).**
MA4 (MID-SLOPES)	**Vegetation for ecosystem function** Interception planting of native woody species to target shallow groundwater **(VE2).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** Interception of shallow lateral groundwater flow with perennial pastures **(VP3).** Maximise agricultural production from pastures by input of additional ameliorants to manage recharge **(VP4).** **Farming Systems** Implement pasture cropping with annual cereals in perennial pastures to manage recharge **(FS1).** Implement rotational cropping with a perennial pasture component to manage recharge **(FS3).**
MA7 (SALINE SITES)	**Salt land rehabilitation** Fence and isolate salt land and discharge areas to promote revegetation **(SR1).** Establish and manage salt land pasture systems to improve productivity **(SR2).**

High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative impacts on salinity (Table 7).

Table 7: Management actions having negative salinity impacts in the Boorook HGL.

At Risk Management Areas	Action
MA1 (RIDGES)	Clearing and poor management of native vegetation **(DLU4).**
MA2/3 (UPPER SLOPES – EROSIONAL & COLLUVIAL)	Long fallows in farming systems **(DLU1).** Poor management of grazing pastures **(DLU2).** Annual cropping with annual plants **(DLU3).** Clearing and poor management of native vegetation **(DLU4).**
MA4 (MID-SLOPES)	Long fallows in farming systems **(DLU1).** Poor management of grazing pastures **(DLU2).** Annual cropping with annual plants **(DLU3).**
MA7 (SALINE SITES)	Locating infrastructure on discharge areas **(DLU7).** Deep ripping of soils to maximise water infiltration to subsoil **(DLU11).**

REFERENCES

DECCW, 2010, *Reconnaissance soil and land resources of the Murray CMA*, NSW Department of Environment, Climate Change and Water, Sydney

Geoscience Australia, 2011, *Australian stratigraphic units database*, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int

Keith, D. A. 2004 *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, Hurstville, NSW Department of Environment and Conservation

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, Office of Environment and Heritage, Sydney, [Accessed: 10 November 2014] www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

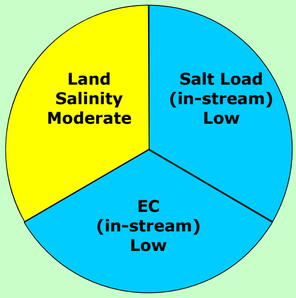
Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia

Stelling, F. 1998, *South west slopes revegetation guide (south of the Murrumbidgee River)*, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

Wooldridge, A., Nicholson, A., Muller R., Jenkins, B. R., Wilford, J. and Winkler, M. 2015, *Guidelines for managing salinity in rural areas*, NSW Office of Environment and Heritage, Sydney, NSW

18. Morgans Range-Black Rock Hydrogeological Landscape

LOCALITIES	Holbrook, Morgans Range, 'Kanimbla'
MAP SHEET	Wagga Wagga 1:250 000
CONFIDENCE LEVEL	Low



OVERVIEW

The Morgans Range-Black Rock Hydrogeological Landscape (HGL) is north-east and south-west of Holbrook, and south east of Morven (Figure 1). It is intersected by the Woomargama and Upper Billabong HGLs. The HGL covers an area of 223 km^2 and receives 650 to 900 mm of rain per annum.

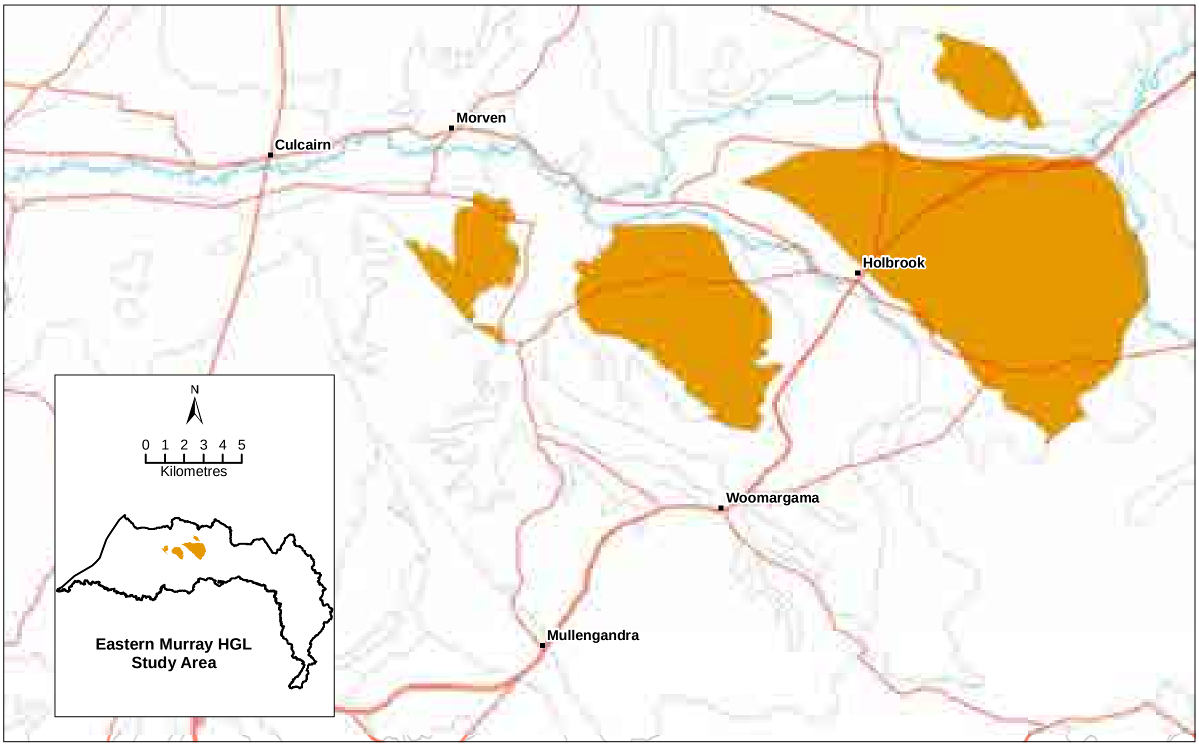


Figure 1: Morgans Range-Black Rock HGL distribution map.

The Morgans Range-Black Rock HGL is variably weathered and is characterised by steep to precipitous, rolling hills, rocky hills, mountains and an undulating plateau surface and foot-slopes and fans on granite-derived colluvium. Long sand plains are a feature of this unit (Figure 2). There is common to abundant rock outcrop occurring as rock bars, scarps and tors. Terracettes are common on cleared slopes. Narrow incised drainage lines in the steeper landforms cut to bedrock. Long slopes of the foot-slopes and fans have mostly parallel drainage lines. This HGL comprises granitic rocks from the Silurian and Devonian periods and associated colluvial material. Soils are shallow and well-drained on crests; very deep and imperfectly to moderately well-drained on upper and mid-slopes; deep and moderately well-drained to imperfectly drained on lower slopes; and very deep and well-drained on fans. Minor to severe branching gully erosion occurs in valley depressions and drainage lines where sodic soils are present. The sodic soils tend to seal and waterlog. This interacts with and contributes to salinity within this HGL.

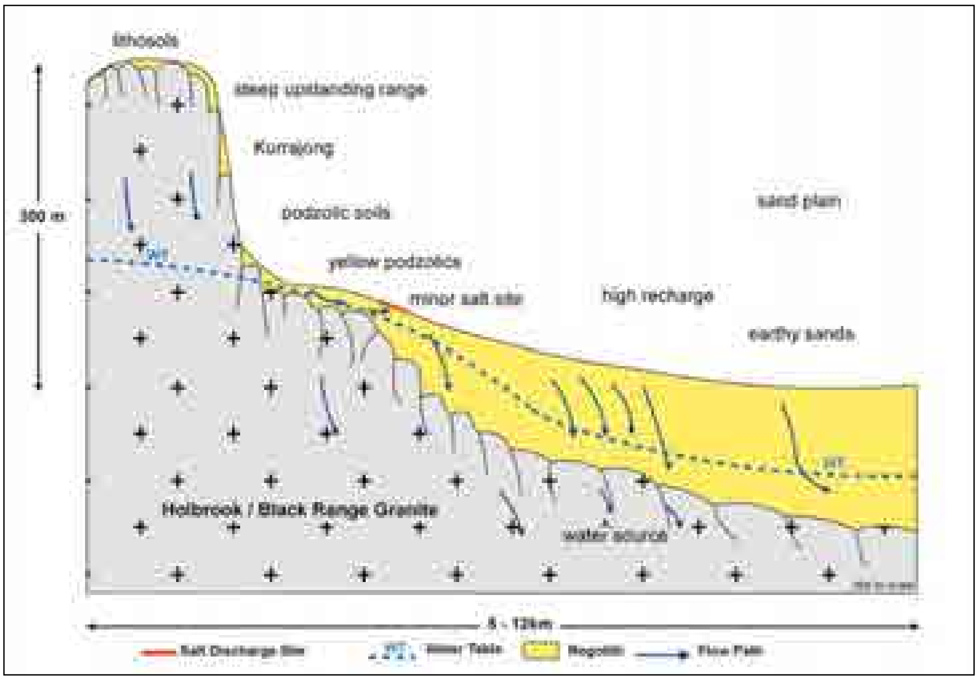


Figure 2: Conceptual cross-section for Morgans Range-Black Rock HGL showing the distribution of regolith and landforms, salt sites if present, and flow paths of water infiltrating the system.

Minor salt sites are common on the mid-slopes of this HGL. Salt load and EC levels are low (Table 1).

Table 1: Morgans Range-Black Rock HGL salinity expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	Moderate – minor salt sites occur on mid slopes
Salt Load (Export)	Low – salt loads are low due to deep recharge in sand plains. Most salt is stored in the higher parts of the landscape
EC (Water Quality)	Water EC is expected to be low

Salt stored within the Morgans Range-Black Rock HGL has high mobility. There is a moderate salt store that has high availability (Table 2).

Table 2: Morgans Range-Black Rock HGL salt store and availability.

SALT MOBILITY			
	Low availability	**Moderate** availability	**High** availability
High salt store			
Moderate salt store			**Morgans Range-Black Rock**
Low salt store			

The overall salinity hazard in the Morgans Range-Black Rock HGL is moderate. This is due to the moderate likelihood that salinity issues will occur that have potentially significant impacts (Table 3).

Table 3: Likelihood of salinity occurrence, potential impact and overall hazard of salinity for the Morgans Range-Black Rock HGL.

OVERALL SALINITY HAZARD			
	Limited potential impact	**Significant** potential impact	**Severe** potential impact
High likelihood of occurrence			
Moderate likelihood of occurrence		**Morgans Range-Black Rock**	
Low likelihood of occurrence			

LANDSCAPE FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 4.

Photo 1: Extensive sand plains border the western side of the steep, rocky ridges of Morgans Range in the Morgans Range-Black Rock HGL (Photo: OEH/R Muller).

Photo 2 Tree decline is a symptom of salinity that occurs on the lower slopes of the Morgans Range-Black Rock HGL (Photo: OEH/R Muller).

Photo 3: Granitic tors are a common feature of the rocky hills and ridges of the Morgans Range-Black Rock HGL (Photo: University of Canberra/A Price).

Photo 4: Soil development is shallow on the rolling hills of the Morgans Range-Black Rock HGL, and rocky out crop is common (Photo: University of Canberra/A Price).

Photo 5: Morgans Range is defined by steep, precipitous, rocky hills and mountains (Photo: OEH/R Muller).

Photo 6: The rocky rolling hills of the Morgans Range-Black Rock HGL have relatively long colluvial foot-slopes (Photo: OEH/R Muller).

Photo 7: The rolling hills of the Morgans Range-Black Rock HGL have relatively long colluvial foot-slopes (Photo: OEH/R Muller).

Table 4: Summary of information used to define the Morgans-Black Range HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2011)*	This HGL comprises granitic rocks from the Silurian and Devonian periods and associated colluvial material. Unconsolidated Cenozoic sand plains and Quaternary alluvium occur on lower slopes and in river valleys. Key lithologies include: • channel and flood plain alluvium – gravel, sand, silt and clay • sand plains – sand dominant, gravel, clay; may include some residual alluvium • Holbrook Granite – felsic, unfractionated granite • Black Rock Granite – granite.
Annual Rainfall	650–900 mm
Regolith and Landforms	The Morgans Range-Black Rock HGL slightly to moderately weathered and is characterised by steep to precipitous rocky hills (90–300 m relief), and low hills (30–90 m relief) forming an undulating plateau surface with inclined colluvial slopes, on Siluro-Devonian granitic bedrock. Slopes are typically 2–30%, local relief is 10–300 m and this HGL is between 170–1000 m elevation. This HGL features abundant rock outcrop as rock bars, scarps and tors on crests and upper slopes, soil creep on colluvial slopes, and sand plains in the low-lying parts of the landscape. Narrow drainage lines crossing steep landform elements incise to bedrock. Colluvial foot-slope and fans deposits have sub-parallel drainage lines. Regolith materials are quartzose clayey sands and sandy clays with quartzose gravels. On ridge crests and upper slopes there are angular pebble and cobble-bearing coarse sandy gravels and gravelly sands.
Soil Landscapes *(DECCW 2010)*	Wagra and Yarra Yarra are the major soil landscapes within this HGL. There are minor occurrences of a number of soil landscapes including Home Flat, Cookardinia, Tipperary, Dora Dora, Billabong Creek, Mountain Creek and Buckargingah. Soils include: shallow (<0.5 m), well-drained Clastic Rudosols and Orthic Tenosols (Lithosols) on crests; very deep (>1.5 m), imperfectly to moderately well-drained Red, Brown and Yellow Chromosols (Podzolic Soils) occur on upper and mid-slopes; deep (1.0–1.5 m), moderately well-drained Brown/Yellow Chromosols (Yellow Podzolic Soils); imperfectly drained Brown and Grey Sodosols and Kurosols (Solodized Solonetz Soils and Soloths) on lower slopes; and very deep (1.5–5.0 m), well-drained Orthic Tenosols (Earthy Sands) on fans. Severe branching gully erosion (1.5–3.0 m deep) occurs in valley depressions (in sodic soils). The sodic soils tend to seal and waterlog. This interacts with and contributes to salinity within this HGL.
Land and Soil Capability *(OEH 2012)*	Class 6

Land Use	Grazing on volunteer, naturalised, native or improved pastures or sown, improved perennial pastures. Steep precipitous rocky hills and mountains of Morgans Range are under native forest
Key Land Degradation Issues	• minor to severe gully erosion (drainage lines) • localised mass movement terracettes (soil creep) • sheet erosion (common in disturbed areas and on steep slopes) • sodic soils • salinity (associated with sodic soils) • waterlogging (associated with sodic soils).
Native Vegetation *(Stelling 1998; Keith 2004)*	Vegetation on the rocky outcrops and hills around Morgan's Ridge tends to be dry sclerophyll forest of Dwyer's red gum, red stringybark and currawang, while white box woodland is more likely to occur on the less rocky hills between Mountain Creek and Native Dog Creek. Tree species on the hills and rocky outcrops can include *Eucalyptus dwyeri* (Dwyer's red gum), *E. goniocalyx* (long-leaf box), *E. polyanthemos* (red box), *Exocarpos cupressiformis* (native cherry), *Acacia dealbata* (silver wattle), and *Acacia implexa* (hickory wattle), as well as *E. albens* (white box); *E. blakelyi* (Blakely's red gum); *Callitris glaucophylla* (white cypress pine); *E. melliodora* (yellow box); and *Brachychiton populneus* (kurrajong) on the hills west of Holbrook, with *E. dealbata* (tumbledown gum) on north-western slopes, or with *E. macrorhyncha* (red stringybark) on south-eastern slopes. The forest on sandy granite soils of Morgans Ridge may also include *A. doratoxylon* (currawang). Understorey species on the rocky outcrops may include *Acacia verniciflua* (varnish wattle) and *Calytrix tetragona* (common fringe-myrtle). Understorey species on the hills west of Holbrook can also include *A. genistifolia* (spreading wattle/early wattle), *A. pycnantha* (golden wattle), *A. rubida* (red-stemmed wattle), *Bursaria spinosa* (sweet bursaria), *Cassinia aculeata* (common cassinia) and *Daviesia latifolia* (hop bitter-pea). Vegetation on the lower hills and rises tends to be Blakely's red gum and yellow box woodland. Additional tree species found on these lower slopes may include *E. macrocarpa* (grey box).

HYDROGEOLOGY

Aquifers within this landscape are unconfined with groundwater flow occurring primarily through fractures in bedrock and saprolite. Some flow occurs through sand plains on lower slopes and alluvial sediments in flow lines. Hydraulic conductivity is moderate to high and transmissivity is moderate. Groundwater recharge rates are estimated to be moderate to high.

Groundwater systems are typically local with short to intermediate flow lengths and are loosely defined by topographic catchments. Water quality within these systems is fresh. Watertable depths are intermediate to deep.

Short to medium residence times are typical. These landscapes have a medium to fast response time to changes in land management.

Typical values for the hydrogeological parameters of this HGL are summarised in Table 5.

Table 5: Summary of values for typical hydrogeological parameters of the Morgans Range-Black Rock HGL.

Aquifer Type	Unconfined in fractured rock and saprolite Lateral flow through unconsolidated colluvial and alluvial sediments on lower slopes and in flow lines
Hydraulic Conductivity	Moderate to high Range: 10^{-2}–>10 m/day
Aquifer Transmissivity	Moderate Range: 2–50 m^2/day
Specific Yield	Moderate to high Range: 5–>15%
Hydraulic Gradient	Moderate to steep Range: >10%
Groundwater Salinity	Fresh Range: <800 µS/cm
Depth to Watertable	Intermediate to deep Range: >2 m
Typical Sub-Catchment Size	Small to medium (100 –1000 ha)
Scale (Flow Length)	Local Flow length: <10 km (short to intermediate)
Recharge Estimate	Moderate to high
Residence Time	Short to medium (months to years)
Responsiveness to Change	Medium to fast (months to years)

MANAGEMENT OPTIONS

Overarching salinity management strategies have specific biophysical outcomes. These are achieved by implementing a series of targeted land management actions that take into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape to impact on salinity. Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Salinity is driven by interactions between water-use capacity of vegetation, physical soil properties and hydrogeological processes within the HGL.

Actions that influence the way water is used by vegetation or stored in the soil profile will have impacts on recharge. The influence of both continual and episodic recharge and the impacts of extreme weather events need to be considered when deciding on appropriate management actions. Short and long-term climate cycles also need to be considered as they have a bearing on salinity processes, particularly salt load and land salinity.

Landscape Salinity Functions – Morgans Range-Black Rock HGL

Functions this landscape provides within a catchment scale salinity context:

- **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
- **G.** The landscape contains important land assets (including infrastructure and high value agricultural land) on which salinity processes impact.

Management Strategy Objectives – Morgans Range-Black Rock HGL

Appropriate strategies pertinent to this landscape:

- **Buffer the salt store – keep it dry and immobile (1):** There are stores of salt in discrete upper colluvial areas which vegetation can buffer, limiting the salinity impact. They are generally in the upper erosional elements of the landscape and comprise a significant percentage of this HGL.
- **Discharge rehabilitation and management (4):** Salt sites are small, exhibit minor salinity and are frequently waterlogged. Discharge management will improve on-site and off-site salinity outcomes.
- **Maintain or maximise runoff (10):** This HGL contributes significant fresh water as dilution flow to the system, particularly the adjoining Upper Billabong HGL. The fresh runoff mitigates the salt load, stream salinity and EC concentration of the local streams.

Key Management Focus – Morgans Range-Black Rock HGL

Grazing management is the key focus for this unit. This includes introduction and management of pasture systems based on perennial plants on both discharge areas and the wider recharging landscape. Grazing infrastructure and management should consider saline, sodic and erosion sites as sensitive areas.

This landscape is important as it provides fresh water within the catchment. This means careful consideration and planning need to be given to land uses which reduce runoff. Large scale revegetation with trees is not recommended on this unit.

Specific Land Management Opportunities

Specific opportunities for this HGL:

- This landscape has short groundwater flow lengths which mean there will be quick response to management change.
- High watertables exist at the colluvial change upslope of sand plains. They offer potential for pastures/grazing systems based on pastures with salt and waterlogging tolerance.
- High recharge areas are frequently covered with native vegetation, which offers the potential to maintain and improve native vegetation.
- The landscape is mainly used for grazing. There are native perennial pastures which could aid in salinity improvements with management change.

Specific Land Management Constraints

Constraints for land management in this HGL include:

- Sodic and dispersible B horizons occur in many soil types – particularly in soil types which are affected by salinity.
- Seasonal waterlogging occurs during low growth periods of the year.
- Sandy soils.
- Shallow rocky slopes in upper landscape and deep sand plains in lower landscape (cropping).

Specific Targeted Actions

Management areas for this HGL are illustrated in Figure 3. The specific management actions for these areas are described in Table 6.

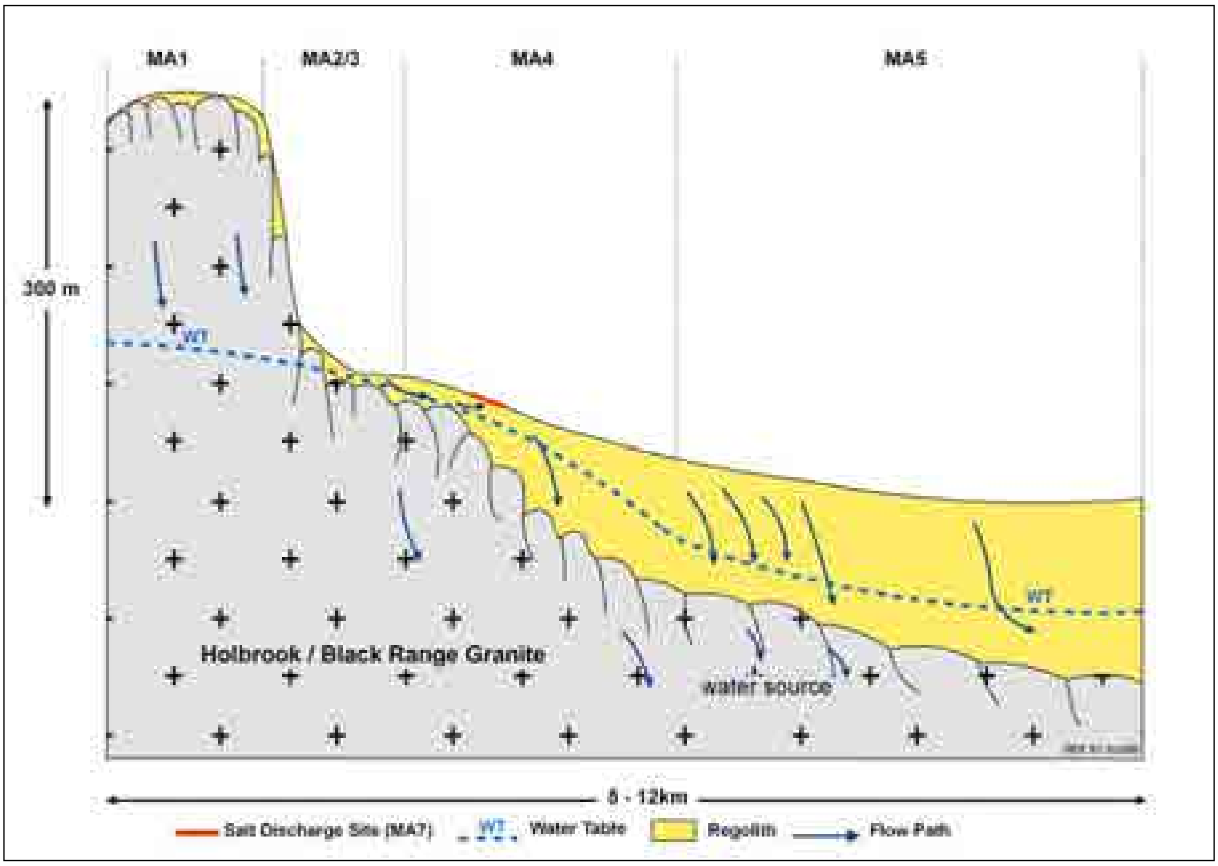


Figure 3: Management cross-section for Morgans Range-Black Rock HGL showing defined management areas.

Table 6: Specific management actions for management areas within the Morgans Range-Black Rock HGL.

Management Area (MA)	Action
MA1 (RIDGES)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).**
MA2/3 (UPPER SLOPES – EROSIONAL & COLLUVIAL)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** **Vegetation for production** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**

Management Area (MA)	Action
MA4 (MID-SLOPES)	**Vegetation for ecosystem function** Establish and manage trees to intercept lateral groundwater flow **(VE2).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge (**VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** **Salt land rehabilitation** Fence and isolate salt land and discharge areas to promote revegetation **(SR1).** Establish and manage salt land pasture systems to improve productivity **(SR2).**
MA5 (LOWER SLOPES – COLLUVIAL)	**Vegetation for ecosystem function** Maintain and improve riparian native vegetation to reduce discharge to streams **(VE4).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge (**VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** Maximise agricultural production from pastures by input of additional ameliorants to manage recharge **(VP4).** **Engineering** Use groundwater to supplement or replace surface water for farm stock **(E1).**

High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative impacts on salinity (Table 7).

Table 7: Management actions having negative salinity impacts in the Morgans Range-Black Rock HGL.

At Risk Management Areas	Action
MA1 (RIDGES)	Clearing and poor management of native vegetation **(DLU4).**
MA2/3 (UPPER SLOPES – EROSIONAL & COLLUVIAL)	Clearing and poor management of native vegetation **(DLU4).**
MA4 (MID-SLOPES)	Long fallows in farming systems **(DLU1).** Poor management of grazing pastures **(DLU2).** Clearing and poor management of native vegetation **(DLU4).** Annual cropping with annual plants **(DLU3).** Poor soil management – tillage causing poor structure **(DLU8).**
MA5 (LOWER SLOPES – COLLUVIAL)	Poor soil management – tillage causing poor structure **(DLU8).**

REFERENCES

DECCW, 2010, *Reconnaissance soil and land resources of the Murray CMA*, NSW Department of Environment, Climate Change and Water, Sydney

Geoscience Australia, 2011, *Australian stratigraphic units database*, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int

Keith, D. A. 2004, *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, Hurstville, NSW Department of Environment and Conservation

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, Office of Environment and Heritage, Sydney, [Accessed: 10 November 2014] www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

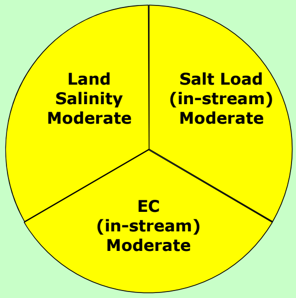
Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia

Stelling, F. 1998, *South west slopes revegetation guide (south of the Murrumbidgee River)*, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

Wooldridge, A., Nicholson, A., Muller R., Jenkins, B. R., Wilford, J. and Winkler, M. 2015, *Guidelines for managing salinity in rural areas*, NSW Office of Environment and Heritage, Sydney, NSW

19. Sweetwater Hydrogeological Landscape

LOCALITIES	**Mullengandra, Sweetwater Creek**
MAP SHEET	**Wagga Wagga 1:250 000**
CONFIDENCE LEVEL	**Low**



OVERVIEW

The Sweetwater Hydrogeological Landscape (HGL) extends to the north-west and south-east of Mullengandra and Woomargama (Figure 1). The HGL covers an area of 251 km^2 and receives 700 to 1100 mm of rain per annum.

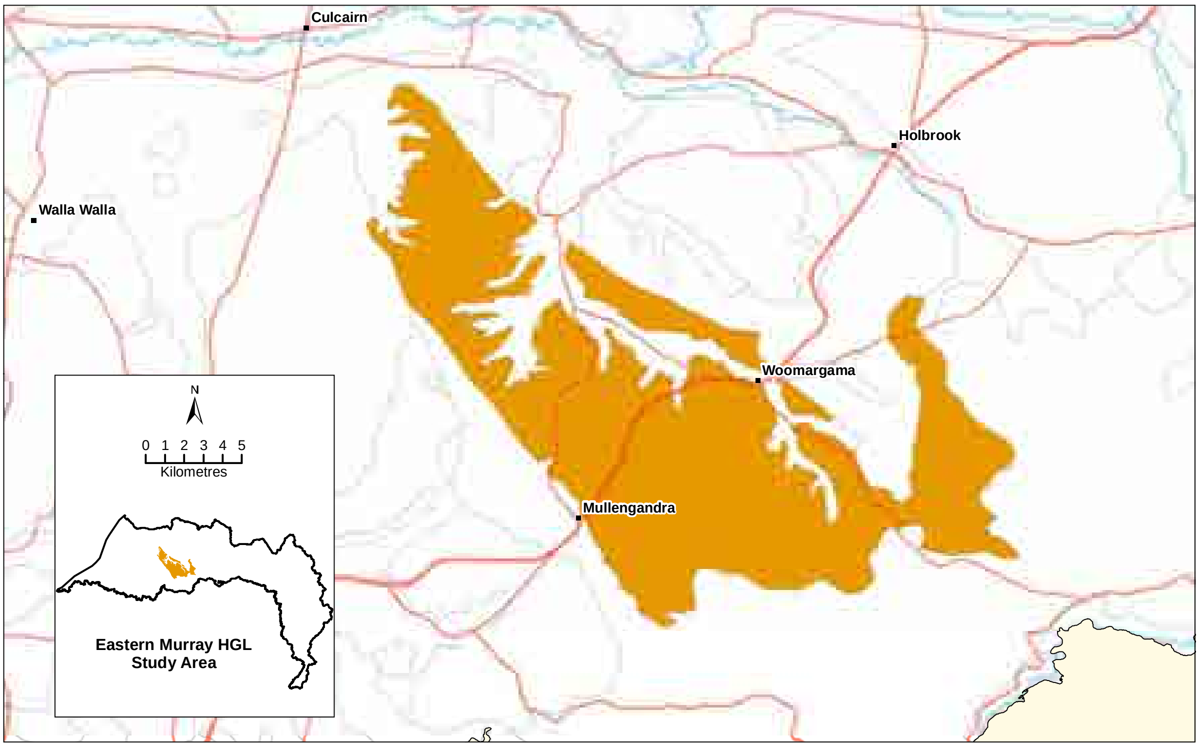


Figure 1: Sweetwater HGL distribution map.

The Sweetwater HGL is variably weathered and is characterised by rolling low to steep hills with broad ridge crests; long, waning middle and lower slopes; broad drainage depressions; and narrow drainage lines (Figure 2). Processes are primarily erosional on the ridge crests and upper slopes; colluvial on the middle to lower slopes; with minor transferral areas occurring along the drainage lines. This HGL includes Ordovician metamorphosed sedimentary rocks. Soils are shallow and well-drained on crests and steeper slopes; deep and well-drained on upper to mid-slopes; moderately deep and well drained on mid to lower slopes; and, moderately deep and imperfectly drained in drainage lines and lower slopes. Sodicity is an issue in this HGL. Topsoils have been degraded by sheet and rill erosion.

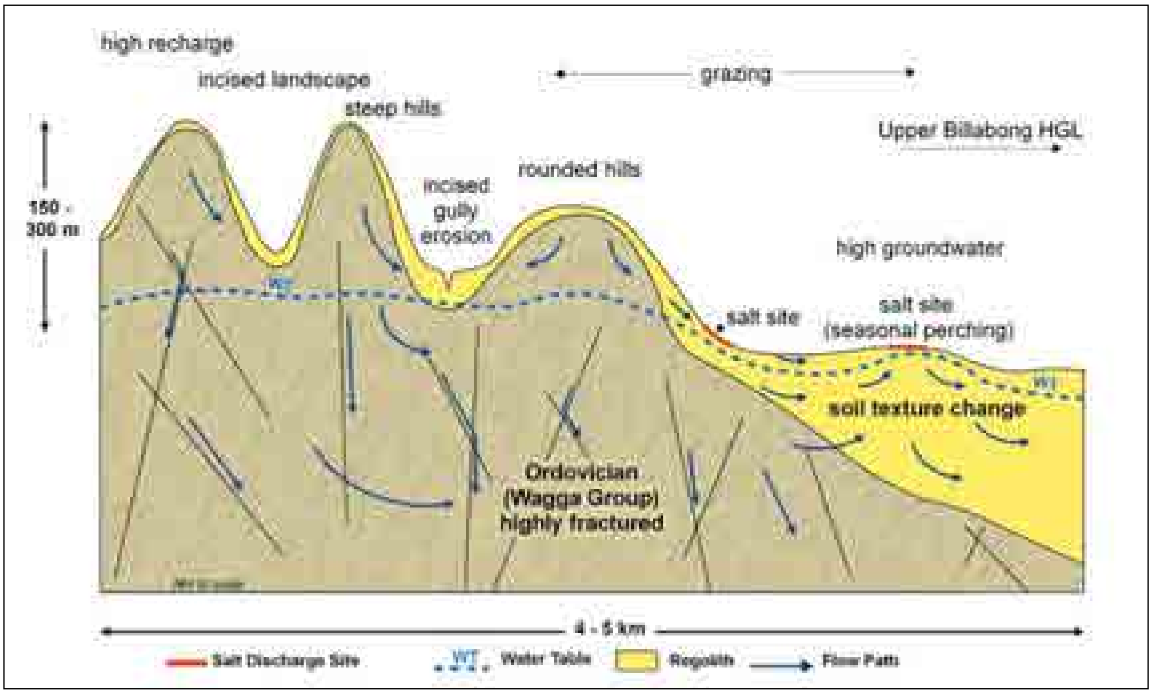


Figure 2: Conceptual cross-section for Sweetwater HGL showing the distribution of regolith and landforms, salt sites

Land salinity commonly occurs at the base of colluvial slopes where seasonal waterlogging due to perching is present. Moderate salt load and EC levels are present in this HGL (Table 1).

Table 1: Sweetwater HGL salinity expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	Moderate – salt sites commonly occur at the base of colluvial slopes and on the lower slope where seasonal perching causes waterlogging
Salt Load (Export)	Moderate – perennial streams carry elevated EC
EC (Water Quality)	Water EC is moderate

Salt stored within the Sweetwater HGL has high mobility. There is a moderate salt store that has high availability (Table 2).

Table 2: Sweetwater HGL salt store and availability.

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

The overall salinity hazard in the Sweetwater HGL is high. This is due to the high likelihood that salinity issues will occur that have potentially significant impacts (Table 3).

Table 3: Likelihood of salinity occurrence, potential impact and overall hazard of salinity for the Sweetwater HGL.

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

LANDSCAPE FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 4.

Photo 1: Rolling low hills of the Sweetwater HGL grade into the alluvial plain of the Upper Billabong HGL in the foreground (Photo: OEH/R Muller).

Photo 2: Much of the Sweetwater HGL is extensively cleared (Photo: OEH/ W Cook).

Photo 3: Drainage lines in the more elevated areas of the Sweetwater HGL are narrow and often areas of ponding and waterlogging (Photo: OEH/ R Muller).

Photo 4: Rolling low hills with long colluvial slopes are characteristic of the less elevated areas of the Sweetwater HGL (Photo: OEH/ R Muller).

Photo 5: The rolling nature of the Sweetwater HGL is well illustrated along the Woomargama – Dora Dora Road (Photo: OEH/ A Nicholson).

Photo 6: The change in slope between the steep upper slopes of the steeper hills of the Sweetwater HGL and the less steep lower slopes is quite pronounced (Photo: OEH/ W Cook).

Photo 7: Broad drainage depressions; and narrow drainage lines are a feature of the Sweetwater HGL. Gully erosion is often present in the drainage lines (Photo: OEH/ W Cook).

Photo 8: Gully erosion in the drainage lines of the Sweetwater HGL can be significant (Photo: OEH/ W Cook).

Photo 9: Rolling low hills with broad ridge crests; long, middle and lower slopes running down to broad drainage depressions and narrow drainage lines are characteristic of the Sweetwater HGL (Photo: OEH/ R Muller).

Photo 10: Waterlogging in drainage lines at slope changes in the Sweetwater HGL are generally a seasonal feature (Photo: OEH/ R Muller).

Table 4: Summary of information used to define the Sweetwater HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2011)*	This HGL comprises locally metamorphosed consolidated sedimentary rocks from the Ordovician period. These are overlain by unconsolidated Quaternary alluvial sediments. Key lithologies include: • channel and flood plain alluvium – gravel, sand, silt and clay • Wagga Group – quartzose siltstone, sandstone, quartz-mica schist, mudstone and chert. Minor quartzite, graphitic schist and hornfels.
Annual Rainfall	700–1100 mm
Regolith and Landforms	The Sweetwater HGL is slightly weathered and is characterised by steep hills (90–300 m relief) and low hills (30–90 m relief) with broad ridge crests; long, colluvial slopes; broad drainage depressions, and narrow drainage lines, on Ordovician metasedimetary bedrock. Slopes are typically 10–40%, and local relief is 30–300 m. This HGL features abundant (0–>50%) but irregularly distributed rock outcrop on crests and upper slopes. Regolith materials are dominantly kaolinite-bearing quartzose clayey sands with minor gravels and some sandy clays. On ridge crests and upper slopes there are angular tabular pebble and cobble-bearing coarse sandy gravels and gravelly sands with variable kaolinitic clay content.
Soil Landscapes *(DECCW 2010)*	This HGL corresponds closely to two soil landscapes, Lloyd and Sweetwater. There are minor occurrences of three other soil landscapes, Four Mile Creek, Mullengandra and Pulletop. Sweetwater soil landscape occupies the steepest hills within the HGL with Lloyd occupying more subdued terrain, typically rolling low hills. Soils are characteristically: shallow (<50 cm), well-drained Leptic Rudosols and Tenosols (Lithosols) on crests and steeper slopes; deep (1.0–1.5 m), well-drained Red Dermosols (Red Podzolic Soils and Red Earths) on upper to mid-slopes; moderately deep (0.5–1.0 m), well drained Brown and Yellow Kandosols (Yellow Earths) on mid to lower slopes; and, moderately deep (0.5–1.0 m), imperfectly drained Brown Kurosols (Yellow Podzolic Soils) in drainage lines and lower slopes. Topsoils have been degraded by sheet erosion over most of this HGL. Gully erosion and acid topsoils are locally common. The near surface hydrology is mostly due to the soil types and landscape shape with break of slope the most common place for saline outbreaks.
Land and Soil Capability *(OEH 2012)*	Class 6
Land Use	Grazing on volunteer, naturalise, native or sown improved perennial pasture. Also included are Benambra and Woomargama National Parks, Woomargama State Conservation Area and some softwood plantations and conservation areas under private conservation agreement

Key Land Degradation Issues	• moderate to severe sheet and rill erosion (upper slopes) • moderate gully erosion (drainage lines) • some trees exhibit dieback • localised saline outbreaks (lower change in slope) • acidity (localised) and associated aluminium toxicity • sodic soils.
Native Vegetation *(Stelling 1998; Keith 2004)*	Vegetation on upper slopes and hills >500 m above sea level can be moist open forest while red box and white box woodland, hill red gum woodland and red stringybark dry forest can also occur in the higher elevations. Tree species can include *Eucalyptus bicostata* (eurabbie) in sheltered areas) and *E. polyanthemos* (red box) on poor but well drained slopes and ridges, *E. albens* (white box) on fertile slopes and ridges and *E. goniocalyx* (long-leaf box) on dry rocky slopes, with *Eucalyptus macrorhyncha* (red stringybark) and *E. mannifera* (brittle gum) on slopes with a southerly or south-eastern aspect. *Eucalyptus camphora* (mountain swamp gum) occurs in creek lines and soaks. Other dominant tree species may include *Acacia dealbata* (silver wattle), *A. implexa* (hickory wattle), *Brachychiton populneus* (kurrajong), *Callitris endlicheri* (black cypress pine) and *Exocarpos cupressiformis* (native cherry). Understorey shrub species may include *Acacia paradoxa* (kangaroo thorn), *Bursaria spinosa* (sweet bursaria), *Cassinia aculeata* (common cassinia) and *Daviesia latifolia* (hop bitter-pea). Vegetation on the lower slopes additionally may include *E. melliodora* (yellow box), *E. bridgesiana* (apple box), *Allocasuarina verticillata* (drooping sheoak) and *Leptospermum continentale* (prickly tea-tree) in poorly drained sites and soaks on lower slopes.

HYDROGEOLOGY

Aquifers within this landscape are unconfined to semi-confined with groundwater flow occurring primarily through fractures in bedrock and saprolite. Some flow occurs through alluvial sediments in flow lines. Hydraulic conductivity is low to moderate and transmissivity is low. Groundwater recharge rates are estimated to be low to moderate.

Groundwater systems are typically local with short flow lengths, and are loosely defined by topographic catchments. Water quality within these systems is marginal. Watertable depths are intermediate.

Medium to long residence times are typical. These landscapes have a medium to fast response time to changes in land management.

Typical values for the hydrogeological parameters of this HGL are summarised in Table 5.

Table 5: Summary of values for typical hydrogeological parameters of the Sweetwater HGL.

Aquifer Type	Unconfined to semi-confined in fractured rock and saprolite Lateral flow through unconsolidated colluvial and alluvial sediments on lower slopes and in flow lines
Hydraulic Conductivity	Low to moderate Range: <10 m/day
Aquifer Transmissivity	Low Range: <2 m^2/day
Specific Yield	Low Range: <5%
Hydraulic Gradient	High Range: >30%
Groundwater Salinity	Marginal Range: 800–1600 µS/cm
Depth to Watertable	Intermediate Range: 2–8 m
Typical Sub-Catchment Size	Medium (100–1000 ha) (smaller in higher zones)
Scale (Flow Length)	Local Flow length: <5 km (short)
Recharge Estimate	Low to moderate
Residence Time	Medium to long (years to decades)
Responsiveness to Change	Fast to medium (months to years)

MANAGEMENT OPTIONS

Overarching salinity management strategies have specific biophysical outcomes. These are achieved by implementing a series of targeted land management actions that take into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape to impact on salinity. Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Salinity is driven by interactions between water-use capacity of vegetation, physical soil properties and hydrogeological processes within the HGL.

Actions that influence the way water is used by vegetation or stored in the soil profile will have impacts on recharge. The influence of both continual and episodic recharge and the impacts of extreme weather events need to be considered when deciding on appropriate

management actions. Short and long-term climate cycles also need to be considered as they have a bearing on salinity processes, particularly salt load and land salinity.

Landscape Functions – Sweetwater HGL

Functions this landscape provides within a catchment scale salinity context:

- **A.** The landscape provides fresh water runoff as an important water 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
- **G.** The landscape contains important land assets (including infrastructure and high value agricultural land) on which salinity processes impact
- **B.** The landscape provides fresh water runoff as an important dilution flow source.

Landscape Management Strategies – Sweetwater HGL

Appropriate strategies pertinent to this landscape:

- **Buffer the salt store – keep it dry and immobile (1**): There are stores of salt in discrete areas that vegetation can buffer, limiting the salinity impact. They are generally in the depositional elements of the landscape in lower landscape positions with associated soil types. These areas can be targeted for significant action in this HGL.
- **Discharge rehabilitation and management (4):** The saline and waterlogged sites are small in size. Discharge management will reduce salt discharge to streams when vegetation is matched to salt sites.
- **Dry out the landscape with diffuse actions over most of the landscape (6):** Encourage plant growth and increase plant water use in order to use excess soil moisture and shallow groundwater. Healthy, actively growing vegetation will also act as a buffer to groundwater accessions in wet seasonal conditions.
- **Access and use groundwater to change the water balance (7):** Shallow groundwater will be low yielding, but suitable for stock.

Key Management Focus – Sweetwater HGL

Grazing management is the key focus for this unit. This includes introduction and management of pasture systems based on perennial plants on both discharge areas and the wider recharging landscape. Grazing infrastructure and management should consider saline and sodic sites as sensitive areas.

Specific Land Management Opportunities

Specific opportunities for this HGL:

- Remnant native vegetation exists in the landscape. Maintaining and improving remnant vegetation is an important component of catchment salinity management.
- This landscape contains significant areas of native grass pastures. They provide an excellent opportunity for building better management systems for native pastures into the future.
- Groundwater systems are small and will respond quickly to changes in management.

Specific Land Management Constraints

Constraints for land management in this HGL include:

- Sodic and dispersible B horizons occur in many soil types – particularly in those which are affected by salinity.
- Waterlogging and hydraulic head occurs in lower area of the landscape.
- Major highway and rail infrastructure are both a victim of, and a contributor to salinity processes.
- Climatic limitations will influence the ability of pasture systems to reduce recharge and manage discharge.
- Infrastructure and management is limited by steep landforms and accessibility.

Specific Targeted Actions

Management areas for this HGL are illustrated in Figure 3. The specific management actions for these areas are described in Table 6.

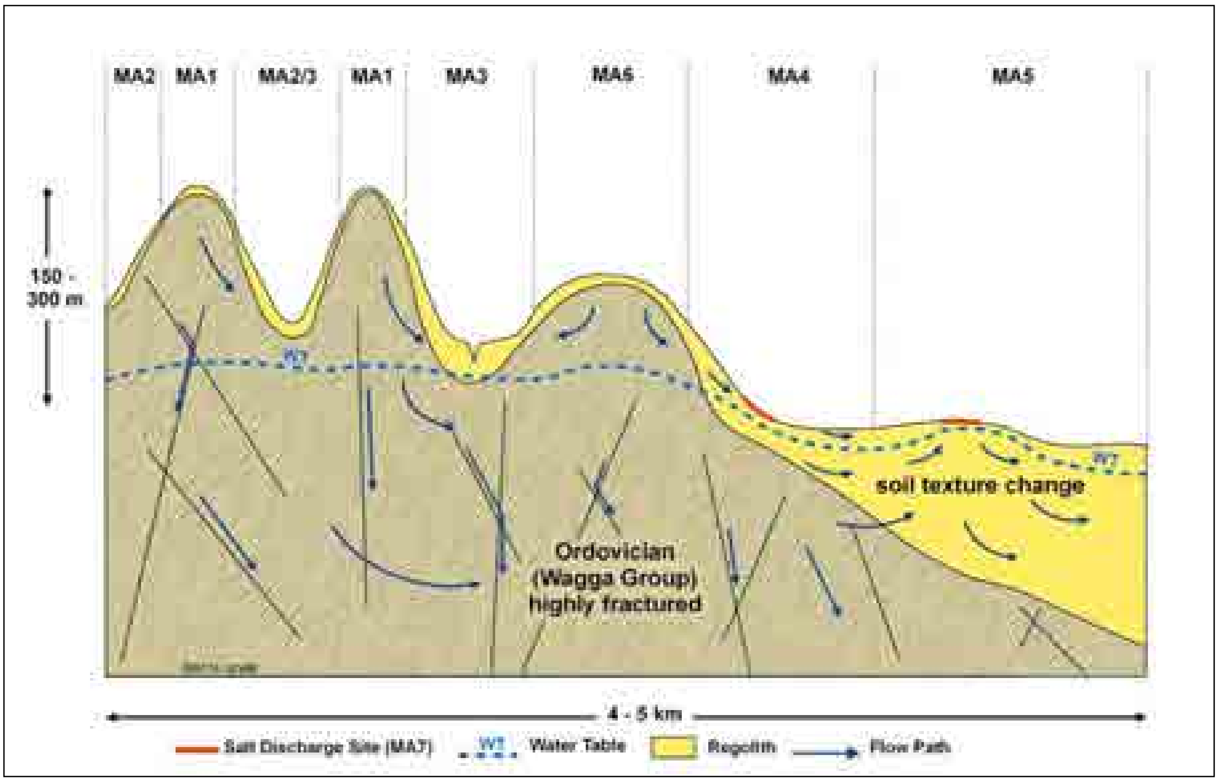


Figure 3: Management cross-section for Sweetwater Creek HGL showing defined management areas.

Table 6: Specific management actions for management areas within the Sweetwater HGL.

Management Area (MA)	Action
MA1 (RIDGES)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** **Vegetation for production** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).** Improve grazing management of existing perennial pastures to manage recharge (**VP1).**
MA2 (UPPER SLOPES – EROSIONAL)	**Vegetation for production** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).** Improve grazing management of existing perennial pastures to manage recharge (**VP1).** **Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).**
MA3 (UPPER SLOPES – COLLUVIAL) MA4 (MID-SLOPES)	**Vegetation for production** Maintain and improve native pastures to manage recharge **(VP5).** Improve grazing management of existing perennial pastures to manage recharge (**VP1).**
MA5 (LOWER SLOPES – COLLUVIAL) MA7 (SALINE SITES)	**Vegetation for ecosystem function** Maintain and improve riparian native vegetation to reduce discharge to streams **(VE4).** **Salt land rehabilitation** Fence and isolate salt land and discharge areas to promote revegetation **(SR1).** Mulch sites to reduce evaporation and promote pasture growth **(SR8).** **Engineering** Use groundwater to supplement or replace surface water for farm stock **(E1).** Construct agricultural earthworks to maximise freshwater runoff and reduce recharge in low areas **(E3).**

Management Area (MA)	Action
MA6 (RISES)	**Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge (**VP1).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).** Establish and manage perennial pastures to manage recharge (**VP2).**

High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative impacts on salinity (Table 7).

Table 7: Management actions having negative salinity impacts in the Sweetwater HGL.

At Risk Management Areas	Action
MA1,2, 3, 6,4 (RIDGES) (UPPER SLOPES – EROSIONAL) (UPPER SLOPES – COLLUVIAL) (RISES) (MID-SLOPES)	Poor management of grazing pastures **(DLU2).** Clearing and poor management of native vegetation **(DLU4).**
MA5 (LOWER SLOPES – COLLUVIAL)	Farm dams in flow lines **(DLU5).** Locating infrastructure on discharge areas **(DLU7).**

REFERENCES

DECCW, 2010, *Reconnaissance soil and land resources of the Murray CMA*, NSW Department of Environment, Climate Change and Water, Sydney

Geoscience Australia, 2011, *Australian stratigraphic units database*, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int

Keith, D. A. 2004, *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, Hurstville, NSW Department of Environment and Conservation

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, Office of Environment and Heritage, Sydney, [Accessed: 10 November 2014] www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

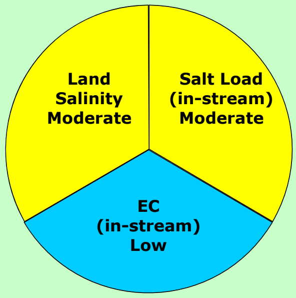
Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia

Stelling, F. 1998, *South west slopes revegetation guide (south of the Murrumbidgee River)*, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

Wooldridge, A., Nicholson, A., Muller R., Jenkins, B. R., Wilford, J. and Winkler, M. 2015, *Guidelines for managing salinity in rural areas*, NSW Office of Environment and Heritage, Sydney, NSW

20. Woomargama Hydrogeological Landscape

LOCALITIES	Mount McKenzie
MAP SHEET	Wagga Wagga 1:250 000
CONFIDENCE LEVEL	Low



OVERVIEW

The Woomargama Hydrogeological Landscape (HGL) extends to the north-west and south-east of Woomargama and south-west of Holbrook (Figure 1). The HGL covers an area of 95 km^2 and receives 700 to 1000 mm of rain per annum.

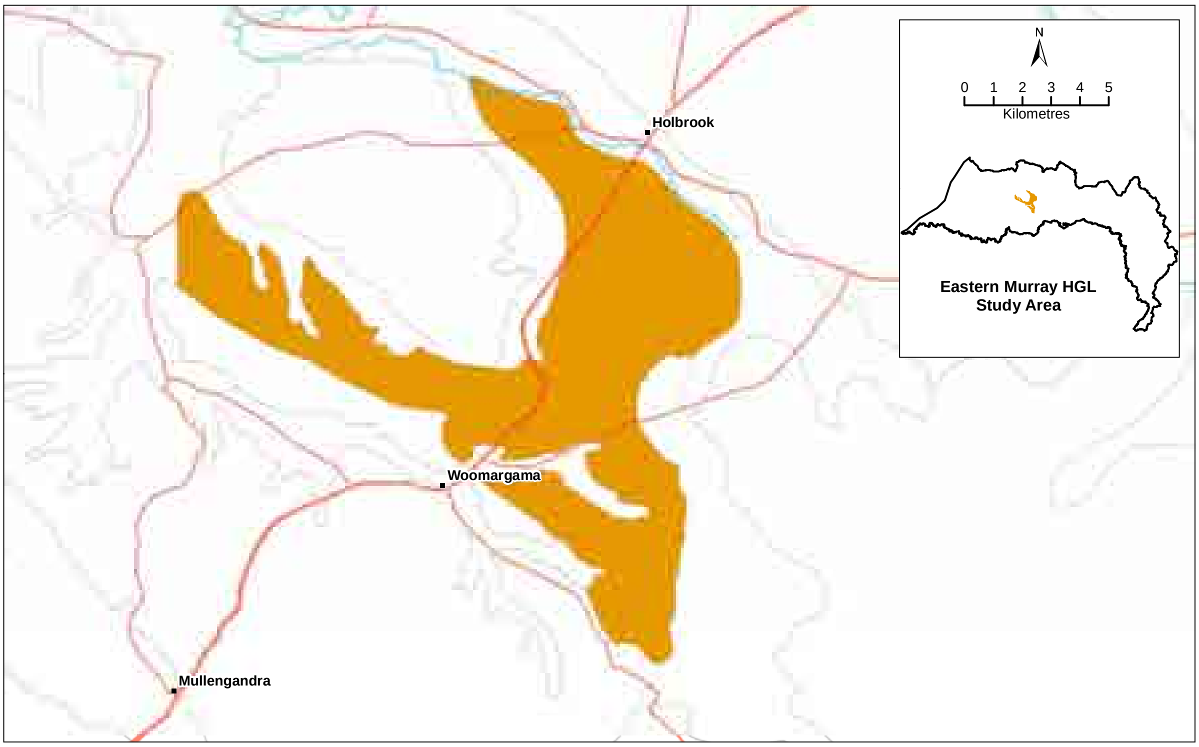


Figure 1: Woomargama HGL distribution map.

The Woomargama HGL is highly weathered and is characterised by steep to precipitous, rocky hills and mountains; rolling to low hills with broad crests and ridges; waxing upper slopes and straight long lower slopes with mostly parallel drainage lines; gently inclined foot-slopes and fans; very gently undulating alluvial plains; extensive to broad sand plains with a number of terrace sequences; and sparse narrow drainage lines (Figure 2). Terracettes are common on cleared slopes. Narrow incised drainage lines cut to bedrock. This HGL includes intrusive granitic rocks and associated sediments from the Silurian period. Soils are shallow and well-drained on crests; very deep and imperfectly to moderately well-drained on upper and mid slopes; deep and moderately well-drained to imperfectly drained on lower slopes; very deep and well-drained on fans; very deep and moderately well-drained on the higher, older terraces; and moderately well drained on the lower younger terraces; and deep and imperfectly drained in recent channels. Severe branching gully erosion occurs in drainage lines on lower slopes in association with sodic soils. Soil structure is poor as a result of topsoil and organic matter loss through cultivation, or where stock trampling has occurred on wet soils.

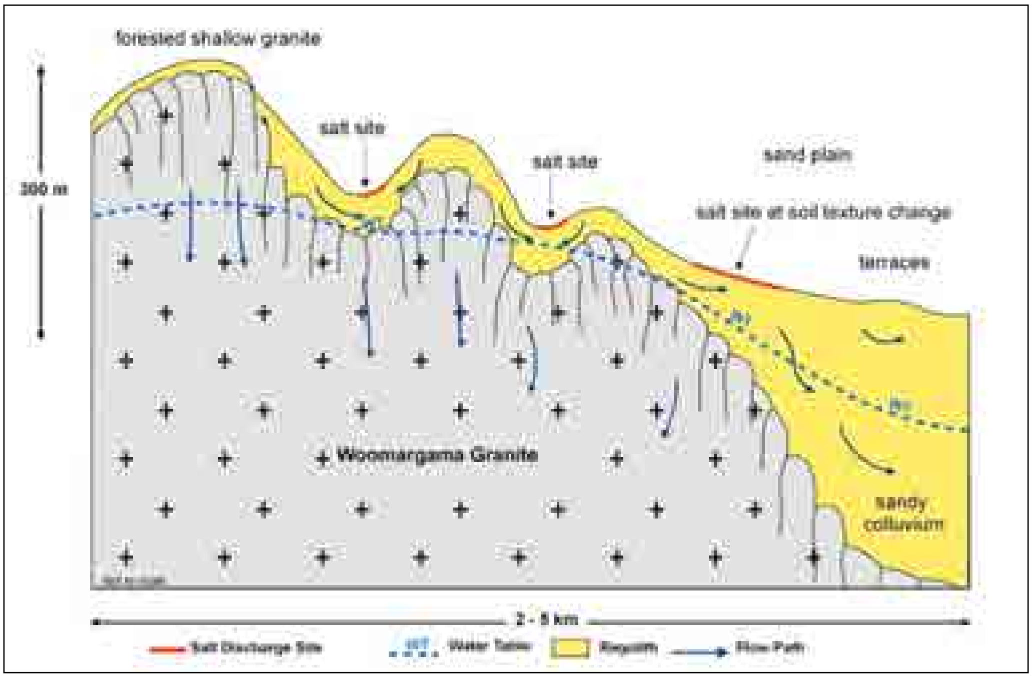


Figure 2: Conceptual cross-section for Woomargama HGL showing the distribution of regolith and landforms, salt sites if present, and flow paths of water infiltrating the system.

Several large areas of land salinity occur on the lower colluvial slopes of this HGL. Salt load is moderate and EC is low (Table 1).

Table 1: Woomargama Rock HGL salinity expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	Moderate – several large salt sites occur on lower colluvial slopes ranging in size from 1–5 ha
Salt Load (Export)	Moderate – perennial streams consistently carry salt loads
EC (Water Quality)	Water EC is low

Salt stored within the Woomargama HGL has high mobility. There is a moderate salt store that has high availability (Table 2).

Table 2: Woomargama HGL salt store and availability.

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

The overall salinity hazard in the Woomargama HGL is low. This is due to the moderate likelihood that salinity issues will occur that have potentially limited impacts (Table 3).

Table 3: Likelihood of salinity occurrence, potential impact and overall hazard of salinity for the Woomargama HGL.

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

LANDSCAPE FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 4.

Photo 1:Rolling to low hills with broad crests long slopes and gently undulating alluvial plains are characteristic of the Woomargama HGL. Stream-bank erosion can be significant in the narrow drainage lines (Photo: OEH/R Muller).

Photo 2: Rolling hills in the Woomargama HGL have broad crests and waxing upper slopes (Photo: OEH/R Muller).

Photo 3: The southern parts of the Woomargama HGL have extensive alluvial plains made up of materials derived from the higher landscape elements (Photo: OEH/R Muller).

Photo 4: Undulating plains are a common feature in the southern parts of the Woomargama HGL (Photo: OEH/R Muller).

Photo 5: Rolling to low hills with waxing upper slopes and long lower slopes, gently inclined foot-slopes and fans; leading down to undulating alluvial plains are a feature of the Woomargama HGL (Photo: OEH/R Muller).

Table 4: Summary of information used to define the Woomargama HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2011)*	This HGL comprises granitic rocks from the Silurian period and associated colluvial material. Unconsolidated Cenozoic sand plains and Quaternary alluvium occur on lower slopes and in river valleys. Key lithologies include: • channel and flood plain alluvium – gravel, sand, silt and clay • sand plains – sand dominant, gravel, clay; may include some residual alluvium • Woomargama Granite – mafic, unfractionated granite.
Annual Rainfall	700–1000 mm
Regolith and Landforms	The Woomargama HGL is highly weathered and is characterised by gently undulating broad alluvial plains (<5 m relief) surrounded by rolling hills (90–210 m relief) low hills (30–90 m relief) and rises (9–30 m relief) with broad crests and ridges, long colluvial slopes with sub-parallel drainage lines, and gently inclined colluvial fans, on Silurian granitic bedrock. Slope is typically 2-25%, local relief is 5-210 m and this HGL is between 170–890 m elevation. This HGL features abundant (0–>50%) but irregularly distributed outcrop on crests and upper slopes. Regolith materials are dominantly quartzose clayey sands with minor gravels and some sandy clays. On ridge crests and upper slopes there are angular tabular pebble and cobble-bearing coarse sandy gravels and gravelly sands.

Soil Landscapes *(DECCW 2010)*	This HGL is not a good fit with soil landscapes. It is mostly covered by Mountain Creek, Yarra Yarra and Wagra soil landscapes with small patches of Four Mile Creek, Buckargingah, Doodle Comer Swamp, Tipperary, Dora Dora and Home Flat. Soils include: shallow (<0.5 m), well-drained Clastic Rudosols and Orthic Tenosols (Lithosols) on crests; very deep (>1.5 m), imperfectly to moderately well-drained Red, Brown and Yellow Chromosols (Podzolic Soils) on upper and mid slopes; deep (1.0–1.5 m), moderately well-drained Brown/Yellow Chromosols (Yellow Podzolic Soils); imperfectly drained Brown and Grey Sodosols and Kurosols (Solodized Solonetz Soils and Soloths) on lower slopes; very deep (1.5–5.0 m), well-drained Orthic Tenosols (Earthy Sands) on fans; very deep (>1.5 m), moderately well-drained Brown, Yellow and Grey Sodosols (Soloths) on the higher, older terraces; deep (1.0–1.5 m), moderately well drained Yellow and Brown Dermosols (Yellow and Brown Earths) on lower younger terraces; and, deep (1.0–1.5 m), imperfectly drained Stratic Rudosols (Alluvial Soils) in recent channels. Severe branching gully erosion (1.5–3.0 m deep) occurs in drainage lines on lower slopes in association with sodic soils (Sodosols and Kurosols). Soil structure is poor as a result of topsoil and organic matter loss through cultivation, or where stock trampling has occurred on wet soils. Localised areas of waterlogging and plough pans are common.
Land and Soil Capability *(OEH 2012)*	Class 5
Land Use	Predominantly grazing of volunteer, naturalised, native or sown, improved perennial pasture. Minimal cropping and some native forest within Woomargama National Park
Key Land Degradation Issues	• gully erosion (localised; severe gully erosion occurs in valley depressions) • seasonal waterlogging • sheet erosion • extensive stream-bank erosion • acidity (localised).

Native Vegetation *(Stelling 1998; Keith 2004)*	This HGL incorporates areas of the Woomargama State Forest. Vegetation on upper slopes >500 m above sea level (east and north-east of Woomargama) can be moist open forest, whereas low hills tend to support dry sclerophyll forest of long-leaf box/silver bundy and red stringybark. Blakely's red gum woodland and Blakely's red gum and yellow box woodland occur on the lower slopes and flats (south-west of Holbrook). Tree species can include *Exocarpos cupressiformis* (native cherry) and *Brachychiton populneus* (kurrajong). *Acacia dealbata* (silver wattle) is prolific in some paddocks. Additional tree species that may grow more commonly towards the lower landscape are *E. albens* (white box) on fertile slopes and ridges, *E. blakelyi* (Blakely's red gum) on loamy soils and *E. melliodora* (yellow box) where the soils are moderately fertile and well drained. Understorey species may include *Acacia deanei* (both subspecies) (Deane's wattle), *Calytrix tetragona* (common fringe-myrtle), *Cassinia aculeate* (common cassinia) *A. paradoxa* (kangaroo thorn), *Bursaria spinosa* (sweet bursaria), and *Daviesia latifolia* (hop bitter-pea). Vegetation on the flats additionally may include *E. bridgesiana* (apple box) and *Leptospermum continentale* (prickly tea-tree) in poorly drained sites and soaks on lower slopes.

HYDROGEOLOGY

Aquifers within this landscape are unconfined with groundwater flow occurring primarily through fractures in bedrock and saprolite. Some flow occurs through colluvial and alluvial sediments on lower slopes and along flow lines. Hydraulic conductivity is moderate to high and transmissivity is moderate. Groundwater recharge rates are estimated to be moderate to high.

Groundwater systems are typically local with short flow lengths and are loosely defined by topographic catchments. Water quality within these systems is fresh. Watertable depths are intermediate to deep.

Short to medium residence times are typical. These landscapes have a medium to fast response time to changes in land management.

Typical values for the hydrogeological parameters of this HGL are summarised in Table 5.

Table 5: Summary of values for typical hydrogeological parameters of the Woomargama HGL.

Aquifer Type	Unconfined in fractured rock and saprolite Lateral flow through unconsolidated colluvial and alluvial sediments on lower slopes and in flow lines
Hydraulic Conductivity	Moderate to high Range: 10^{-2}–>10 m/day
Aquifer Transmissivity	Moderate Range: 2–100 m^2/day
Specific Yield	Moderate to high Range: 5–>15%
Hydraulic Gradient	Moderate to steep Range: 10–>30%
Groundwater Salinity	Fresh Range: <800 µS/cm
Depth to Watertable	Intermediate to deep Range: 2–>8 m
Typical Sub-Catchment Size	Small (<100 ha)
Scale (Flow Length)	Local Flow length: <5 km (short)
Recharge Estimate	Moderate to high
Residence Time	Short to medium (months to years)
Responsiveness to Change	Fast to medium (months to years)

MANAGEMENT OPTIONS

Overarching salinity management strategies have specific biophysical outcomes. These are achieved by implementing a series of targeted land management actions that take into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape to impact on salinity. Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Salinity is driven by interactions between water-use capacity of vegetation, physical soil properties and hydrogeological processes within the HGL.

Actions that influence the way water is used by vegetation or stored in the soil profile will have impacts on recharge. The influence of both continual and episodic recharge and the impacts of extreme weather events need to be considered when deciding on appropriate

management actions. Short and long-term climate cycles also need to be considered as they have a bearing on salinity processes, particularly salt load and land salinity.

Landscape Salinity Functions – Woomargama HGL

Functions this landscape provides within a catchment scale salinity context:

- **B.** The landscape provides fresh water runoff as an important dilution flow source
- **D.** The landscape generates salt loads which enter the streams and are redistributed in the catchment
- **G.** The landscape contains important land assets (including infrastructure and high value agricultural land) on which salinity processes impact.

Management Strategy Objectives – Woomargama HGL

Appropriate strategies pertinent to this landscape:

- **Buffer the salt store – keep it dry and immobile (1):** There are stores of salt in this landscape that vegetation can buffer, limiting the salinity impact. These areas are generally in the depositional elements of the landscape and also where this unit joins with adjacent colluvial/depositional units.
- **Discharge rehabilitation and management (4):** Salt sites range in size and severity. Discharge management will improve on-site and off-site salinity outcomes.

Key Management Focus – Woomargama HGL

This landscape is important as it provides fresh water within the catchment. This means careful consideration and planning need to be given to land uses which reduce runoff. Large scale revegetation with trees is not recommended on this unit.

Grazing management is the key focus for this HGL. This includes introduction and management of pasture systems based on perennial plants on both discharge areas and the wider recharging landscape. Grazing infrastructure and management should consider saline and sodic sites as sensitive areas.

Specific Land Management Opportunities

Specific opportunities for this HGL:

- Improving on-site and off-site salinity outcome on saline areas by changing management, particularly grazing management
- The outbreaks of salt land occur at defines specific points in the landscape

Specific Land Management Constraints

Constraints for land management in this HGL include:

- Sodic and dispersible B horizons occur in many soil types – particularly in soil types affected by salinity.
- Soil constraints over the majority of the landscape will restrict pasture growth – particularly soil acidity and sodicity on the large sand plains.
- Seasonal waterlogging occurs during low growth periods of the year.

Specific Targeted Actions

Management areas for this HGL are illustrated in Figure 3. The specific management actions for these areas are described in Table 6.

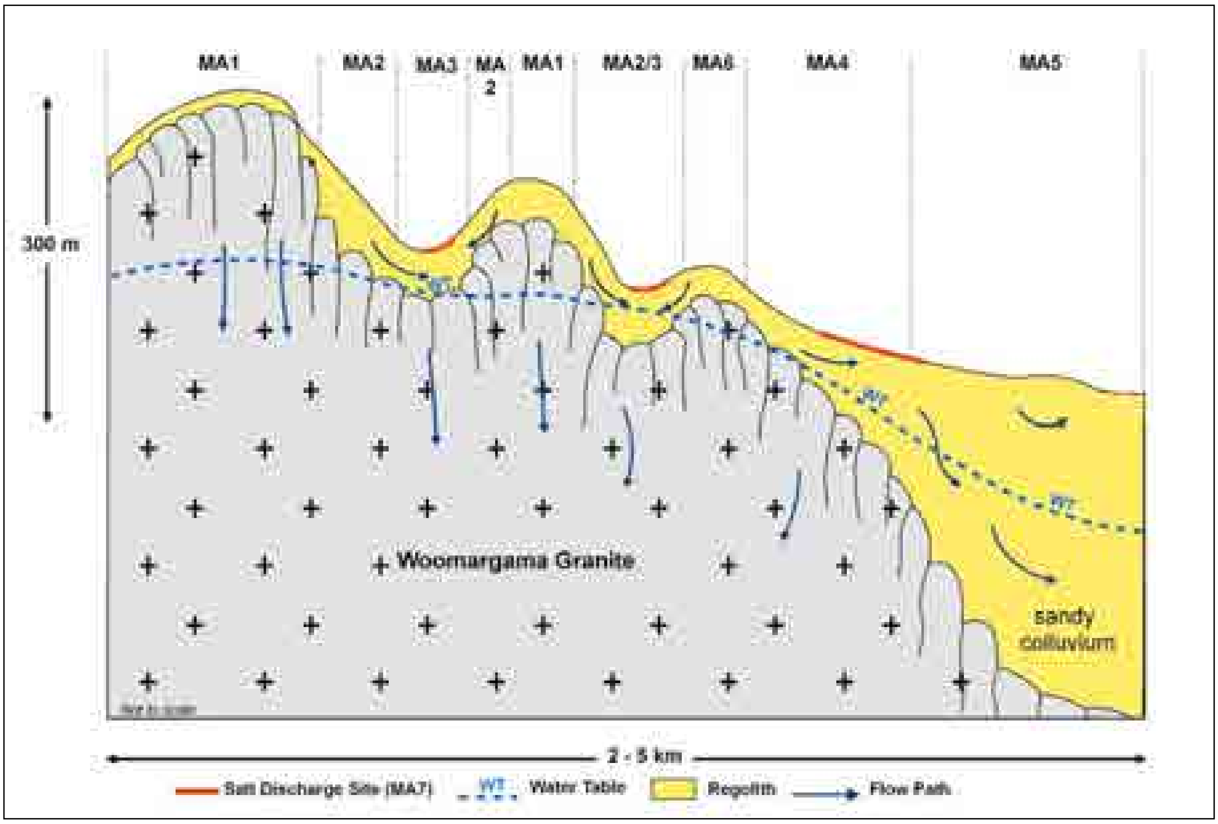


Figure 3: Management cross-section for Woomargama HGL showing defined management areas.

Table 6: Specific management actions for management areas within the Woomargama HGL.

Management Area (MA)	Action
MA1 (RIDGES)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).**
MA2 (UPPER SLOPES – EROSIONAL)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** **Vegetation for production** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**
MA3 (UPPER SLOPES – COLLUVIAL)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** **Vegetation for production** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).** **Salt land rehabilitation** Fence and isolate salt land and discharge areas to promote revegetation **(SR1).** Establish and manage salt land pasture systems to improve productivity **(SR2).**
MA4 (MID-SLOPES)	**Vegetation for ecosystem function** Establish and manage trees to intercept lateral groundwater flow **(VE2).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge (**VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** **Salt land rehabilitation** Fence and isolate salt land and discharge areas to promote revegetation **(SR1).** Establish and manage salt land pasture systems to improve productivity **(SR2).**

Management Area (MA)	Action
MA5 (LOWER SLOPES – COLLUVIAL)	**Vegetation for ecosystem function** Maintain and improve riparian native vegetation to reduce discharge to streams **(VE4).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge (**VP1).** Establish and manage perennial pastures to manage recharge (**VP2).**
MA6 (RISES)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge (**VP1).** Establish and manage perennial pastures to manage recharge (**VP2).**
MA7 (SALINE SITES)	**Salt land rehabilitation** Fence and isolate salt land and discharge areas to promote revegetation **(SR1).** Establish and manage salt land pasture systems to improve productivity **(SR2).**

High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative impacts on salinity (Table 7).

Table 7: Management actions having negative salinity impacts in the Woomargama HGL.

At Risk Management Areas	Action
MA1 & MA6 (RIDGES & RISES)	Clearing and poor management of native vegetation **(DLU4).**
MA2 & MA3 (UPPER SLOPES – EROSIONAL & COLLUVIAL)	Poor management of grazing pastures **(DLU2).** Clearing and poor management of native vegetation **(DLU4).**
MA4 (MID-SLOPES)	Annual cropping with annual plants **(DLU3).** Poor soil management – tillage causing poor structure **(DLU8).**
MA5 (LOWER SLOPES – COLLUVIAL)	Annual cropping **(DLU3).** Farm dams in flow lines **(DLU5).** Poor soil management – tillage causing poor structure **(DLU8).**
MA7 (SALINE SITES)	Locating infrastructure on discharge areas **(DLU7).**

REFERENCES

DECCW, 2010, *Reconnaissance soil and land resources of the Murray CMA*, NSW Department of Environment, Climate Change and Water, Sydney

Geoscience Australia, 2011, *Australian stratigraphic units database*, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int

Keith, D. A. 2004, *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, Hurstville, NSW Department of Environment and Conservation

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, Office of Environment and Heritage, Sydney, [Accessed: 10 November 2014] www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

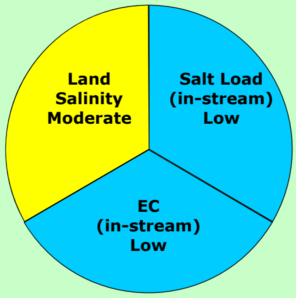
Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia

Stelling, F. 1998, *South west slopes revegetation guide (south of the Murrumbidgee River)*, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

Wooldridge, A., Nicholson, A., Muller R., Jenkins, B. R., Wilford, J. and Winkler, M. 2015, *Guidelines for managing salinity in rural areas*, NSW Office of Environment and Heritage, Sydney, NSW

21. Wymah-Jergyle Hydrogeological Landscape

LOCALITIES	**Wymah, Reddalls Valley, Dora Dora, Tin Mines, Mount Jergyle, Mount Paynter**
MAP SHEET	**Tallangatta 1:250 000** **Wagga Wagga 1:250 000**
CONFIDENCE LEVEL	**Low**



OVERVIEW

The Wymah-Jergyle Hydrogeological Landscape (HGL) is north of the Murray River between Lake Hume and Jingellic (Figure 1). The HGL covers an area of 685 km^2 and receives 700 to 1200 mm of rain per annum.

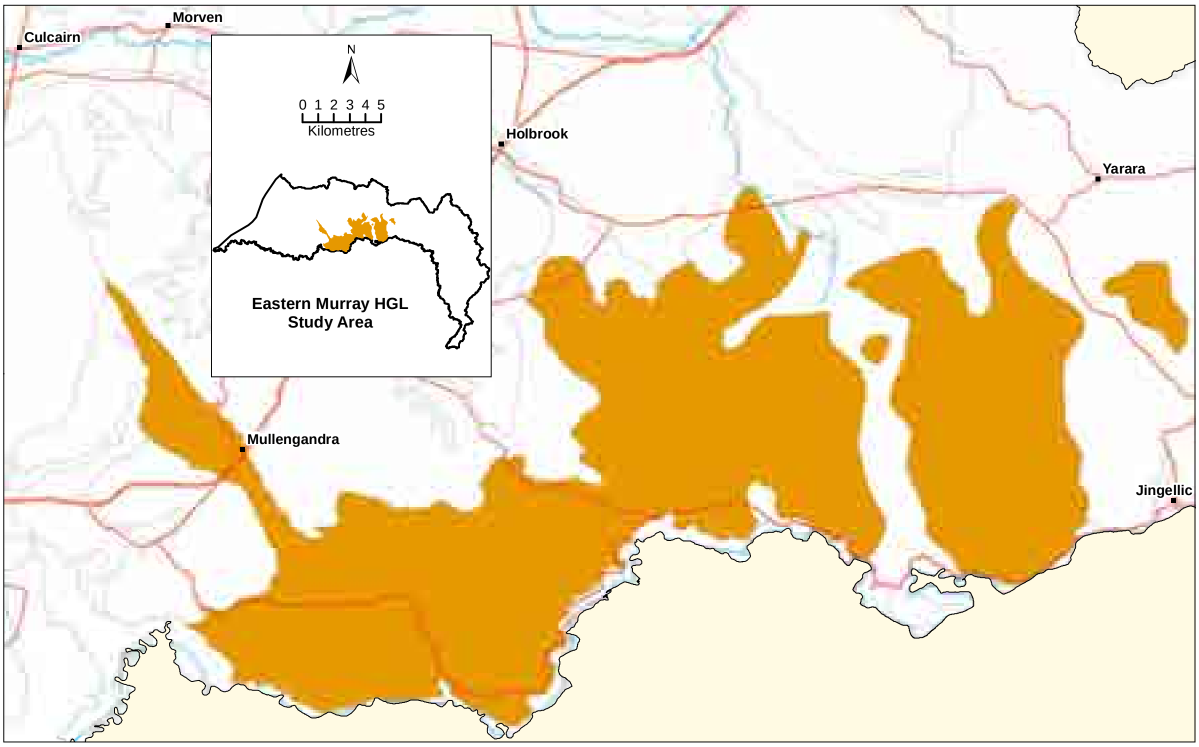


Figure 1: Wymah-Jergyle HGL distribution map.

The Wymah-Jergyle HGL is generally moderately to highly weathered and is characterised by steep to precipitous, rocky hills and mountains; rolling hills and low hills with broad crests and ridges, waxing upper slopes and straight lower slopes; and closed drainage depressions, straight slopes and widely spaced drainage lines (Figure 2). Undulating plateau surfaces occur. Terracettes are common on cleared slopes. Narrow incised drainage lines cut to bedrock. This HGL includes intrusive granitic rocks from the Silurian and Devonian periods and associated colluvial material. Soils are shallow, sandy and discontinuous, with little subsoil development on steep rocky hills and crests; isolated deep and moderately well-drained on flat crests, upper slopes and mid-slopes; and deep and moderately well-drained on lower slopes. This HGL is extremely vulnerable to sheet erosion when disturbed.

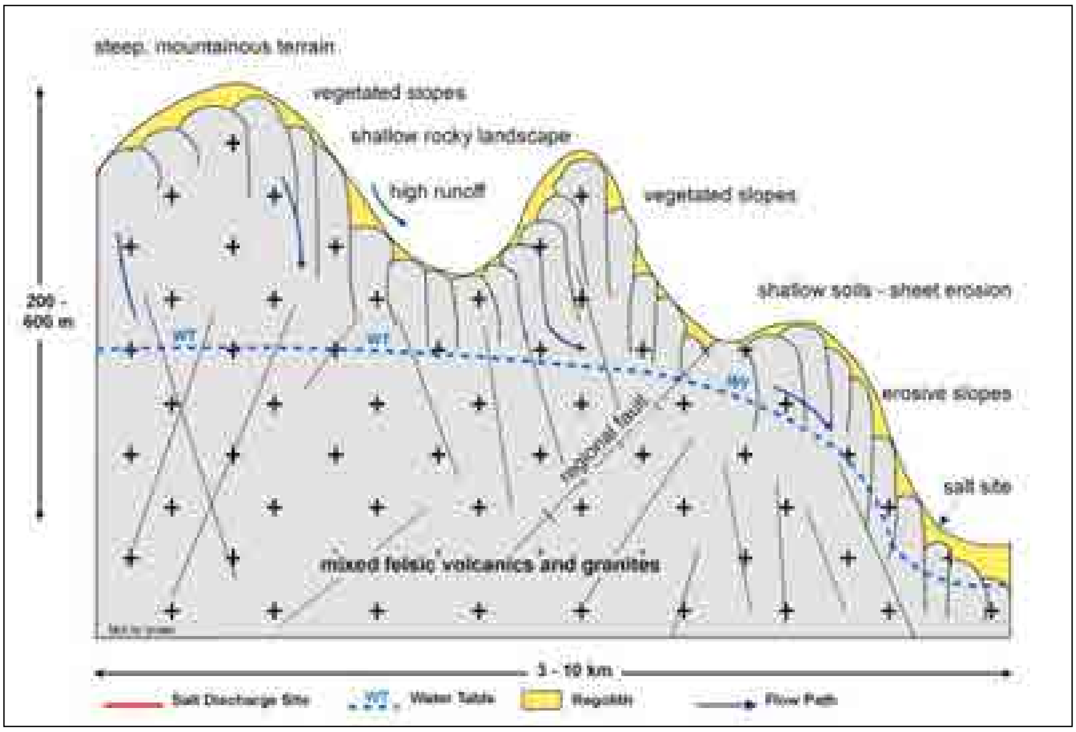


Figure 2: Conceptual cross-section for Wymah-Jergyle HGL showing the distribution of regolith and landforms, salt sites if present, and flow paths of water infiltrating the system.

Minor areas of land salinity are observed in isolated flow lines close to the margins of the HGL. Salt loads and EC levels are low (Table 1).

Table 1: Wymah-Jergyle HGL salinity expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	Moderate – minor salt sites observed in isolated flow lines and on the margins of the HGL
Salt Load (Export)	Low – seasonal flow, high rainfall
EC (Water Quality)	Water EC is low

Salt stored within the Wymah-Jergyle HGL has low mobility. There is a low salt store that has moderate availability (Table 2).

Table 2: Wymah-Jergyle HGL salt store and availability.

SALT MOBILITY			
	Low availability	**Moderate** availability	**High** availability
High salt store			
Moderate salt store			
Low salt store		**Wymah-Jergyle**	

The overall salinity hazard in the Wymah-Jergyle HGL is low. This is due to the moderate likelihood that salinity issues will occur that have potentially limited impacts (Table 3).

Table 3: Likelihood of salinity occurrence, potential impact and overall hazard of salinity for the Wymah-Jergyle HGL.

OVERALL SALINITY HAZARD			
	Limited potential impact	**Significant** potential impact	**Severe** potential impact
High likelihood of occurrence			
Moderate likelihood of occurrence	**Wymah-Jergyle**		
Low likelihood of occurrence			

LANDSCAPE FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 4.

Photo 1: The higher and steeper elements (background) of the Wymah-Jergyle HGL south-east of Holbrook are mostly covered with native forests. The more gently inclined slopes (foreground) are farmed (Photo: OEH/R Muller).

Photo 2: Salt sites are evident in the lower landscape elements (Photo: OEH/A Nicholson).

Photo 3: Sheep licking sodium chloride sites (Photo: OEH/A Nicholson).

Photo 4: Soils of the steeper slopes of the Wymah-Jergyle HGL are fragile and susceptible to erosion once disturbed (Photo: OEH/A Nicholson).

Photo 5: Soil creep (terracettes) and wet seepages are common land degradation issues on the steeper slopes of the Wymah-Jergyle HGL (Photo: OEH/A Nicholson).

Photo 6: The southern end of the Wymah-Jergyle HGL adjacent to the Murray River is steep and rocky with little soil cover (Photo: OEH/A Nicholson).

Photo 7: The higher and steeper elements (background) of the Wymah-Jergyle HGL west of Lankeys Creek are mostly covered with native forests. The more gently inclined slopes (foreground) are farmed (Photo: OEH/W Cook).

Photo 8: The rolling hills with broad crests, waxing upper slopes and straight lower slopes in the Wymah-Jergyle HGL are evident between Reddalls Valley and Woomargama landscape. Rock outcrop is variable (Photo: OEH/R Muller).

Photo 9: Typical Wymah-Jergyle landscape in the Dora Dora area (Photo: OEH/A Nicholson).

Table 4: Summary of information used to define the Wymah-Jergyle HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2011)*	This HGL comprises granitic rocks from the Silurian and Devonian periods and associated colluvial material. Unconsolidated Quaternary alluvium occurs along river valleys. Key lithologies include: • channel and flood plain alluvium – gravel, sand, silt and clay • Thologolong Granite – pink, A-type, highly magnetic, coarse-grained, two mica granite with a slightly finer grained marginal phase • Koetong Granite – nonmagnetic, bluish grey, two mica cordierite granite; coarse grained biotite muscovite granite; mostly equigranular but centre is porphyritic and parts of margins are fine grained; locally abundant enclaves. • Granya Granite – fractionated, felsic, biotite-muscovite granite with abundant xenoliths • Corryong Granite – nonmagnetic, grey, medium to very coarse-grained, equigranular to strongly porphyritic in K-feldspar, two-mica-cordierite S-type granite; locally contains sillimanite or andalusite.
Annual Rainfall	700–1200 mm.

Regolith and Landforms	The Wymah-Jergyle HGL is slightly to moderately weathered and is characterised by steep to precipitous rocky mountains (300–600 m relief), hills 90–300 m relief) and rolling low hills (30–90 m relief) with broad crests and ridges, forming an undulating plateau surface with long colluvial slopes, on Siluro-Devonian granitic bedrock. Slopes are typically 10–>30%, local relief is 20–600 m and this HGL is between 170–1000m elevation. It features rock outcrop on crests and upper slopes as rock bars, scarps and tors; soil creep is common on cleared slopes, and narrow incised drainage lines incise to bedrock. The undulating plateau surface has some closed drainage depressions. Regolith materials are dominantly quartzose sands with minor gravels and some sandy clays. On ridge crests and upper slopes there are angular pebble and cobble-bearing coarse sandy gravels and gravelly sands.
Soil Landscapes *(DECCW 2010)*	Tipperary and Wagra are the major soil landscapes within this HGL. There are minor occurrences of a number of soil landscapes including Home Flat, Yarra Yarra, Bowna, Pleasure Point and Lloyd. Soils include: shallow, sandy, discontinuous Tenosols and Rudosols (Lithosols, Siliceous Sands and Earthy Sands), with little subsoil development on steep rocky hills and crests; isolated patches of deep (1.0–1.5 m), moderately well-drained Red Chromosols and Kurosols (Red Podzolic Soils) on flat crests, upper slopes and mid-slopes; and, deep (1.0–1.5 m), moderately well-drained Brown/Yellow Chromosols and Kurosols (Yellow Podzolic Soils) on lower slopes. Extremely vulnerable to sheet erosion when disturbed.
Land and Soil Capability *(OEH 2012)*	Class 6
Land Use	Much of Wymah-Jergyle HGL is under native vegetation within Woomargama National Park, Woomargama and Mullengandra State Conservation Areas, and Woomargama State Forest. Land use outside of these tenures is grazing on volunteer, naturalised, native or improved perennial pasture
Key Land Degradation Issues	• terracettes (soil creep) (common) • sheet erosion (common) • minor active rill erosion if disturbed • mass movement (localised on steeper slopes) • gully erosion (common on drainage lines) • moderate gully and stream-bank erosion (within drainage depressions).
Native Vegetation *(Stelling 1998; Keith 2004)*	This HGL incorporates areas of the Woomargama National Park, Woomargama and Mullengandra State Conservation Areas, and Woomargama State Forest. Communities across this HGL change from east to west with increasing elevation and rainfall. There is therefore a difference

	between communities around the Wymah area from the communities around the Jergyle area due to the higher elevation in the east of the HGL around Jergyle. Communities below approximately 500m above sea level tend to be dry sclerophyll forest of red stringybark and red box. At higher elevations (over 500 m above sea level) and on sheltered, south and south-east facing slopes which are typical in east of the HGL, the landscape can support more moisture dependant species such as *Acacia melanoxylon* (blackwood), *E. dives* (broad-leaved peppermint), *E. rubida* (candlebark) and *E. robertsonii* (Robertson's reppermint). Vegetation above 500m above sea level may also include *E. camphora* (mountain gum) in soaks or poorly drained sites, *E. bicostata* (eurabbie), *E. mannifera* (brittle gum), *E. viminalis* (manna gum) and *E. pauciflora* (white sally/snow gum). Common tree species in the east of the HGL can include *Eucalyptus goniocalyx* (long-leaf box), *E. macrorhyncha* (red stringybark), *E. polyanthemos* (red box), *Acacia dealbata* (silver wattle) and *A. melanoxylon* (blackwood). Common tree species on the upper slopes in the west may include *E. blakelyi* (Blakely's red gum), *E. polyanthemos* (red box), *Exocarpos cupressiformis* (native cherry), *Acacia dealbata* (silver wattle), *Acacia implexa* (hickory wattle), *Callitris endlicheri* (black cypress pine), *Allocasuarina verticillata* (drooping sheoak) and *Brachychiton populneus* (kurrajong). Understorey species can commonly include *Calytrix tetragona* (common fringe-myrtle), *Cassinia aculeate* (common cassinia), *Acacia rubida* (red-stemmed wattle) and *A. verniciflua* (varnish wattle). *Acacia paradoxa* (kangaroo thorn) and *Pultenaea foliolosa* (bush-pea) tend to occur towards the western end of the HGL around Wymah, whereas *Kunzea ericoides* (burgan), *K. parvifolia* (violet kunzea) and *Pultenaea cunninghamii* (grey bush-pea) tend to occur in higher rainfall areas towards the east of the HGL. Vegetation on mid-slopes tends to be White Box woodland which is dominated by *E. albens* (white box). Lower slopes tend to support box – Blakely's red gum woodland around Talmalmo, which includes *E. blakelyi* (Blakely's red gum), *E. polyanthemos* and *A. melanoxylon* (blackwood); and yellow box woodland around Wymah, which is dominated by *E. melliodora* (yellow box). Additional species at lower elevations may include *E. dealbata* (tumbledown gum) particularly along creeks, and *Brachychiton populneus* (kurrajong). Vegetation along the creeks and rivers can include *Eucalyptus bridgesiana* (apple box) and *Acacia dealbata* (silver wattle) along with *E. camaldulensis* (river red gun). Understorey species in the alluvial areas may be *Bursaria lasiophylla* (hairy bursaria), *Callistemon sieberi* (river bottlebrush) and *Hymenanthera dentate* (tree violet).

HYDROGEOLOGY

Aquifers within this landscape are unconfined with groundwater flow occurring primarily through fractures in bedrock and saprolite. Some flow occurs through colluvial and alluvial sediments on lower slopes and along flow lines. Hydraulic conductivity is moderate and transmissivity is low to moderate. Groundwater recharge rates are estimated to be moderate to high.

Groundwater systems are typically local to intermediate with short to intermediate flow lengths and are loosely defined by topographic catchments. Water quality within these systems is fresh. Watertable depths are intermediate to deep.

Medium residence times are typical. These landscapes have a medium to fast response time to changes in land management.

Typical values for the hydrogeological parameters of this HGL are summarised in Table 5.

Table 5: Summary of values for typical hydrogeological parameters of the Wymah-Jergyle HGL.

Aquifer Type	Unconfined in fractured rock and saprolite Lateral flow through unconsolidated colluvial and alluvial sediments on lower slopes and in flow lines
Hydraulic Conductivity	Moderate Range: 10^{-2}–10 m/day
Aquifer Transmissivity	Low to moderate Range: <2–50 m^2/day
Specific Yield	Moderate Range: 5–15%
Hydraulic Gradient	Moderate to steep Range: 10–>30%
Groundwater Salinity	Fresh Range: <800 µS/cm
Depth to Watertable	Intermediate to deep Range: 2 –>8m
Typical Sub-Catchment Size	Small (<100 ha)
Scale (Flow Length)	Local to intermediate Flow length: <10 km (short to intermediate)
Recharge Estimate	Moderate to high
Residence Time	Medium (years)
Responsiveness to Change	Fast to medium (months to years)

MANAGEMENT OPTIONS

Overarching salinity management strategies have specific biophysical outcomes. These are achieved by implementing a series of targeted land management actions that take into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape to impact on salinity. Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Salinity is driven by interactions between water-use capacity of vegetation, physical soil properties and hydrogeological processes within the HGL.

Actions that influence the way water is used by vegetation or stored in the soil profile will have impacts on recharge. The influence of both continual and episodic recharge and the impacts of extreme weather events need to be considered when deciding on appropriate management actions. Short and long-term climate cycles also need to be considered as they have a bearing on salinity processes, particularly salt load and land salinity.

Landscape Salinity Functions – Wymah-Jergyle HGL

Functions this landscape provides within a catchment scale salinity context:

- **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
- **G.** The landscape contains important land assets (including infrastructure and high value agricultural land) on which salinity processes impact.

Management Strategies – Wymah-Jergyle HGL

Appropriate strategies pertinent to this landscape:

- **Maintain or maximise runoff (10):** This HGL contributes significant amounts of fresh water runoff. The quantity and quality of the runoff water is important in the catchment salinity context. This water is important as both a source (quantity) and as a dilution flow (quality) to the local stream system. The fresh runoff mitigates the salt load, stream salinity and EC concentration of the local streams.
- **Discharge rehabilitation and management (4):** Salt sites are small and exhibit a range of salinity symptoms from scalding and erosion to frequent waterlogging. Discharge management will improve on-site and off-site salinity outcomes.

Key Management Focus – Wymah-Jergyle HGL

This unit has low hazard for catchment salinity impacts. Key focus should include monitoring of water quality and management of existing remnant vegetation areas. This landscape is important as it provides fresh water within the catchment. This means careful consideration and planning need to be given to land uses which reduce runoff. Large scale revegetation with trees is not recommended on this unit.

Specific Land Management Opportunities

Specific opportunities for this HGL:

- This landscape contains significant areas of native grass pastures. These provide an excellent base to build better management of native pastures into the future.
- Improving grazing management of existing native pastures particularly on areas which are seasonally waterlogged.
- Grazing management on and around discharge sites.
- Remnant native vegetation exists in the landscape. Maintaining and improving remnant vegetation is an important component of catchment salinity management actions.

Specific Land Management Constraints

Constraints for land management in this HGL include:

- Infrastructure and management limited by steep landforms and accessibility.
- Climate conditions will restrict pasture growth – particularly in winter.

Specific Targeted Actions

Management areas for this HGL are illustrated in Figure 3. The specific management actions for these areas are described in Table 6.

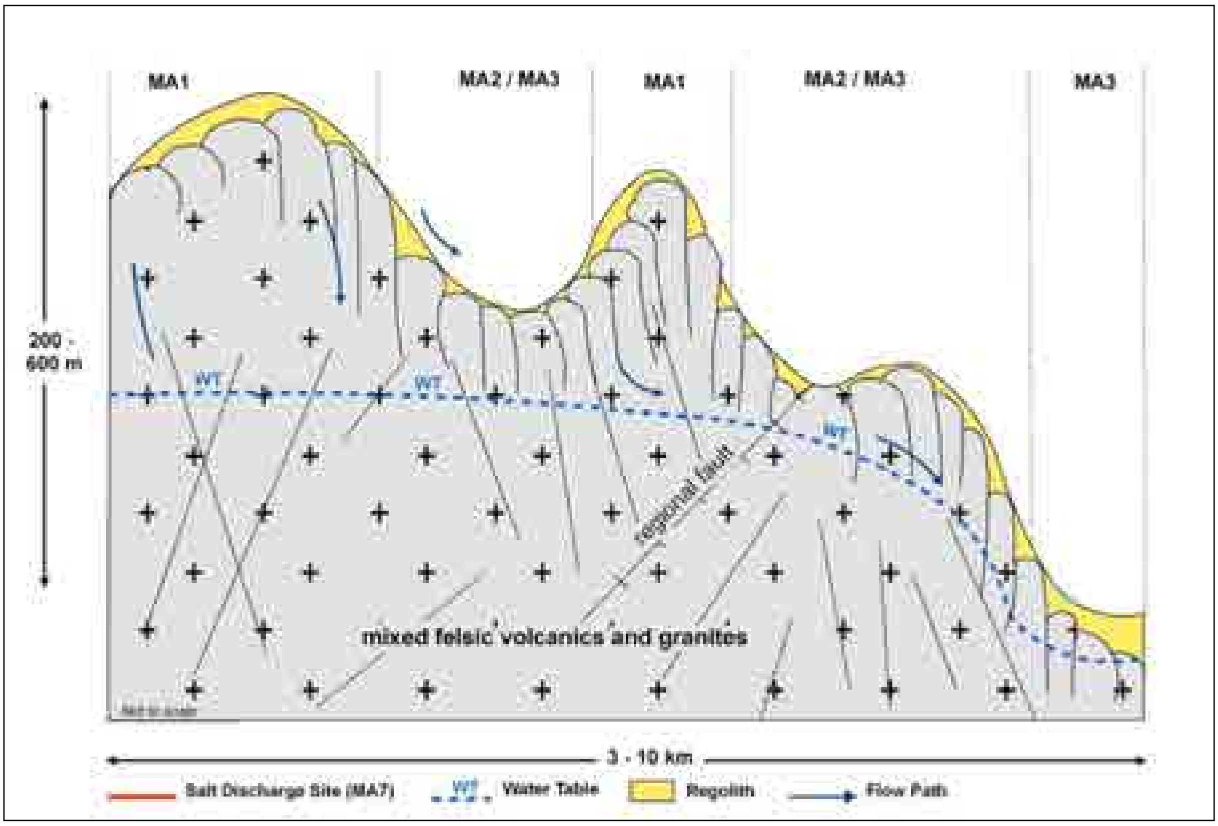


Figure 3: Management cross-section for Wymah-Jergyle HGL showing defined management areas.

Table 6: Specific management actions for management areas within the Wymah-Jergyle HGL.

Management Area (MA)	Action
MA1 (RIDGES)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).**
MA2 & MA3 (UPPER SLOPES – EROSIONAL & COLLUVIAL)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**
MA7 (SALT SITE)	**Salt land rehabilitation** Fence and isolate salt land and discharge areas to promote revegetation **(SR1).** Establish and manage salt land pasture systems to improve productivity **(SR2).** Mulch sites to reduce evaporation and promote pasture growth **(SR8).**

High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative impacts on salinity (Table 7).

Table 7: Management actions having negative salinity impacts in the Wymah-Jergyle HGL.

At Risk Management Areas	Action
MA1, MA2 & MA3 (RIDGES) (UPPER SLOPES – EROSIONAL & COLLUVIAL)	Clearing and poor management of native vegetation **(DLU4).**
MA7 (SALT SITE)	Deep ripping of soils to maximise water infiltration to subsoil **(DLU11).**

REFERENCES

DECCW, 2010, *Reconnaissance soil and land resources of the Murray CMA*, NSW Department of Environment, Climate Change and Water, Sydney

Geoscience Australia, 2011, *Australian stratigraphic units database*, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int

Keith, D. A. 2004, *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, Hurstville, NSW Department of Environment and Conservation

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, Office of Environment and Heritage, Sydney, [Accessed: 10 November 2014] www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

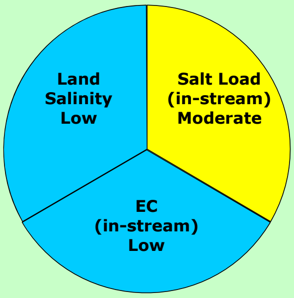
Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia

Stelling, F. 1998, *South west slopes revegetation guide (south of the Murrumbidgee River)*, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

Wooldridge, A., Nicholson, A., Muller R., Jenkins, B. R., Wilford, J. and Winkler, M. 2015, *Guidelines for managing salinity in rural areas*, NSW Office of Environment and Heritage, Sydney, NSW

22. Cookardinia Hydrogeological Landscape

LOCALITIES	**Cookardinia**
MAP SHEET	**Wagga Wagga 1:250 000**
CONFIDENCE LEVEL	**Low**



OVERVIEW

The Cookardinia Hydrogeological Landscape is north of Morven in the Cookardinia district (Figure 1). The HGL covers an area of 154 km^2 and receives 600 to 800 mm of rain per annum.

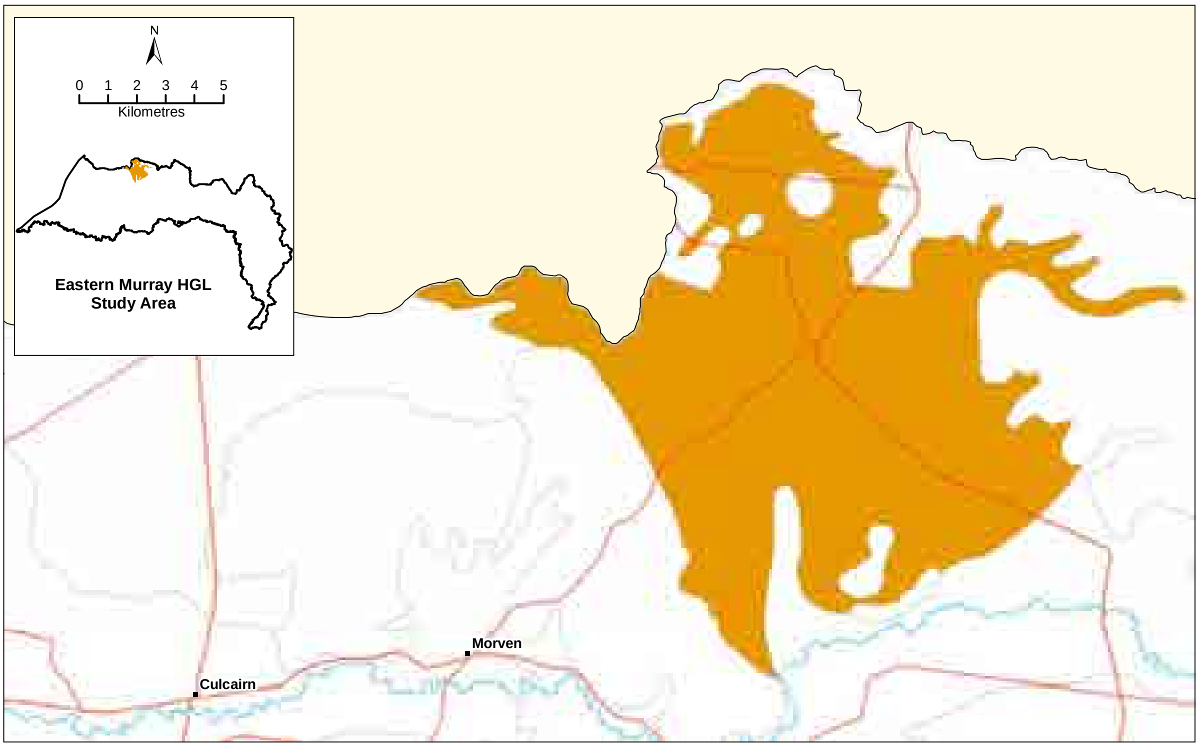


Figure 1: Cookardinia HGL distribution map.

The Cookardinia HGL is moderately to highly weathered and is characterised by extensive level alluvial plains and undulating residual low hills and rises. It includes inset floodplains, extensive plains with sparse narrow drainage lines and numerous terrace sequences. Other landscape elements are gently inclined foot-slopes and fans on colluvium. Hills have broad crests and ridges, with long straight slopes and widely spaced, mostly parallel drainage lines. The southern end of the HGL is more resistant to weathering and is prominent in the landscape as a high rocky hill (Figure 2). This HGL includes granitic rocks from the Silurian period and associated colluvial material. Unconsolidated Cenozoic sand plains and Quaternary alluvial gravel, sand, silt and clay occur on lower slopes and in drainage lines. Soils vary greatly and are shallow, sandy and discontinuous with little subsoil development on the steepest terrain; moderately well-drained on flat crests and slopes; very and moderately well-drained on higher, older terraces; deep and moderately well-drained on lower, younger terraces; deep and imperfectly drained in recent channels; and moderately well drained close to channels (representing more recent deposits). Small Gilgai areas with micro-relief and back plains have been noted. Sheet erosion and mass movement occur on the steepest slopes and stream bank erosion is evident along major drainage lines.

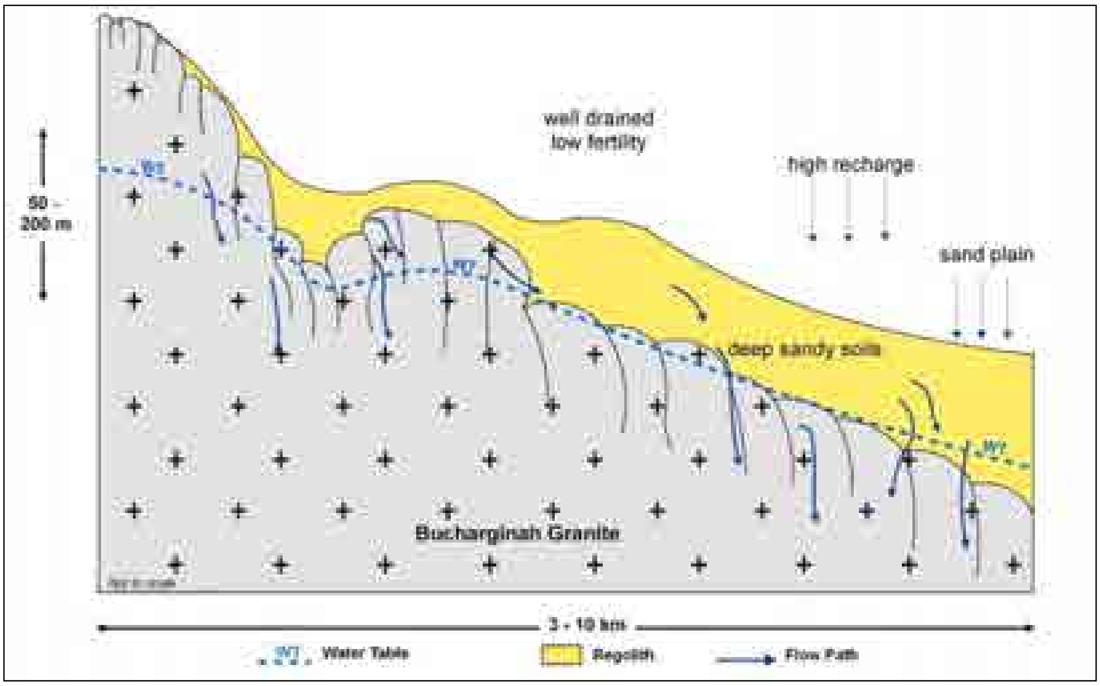


Figure 2: Conceptual cross-section for Cookardinia HGL showing the distribution of regolith and landforms, salt sites if present, and flow paths of water infiltrating the system.

Land salinity was not observed, but there is potential for rare salt sites to occur down-slope of skeletal soils. Salt load is moderate and EC is low in this HGL (Table 1).

Table 1: Cookardinia HGL salinity expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	Low – no observed salinity sites but potential for rare salt sites down-slope of skeletal soils
Salt Load (Export)	Moderate – deeply weathered landscape with perennial creeks supplying constant load
EC (Water Quality)	Low – no high salinity readings observed during study

Salt stored within the Cookardinia HGL has high mobility. There is a moderate salt store that has high availability (Table 2).

Table 2: Cookardinia HGL salt store and availability.

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

The overall salinity hazard in the Cookardinia HGL is moderate. This is due to the high likelihood that salinity issues will occur that have potentially limited impacts (Table 3).

Table 3: Likelihood of salinity occurrence, potential impact and overall hazard of salinity for the Cookardinia HGL.

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

LANDSCAPE FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 4.

Photo 1: South of Cookardinia, the Cookardinia HGL is dominated by broad, gently inclined slopes and sand plains (Photo: University of Canberra/A Price).

Photo 2: The sandy nature of the soils on the higher slopes of the Cookardinia HGL are susceptible to sheet erosion (Photo: University of Canberra/A Price).

Photo 3:Along the Cookardinia–Henty Road, undulating low hills with long slopes and gently inclined alluvial plains are a feature of the Cookardinia HGL (Photo: University of Canberra/K Harvey).

Photo 4: Along the Cookardinia–Henty Road, undulating low hills and rises with long slopes and gently inclined alluvial plains are typical of the Cookardinia HGL (Photo: OEH/R Muller).

Photo 5: In the vicinity of Mt Cookardinia, the hills have shallow soils and areas of rock outcrop (Photo: OEH/R Muller).

Photo 6: On the southern side of Mt Cookardinia, undulating hills with waxing slopes run down to gently inclined alluvial plains (Photo: OEH/R Muller).

Photo 7: Mt Cookardinia is the result of the underlying geology being more resistant to weathering. In this part of the Cookardinia HGL, soils are shallow and rock outcrop is common (Photo: OEH/R Muller).

Photo 8: The Mt Cookardinia ridge in the south-west part of the Cookardinia HGL is the highest element in this landscape (Photo: OEH/R Muller).

Table 4: Summary of information used to define the Cookardinia HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2011)*	This HGL comprises granitic rocks from the Silurian period and associated colluvial material. Unconsolidated Cenozoic sand plains and Quaternary alluvium occur on lower slopes and in river valleys. Key lithologies include: • channel and flood plain alluvium – gravel, sand, silt and clay • sand plains – sand dominant, gravel, clay; may include some residual alluvium • Buchargingah Granite – granite.
Annual Rainfall	600–800 mm
Regolith and Landforms	The Cookardinia HGL is slightly to moderately weathered and is characterised by undulating low hills (30–90 m relief) and rises (9–30 m) with broad crests and ridges, long colluvial slopes and widely spaced, sub-parallel drainage lines, and isolated hills (90–200 m relief) in the south, on Silurian granitic bedrock. Extensive level alluvial plains form low-lying areas of the landscape. Slopes are typically 2-10%, local relief is 5–200 m and this HGL is between 170–520 m elevation. The HGL features inset floodplains and numerous terrace sequences. Gilgai are present on the alluvial plains in localised areas. Regolith materials are dominantly quartzose sands with minor gravels and some sandy clays. On ridge crests and upper slopes there are angular pebble and cobble-bearing coarse sandy gravels and gravelly sands.
Soil Landscapes *(DECCW 2010)*	Billabong Creek is the most commonly occurring soil landscape found within this HGL. Minor occurrences of many other soil landscapes including Cookardinia, Buckargingah, O'Briens Creek, Yarra Yarra, Four Mile Creek, Wagra and Tipperary. Soils vary greatly and include: shallow, sandy, discontinuous Tenosols and Rudosols (Lithosols, Siliceous Sands and Earthy Sands), with little subsoil development on the steepest terrain; moderately well-drained Red Chromosols and Kurosols (Red Podzolic Soils) on flat crests and slopes; very deep (>1.5 m), moderately well-drained Brown, Yellow and Grey Sodosols (Soloths) and Chromosols (Podzolic Soils) on higher, older terraces; deep (1.0–1.5 m), moderately well-drained Brown Chromosols and Kurosols (Brown Podzolic Soils) on lower, younger terraces; deep (1.0–1.5 m), imperfectly drained Stratic Rudosols (Alluvial Soils) in recent channels and deep (1.0–1.5 m), moderately well drained Brown Dermosols (Yellow Podzolic Soils) close to channels (representing more recent deposits); and, small areas of Grey Vertosols (Grey Clays) with Gilgai micro-relief and back plains. Degradation is generally linked to topography, with sheet erosion and mass movement on the steepest slopes and stream bank erosion along major drainage lines. Salinity is generally related to deep subsurface systems.

Land and Soil Capability *(OEH 2012)*	Class 5
Land Use	Grazing on volunteer, naturalised, native or sown improved perennial pastures, and cropping (continuous or rotation)
Key Land Degradation Issues	• poor soil structure • waterlogging (localised) • soil compaction and hard-setting surfaces • moderate gully and stream-bank erosion (within drainage depressions) • sodic soils.
Native Vegetation *(Stelling 1998; Keith 2004)*	Vegetation on the hills tends to be white box woodland and red stringybark dry forest. Sand plains tend to support Blakely's red gum and yellow box woodland, with some grey box woodland. Tree species on the hills, lower slopes and flats can include *Eucalyptus albens* (white box) on fertile slopes and ridges, *E. blakelyi* (Blakely's red gum) on loamy soils and *Acacia implexa* (hickory wattle). *Eucalyptus macrorhyncha* (red stringybark) can occur on the south and south-east facing slopes. Other species that occur specifically on the granite hills may include *Acacia dealbata* (silver wattle), *A. lanigera* (woolly acadia) which is common as a paddock tree, *Allocasuarina verticillata* (drooping sheoak) on dry ridges and *Cassinia aculeate* (common cassinia) in the understorey. Vegetation on the alluvial flats tends to include additional species of *E. bridgesiana* (apple box), *E. melliodora* (yellow box) where the soils are moderately fertile and well drained, *E. microcarpa* (grey box) on heavier soils, *Callitris glaucophylla* (white cypress pine), and understorey species of *A. acinacea* (gold-dust wattle) and *A. deanei* (Deane's wattle). *Brachychiton populneus* (kurrajong) may occur on sandy soils (though not clay soils) and *E. camaldulensis* (river red gun) occurs only in the creek-lines.

HYDROGEOLOGY

Aquifers within this landscape are unconfined, with groundwater flow occurring primarily through fractures in bedrock and saprolite. Some flow occurs through sand plains on lower slopes and alluvial sediments in flow lines. Hydraulic conductivity is moderate to high and transmissivity is moderate. Groundwater recharge rates are estimated to be moderate to high.

Groundwater systems are typically local with short flow lengths and are loosely defined by topographic catchments. Water quality within these systems is fresh to marginal. Watertable depths are intermediate to deep.

Short to medium residence times are typical. These landscapes have a medium to fast response time to changes in land management.

Typical values for the hydrogeological parameters of this HGL are summarised in Table 5.

Table 5: Summary of values for typical hydrogeological parameters of the Cookardinia HGL.

Aquifer Type	Unconfined in fractured rock and saprolite Lateral flow through unconsolidated colluvial and alluvial sediments on lower slopes and in flow lines
Hydraulic Conductivity	Moderate to high Range: 10^{-2}–>10 m/day
Aquifer Transmissivity	Moderate Range: 2–100 m^2/day
Specific Yield	Moderate to high Range: 5–>15%
Hydraulic Gradient	Gentle to moderate Range: <10–30%
Groundwater Salinity	Fresh to marginal Range: <800–1600 µS/cm
Depth to Watertable	Intermediate to deep Range: 2–>8 m
Typical Sub-Catchment Size	Small (<100 ha)
Scale (Flow Length)	Local Flow length: <5 km (short)
Recharge Estimate	Moderate to high
Residence Time	Short to medium (months to years)
Responsiveness to Change	Fast to medium (months to years)

MANAGEMENT OPTIONS

Overarching salinity management strategies have specific biophysical outcomes. These are achieved by implementing a series of targeted land management actions that take into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape to impact on salinity. Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Salinity is driven by interactions between water-use capacity of vegetation, physical soil properties and hydrogeological processes within the HGL.

Actions that influence the way water is used by vegetation or stored in the soil profile will have impacts on recharge. The influence of both continual and episodic recharge and the

impacts of extreme weather events need to be considered when deciding on appropriate management actions. Short and long-term climate cycles also need to be considered as they have a bearing on salinity processes, particularly salt load and land salinity.

Landscape Salinity Functions – Cookardinia HGL

Functions this landscape provides within a catchment scale salinity context:

- **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.

Management Strategy Objectives – Cookardinia HGL

Appropriate strategies pertinent to this landscape:

- **Maintain or maximise runoff (10):** This HGL contributes significant fresh water as dilution flow to the local stream system. The fresh runoff mitigates the salt load, stream salinity and EC concentration of the local streams.
- **Discharge rehabilitation and management (4):** Discharge sites appear in the landscape through wet climatic cycles. Improved management of these saline areas can reduce the impact of salinisation and prevent large negative impacts during wet cycles.
- **Buffer the salt store – keep it dry and immobile (1):** There are stores of salt in discrete lower colluvial areas, which perennial vegetation can buffer, limiting the salinity impact.

Key Management Focus – Cookardinia HGL

Grazing management is the key focus for this unit. This includes management of pasture systems based on perennial plants on current and potential discharge areas, and within the wider mixed farming landscape. The important area to focus on is the lower colluvial slopes.

Specific Land Management Opportunities

Specific opportunities for this HGL:

- Soils types in seasonal discharge areas can be well drained – this means pasture establishment will have immediate impacts.
- Salinity occurs during wet climatic periods. Dry times offer the opportunity for preventative land management actions to be taken.

Specific Land Management Constraints

Constraints for land management in this HGL include:

- A high reliance on annual cropping of winter cereals by landholders has been observed.
- Soil constraints over the majority of the landscape will restrict pasture growth – particularly soil acidity and sodicity.

Specific Targeted Actions

Management areas for this HGL are illustrated in Figure 3. The specific management actions for these areas are described in Table 6.

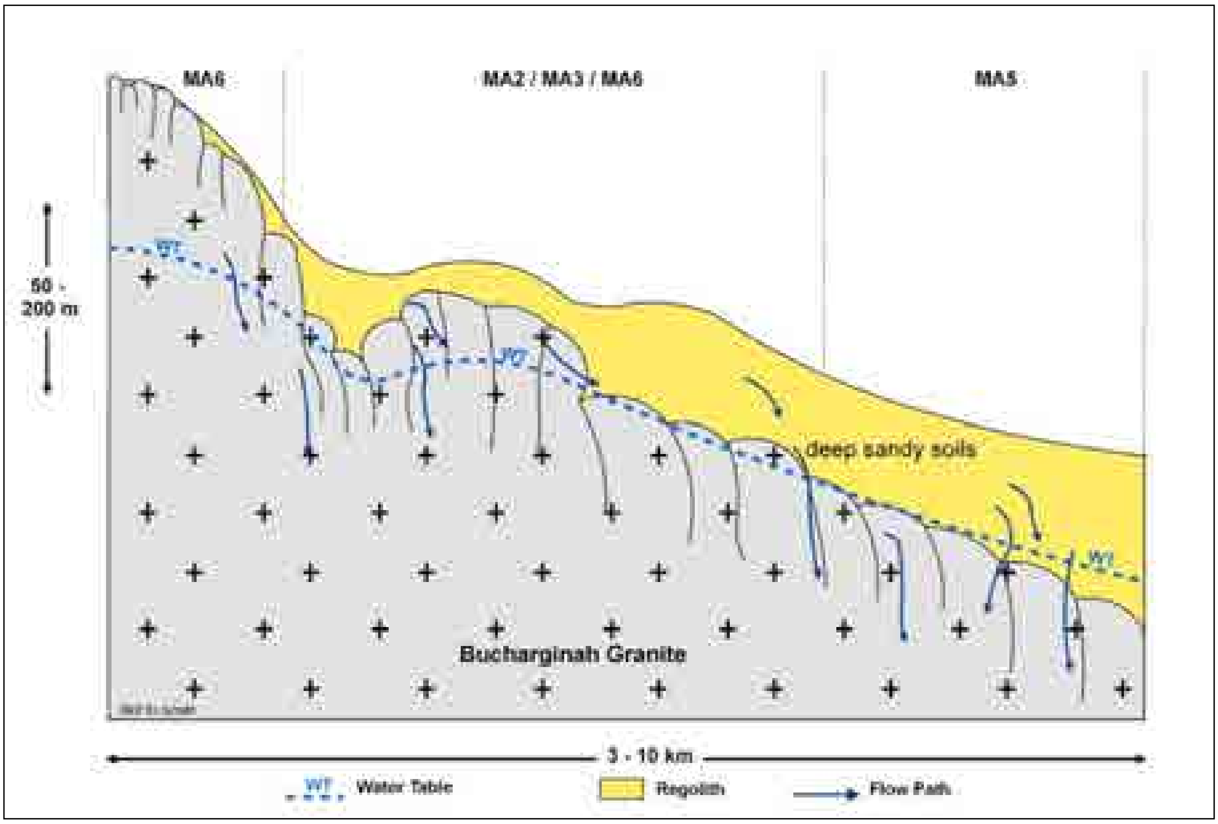


Figure 3: Management cross-section for Cookardinia HGL showing defined management areas.

Table 6: Specific management actions for management areas within the Cookardinia HGL.

Management Area (MA)	Action
MA1/6 (RIDGES & RISES)	**Vegetation for ecosystem function** Clearing and poor management of native vegetation **(VE3).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).**
MA2/3/6 (RISES & UPPER SLOPES – EROSIONAL & COLLUVIAL)	**Vegetation for ecosystem function** Clearing and poor management of native vegetation **(VE3).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).** **Farming Systems** Implement pasture cropping with annual cereals in perennial pastures to manage recharge **(FS1).** Implement rotational cropping with a perennial pasture component to manage recharge **(FS3).**
MA5 (LOWER SLOPES – COLLUVIAL)	**Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).**
MA7 (RARE SALT SITE)	**Salt land rehabilitation** Fence and isolate salt land and discharge areas to promote revegetation **(SR1).** Establish and manage salt land pasture systems to improve productivity **(SR2).**

High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative impacts on salinity (Table 7).

Table 7: Management actions having negative salinity impacts in the Cookardinia HGL.

At Risk Management Areas	Action
MA1/6 (RIDGES & RISES)	Clearing and poor management of native vegetation **(DLU4).**
MA2/3/6 (RISES & UPPER SLOPES – EROSIONAL & COLLUVIAL)	Long fallows in farming systems **(DLU1).** Annual cropping with annual plants **(DLU3).** Clearing and poor management of native vegetation **(DLU4).**

REFERENCES

DECCW, 2010, *Reconnaissance soil and land resources of the Murray CMA*, NSW Department of Environment, Climate Change and Water, Sydney

Geoscience Australia, 2011, *Australian stratigraphic units database*, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int

Keith, D. A. 2004, *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, Hurstville, NSW Department of Environment and Conservation

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, Office of Environment and Heritage, Sydney, [Accessed: 10 November 2014] www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

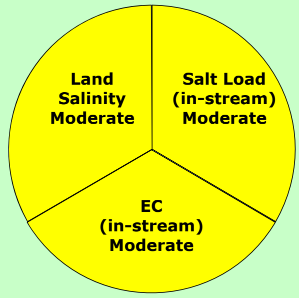
Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia

Stelling, F. 1998, *South west slopes revegetation guide (south of the Murrumbidgee River)*, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

Wooldridge, A., Nicholson, A., Muller R., Jenkins, B. R., Wilford, J. and Winkler, M. 2015, *Guidelines for managing salinity in rural areas*, NSW Office of Environment and Heritage, Sydney, NSW

23. Stonehaven Hydrogeological Landscape

LOCALITIES	**Nest Hill, Lunt's Sugarloaf, Black Hill, 'Trevellin'**
MAP SHEET	**Wagga Wagga 1:250 000**
CONFIDENCE LEVEL	**Low**



OVERVIEW

The Stonehaven Hydrogeological Landscape (HGL) extends from Little Billabong in the east, Chinamans Gap in the South and the west of Cookardinia in the west (Figure 1). The HGL covers an area of 376 km^2 and receives 700 to 850 mm of rain per annum.

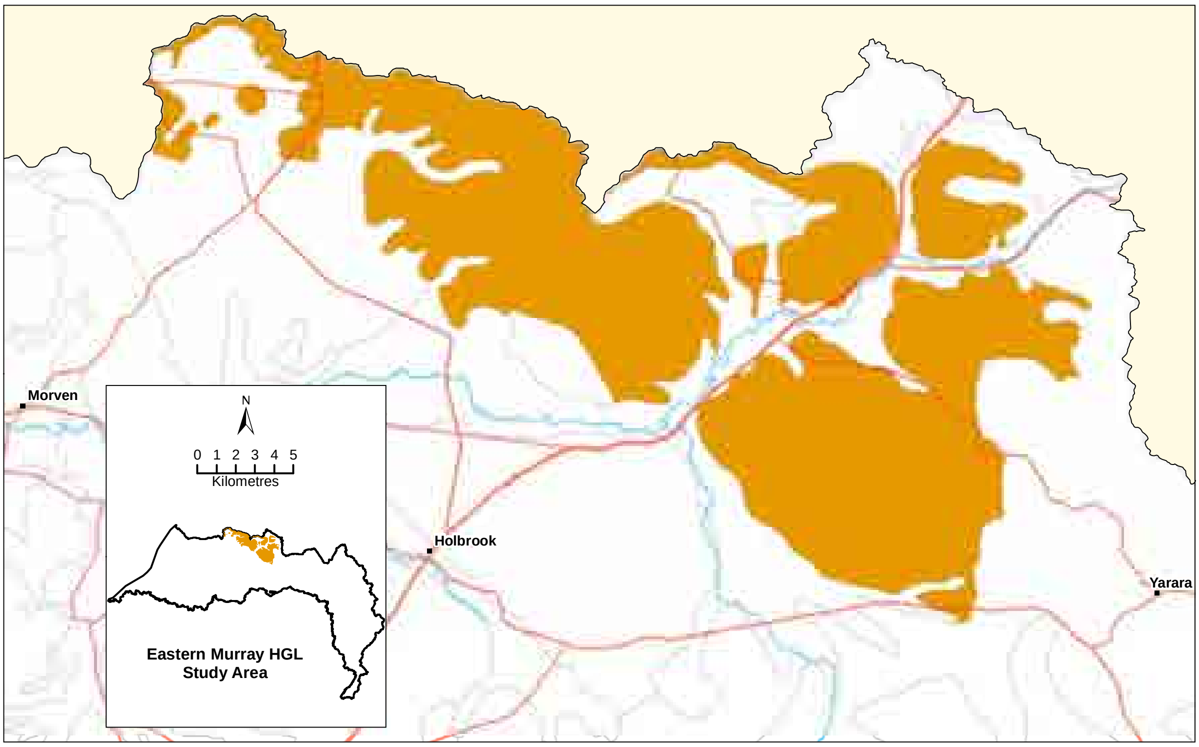


Figure 1: Stonehaven HGL distribution map.

The Stonehaven HGL is slightly to moderately weathered, characterised by rolling low hills and hills with broad ridge crests; long, waning middle and lower slopes, broad drainage depressions and narrow drainage lines. Rock outcrop is variable (Figure 2). Processes are primarily erosional on the ridge crests and upper slopes; colluvial on the middle to lower slopes; with minor transferral areas occurring along the drainage lines.This HGL includes metamorphosed consolidated sedimentary rocks from the Ordovician period. Unconsolidated colluvial and alluvial sand, gravel and clay derived from the surrounding rocks have been deposited on lower slopes and along streams that pass through. Soils are typically shallow and moderately well-drained on some crests, ridges and upper slopes; deep and imperfectly drained on other crests and upper slopes; moderately deep and moderately well-drained on mid to lower slopes; and, moderately deep and imperfectly drained in drainage lines and on lower slopes. Sheet and rill erosion are common and widespread with most topsoils degraded to some extent.

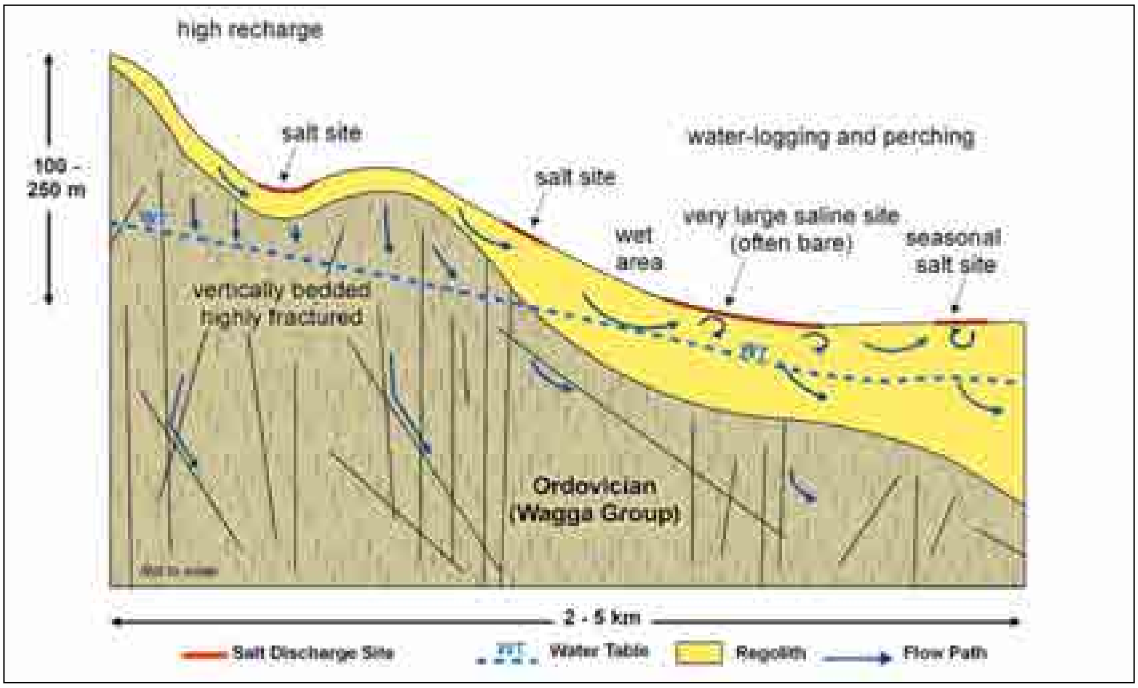


Figure 2: Conceptual cross-section for Stonehaven HGL showing the distribution of regolith and landforms, salt sites if present, and flow paths of water infiltrating the system.

Areas of land salinity that occur in this HGL are generally large. Moderate salt load and EC levels exist (Table 1).

Table 1: Stonehaven HGL salinity expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	Moderate – common large salt sites and associated with changes in slope
Salt Load (Export)	Moderate – perennial flows with moderate EC
EC (Water Quality)	Moderate – water EC measured during study around 400 µS/cm. Historically, high EC readings have been measured in this HGL

Salt stored within the Stonehaven HGL has moderate mobility. There is a moderate salt store that has moderate availability (Table 2).

Table 2: Stonehaven HGL salt store and availability.

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

The overall salinity hazard in the Stonehaven HGL is moderate. This is due to the high likelihood that salinity issues will occur that have potentially limited impacts (Table 3).

Table 3: Likelihood of salinity occurrence, potential impact and overall hazard of salinity for the Stonehaven HGL.

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

LANDSCAPE FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 4.

Photo 1: Rolling low hills with long waning colluvial slopes are characteristic of the Stonehaven HGL (Photo: OEH/R Muller).

Photo 2: Rolling low hills and hills drain into broad drainage depressions lower in the Stonehaven HGL (Photo: OEH/R Muller).

Photo 3: Salt sites can be seen at changes in slope adjacent to narrow drainage lines in the Stonehaven HGL (Photo: University of Canberra/A Price).

Photo 4: Rolling low hills and hills with broad crests and long lower slopes are characteristic of the Stonehaven HGL (Photo: University of Canberra/A Price).

Photo 5: Rolling low hills and hills with broad crests are a feature of the upper parts of the Stonehaven HGL (Photo: University of Canberra/A Price).

Photo 6: During wet periods, salt sites and waterlogging can be observed at changes in slope in the Stonehaven HGL (Photo: OEH/R Muller).

Table 4: Summary of information used to define the Stonehaven HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2011)*	This HGL comprises locally metamorphosed consolidated sedimentary rocks from the Ordovician period. These are overlain by unconsolidated Cenozoic sand plains and minor alluvium on lower slopes and in river valleys. Key lithologies include: • sand plains – sand dominant, gravel, clay; may include some residual alluvium • Wagga Group – quartzose siltstone, sandstone, quartz-mica schist, mudstone and chert. Minor quartzite, graphitic schist and hornfels.
Annual Rainfall	700–850 mm
Regolith and Landforms	The Stonehaven HGL is slightly to moderately weathered and is characterised by rolling hills (90–250 m relief) and low hills (30–90 m relief) with broad ridge crests; long colluvial slopes; broad drainage depressions, and narrow drainage lines on Ordovician metasedimentary bedrock. Slopes are typically 10–20%, and local relief is 30–250 m. This HGL features abundant (0–>50%) but irregularly distributed outcrop on crests and upper slopes. Regolith materials are dominantly kaolinite-bearing quartzose clayey sands with minor gravels and some sandy clays. On ridge crests and upper slopes there are some angular tabular pebble and cobble-bearing coarse sandy gravels and gravelly sands with variable kaolinitic clay content.
Soil Landscapes *(DECCW 2010)*	Small occurrences of a number of soil landscapes can be found within the boundaries of this HGL but Lloyd dominates. Soils are typically: shallow (<0.5 m), moderately well-drained Paralithic Leptic Rudosols (Lithosols) on some crests, ridges and upper slopes; deep (1.0–1.5 m), imperfectly drained Red Kurosols (Red Podzolic Soils) on other crests and upper slopes; moderately deep (0.5–1.0 m), moderately well-drained Red Chromosols and Kurosols (Red Podzolic Soils) on mid to lower slopes; and, moderately deep (0.5–1.0 m), imperfectly drained Brown Kurosols (Yellow Podzolic Soils) in drainage lines and on lower slopes. Sheet and rill erosion are common and widespread with most topsoils degraded to some extent. Gully erosion is locally common. Saline outbreaks attributable to soil type and landscape shape can be found at the break of slope.
Land and Soil Capability *(OEH 2012)*	Class 5
Land Use	Grazing (dominant) on volunteer, naturalised, native or improved pastures, or sown, improved perennial pastures, and cropping (continuous or rotation)

Key Land Degradation Issues	• moderate to severe sheet and rill erosion (upper slopes and cultivated lower slopes) • minor gully erosion (drainage lines) • some trees with dieback • localised saline outbreaks (lower change of slope) • acidity (localised) and associated aluminium toxicity • waterlogging.
Native Vegetation *(Stelling 1998; Keith 2004)*	Vegetation on the hills and upper slopes tends to be red box and red stringybark dry forest, or scribbly gum/snap gum dry forest in some locations (such as around Nest Hill). These communities have developed on the quartzite, slate, phyllite, greywacke, hornfels and schist typical of the Ordovician geologies of this HGL. Lower slopes and flats tend to support yellow box and Blakely's red gum woodland. Tree species on the upper slopes and hills include *Eucalyptus nortonii* (silver bundy) on dry rocky slopes, *E. polyanthemos* (red box) and *E. dwyeri* (Dwyer's red gum) on well drained soils, *E. melliodora* (yellow box), *E. albens* (white box), *Allocasuarina verticillata* (drooping sheoak), *Brachychiton populneus* (kurrajong), *Callitris endlicheri* (black cypress pine), *Acacia dealbata* (silver wattle) and *A. implexa* (hickory wattle) and *Exocarpos cupressiformis* (native cherry). Tree species of *E. rossii* (Scribbly Gum) and *E. macrorhyncha* (red stringybark) occur mainly on slopes with south and south-eastern aspects. Understorey species include *Leptospermum multicaule* (Silver Tea-tree) and *Pultenaea foliolosa* (Bush-pea). Additional species that occur on the lower slopes and flats may include *E. blakelyi* (Blakely's red gum), *E. bridgesiana* (Apple box) and *Acacia melanoxylon* (blackwood) (particularly in creeks). Grey Box woodland may occur on alluvial flats, and other species may include *E. camaldulensis* (river red gun) (in creek lines of the flat areas; not in higher altitude streams which support *E. blakelyi* and *E. dwyeri*), *E. microcarpa* (grey box) and a variety of acacia species. Native vegetation in Stonehaven HGL includes the areas of Nest Hill Nature Reserve and Murraguldrie State Forest.

HYDROGEOLOGY

Aquifers within this landscape are unconfined to semi-confined with groundwater flow occurring primarily through fractures in bedrock and saprolite. Some flow occurs through alluvial sediments on lower slopes and in flow lines. Hydraulic conductivity is low to moderate. Transmissivity is low. Groundwater recharge rates are estimated to be moderate.

Groundwater systems are typically local to intermediate with short to intermediate flow lengths and are loosely defined by topographic catchments. Water quality within these systems is fresh to marginal. Watertable depths are intermediate.

Medium to long residence times are typical. These landscapes have a medium response time to changes in land management.

Typical values for the hydrogeological parameters of this HGL are summarised in Table 5.

Table 5: Summary of values for typical hydrogeological parameters of the Stonehaven HGL.

Aquifer Type	Unconfined to semi-confined in fractured rock and saprolite Lateral flow through unconsolidated alluvial sediments on lower slopes and in flow lines
Hydraulic Conductivity	Low to moderate Range: <10 m/day
Aquifer Transmissivity	Low Range: <2 m^2/day
Specific Yield	Low Range: <5%
Hydraulic Gradient	Moderate Range: 10–30%
Groundwater Salinity	Fresh to marginal Range: <1600 µS/cm
Depth to Watertable	Intermediate Range: 2–8 m
Typical Sub-Catchment Size	Medium (100–1000 ha)
Scale (Flow Length)	Local to intermediate Flow length: <10 km (short to intermediate)
Recharge Estimate	Moderate
Residence Time	Medium to long (years to decades)
Responsiveness to Change	Medium (years)

MANAGEMENT OPTIONS

Overarching salinity management strategies have specific biophysical outcomes. These are achieved by implementing a series of targeted land management actions that take into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape to impact on salinity. Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Salinity is driven by interactions between water-use capacity of vegetation, physical soil properties and hydrogeological processes within the HGL.

Actions that influence the way water is used by vegetation or stored in the soil profile will have impacts on recharge. The influence of both continual and episodic recharge and the impacts of extreme weather events need to be considered when deciding on appropriate management actions. Short and long-term climate cycles also need to be considered as they have a bearing on salinity processes, particularly salt load and land salinity.

Landscape Functions – Stonehaven HGL

Functions this landscape provides within a catchment scale salinity context:

- **B.** The landscape provides fresh water runoff as an important dilution flow source
- **C.** The landscape provides important base flows to local streams
- **G.** The landscape contains important land assets (including infrastructure and high value agricultural land) on which salinity processes impact
- **D.** The landscape generates salt loads which enter the streams and are redistributed in the catchment.

Landscape Management Strategies – Stonehaven HGL

Appropriate strategies pertinent to this landscape:

- **Discharge rehabilitation and management (4):** Salt sites frequently occur. The sites range in size and exhibit a range of salinity symptoms from scalding and erosion to frequent waterlogging. Discharge management will improve on-site and off-site salinity outcomes. Discharge management will reduce salt discharge to streams when vegetation is matched to salt sites.
- **Intercept the shallow lateral flow and shallow groundwater (2):** It is possible to target shallow watertables that occur where bedrock is close to the surface. Rows of trees (8–30 rows) can be effective in interception of lateral flow. Rooting depth will intercept shallow groundwater when plantings are correctly targeted.

Key Management Focus – Stonehaven HGL

Grazing management is the key focus for this unit. This includes management of pasture systems based on perennial plants on current and potential discharge areas, and within the wider mixed farming landscape. This unit exhibits high salt concentrations within it rather than having an impact on the water quality down stream.

Specific Land Management Opportunities

Specific opportunities for this HGL:

- Interception plantings can be readily targeted.
- Discharge sites can be productive pasture systems based on salt and waterlogging tolerant species.

Specific Land Management Constraints

Constraints for land management in this HGL include:

- Revegetating hill areas should not be undertaken without managing lower areas of the landscape.
- Localised management causes local impact, not catchment impact.

- A high reliance on annual cropping of winter cereals by landholders in this unit has been observed.
- High level of landscape understanding is needed to successfully target interception plantings.
- High level on landscape understanding is required to successfully target saline pasture areas.

Specific Targeted Actions

Management areas for this HGL are illustrated in Figure 3. The specific management actions for these areas are described in Table 6.

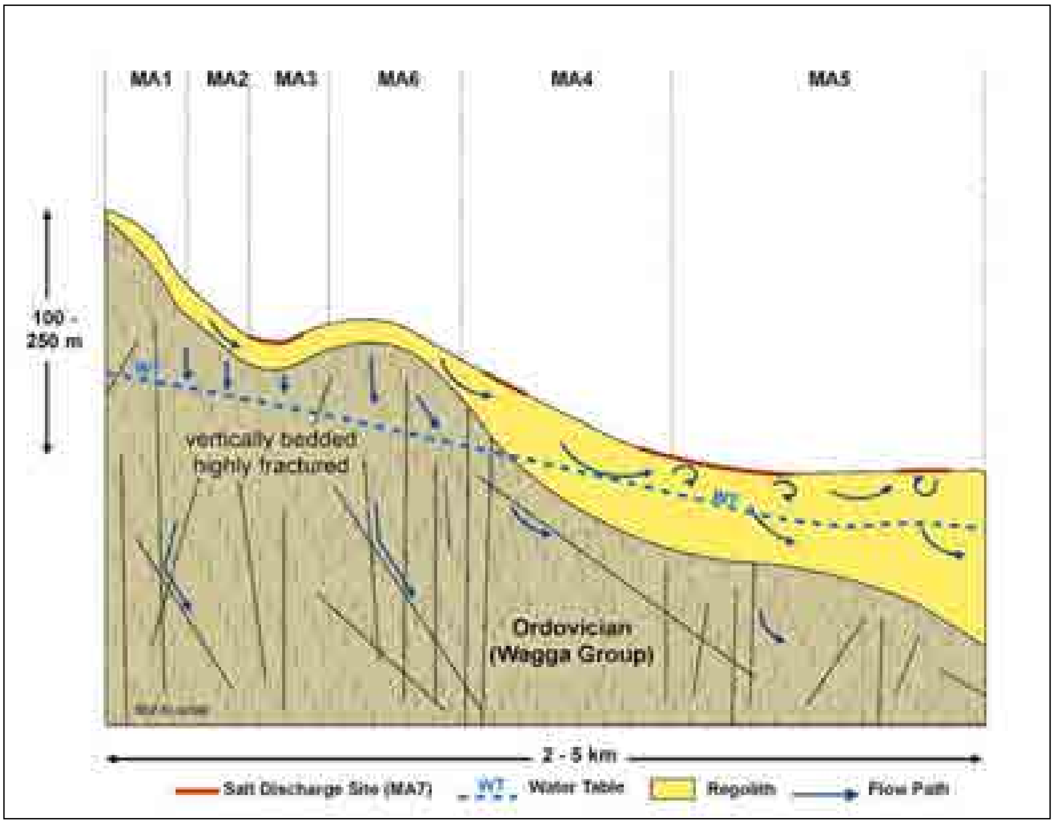


Figure 3: Management cross-section for Stonehaven HGL showing defined management areas.

Table 6: Specific management actions for management areas within the Stonehaven HGL.

Management Area (MA)	Action
MA1 (RIDGES)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**
MA2 (UPPER SLOPES – EROSIONAL) MA3 (UPPER SLOPES – COLLUVIAL)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).** **Farming Systems** Implement pasture cropping with annual cereals in perennial pastures to manage recharge **(FS1).**

Management Area (MA)	Action
MA4 (MID-SLOPES) MA5 (LOWER SLOPES – COLLUVIAL)	**Vegetation for ecosystem function** Establish and manage trees to intercept lateral groundwater flow **(VE2).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** Establish and manage perennial pastures to intercept shallow lateral groundwater flow **(VP3).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).** **Farming Systems** Implement pasture cropping with annual cereals in perennial pastures to manage recharge **(FS1).**
MA6 (RISES)	**Vegetation for ecosystem function** Establish and manage trees to intercept lateral groundwater flow **(VE2).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** Establish and manage perennial pastures to intercept shallow lateral groundwater flow **(VP3).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**
MA7 (SALINE SITES)	**Salt land rehabilitation** Fence and isolate salt land and discharge areas to promote revegetation **(SR1).** Establish and manage salt land pasture systems to improve productivity **(SR2).** Establish forestry systems on salt land to improve productivity **(SR3).** Mulch sites to reduce evaporation and promote pasture growth **(SR8).**

High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative impacts on salinity (Table 7).

Table 7: Management actions having negative salinity impacts in the Stonehaven HGL.

At Risk Management Areas	Action
MA1 & MA2 (RIDGES & UPPER SLOPES – EROSIONAL)	Poor management of grazing pastures **(DLU2).** Annual cropping with annual plants **(DLU3).** Clearing and poor management of native vegetation **(DLU4).**
MA3 (UPPER SLOPES – COLLUVIAL)	Poor management of grazing pastures **(DLU2).** Annual cropping with annual plants **(DLU3).**
MA4 & MA5 (MID-SLOPES & LOWER SLOPES – COLLUVIAL)	Poor management of grazing pastures **(DLU2).** Farm dams in flow lines **(DLU5).**
MA6 (RISES)	Poor management of grazing pastures **(DLU2).**
MA7 (SALINE SITES)	Locating infrastructure on discharge areas **(DLU7).** Flat contour banks **(DLU12).**

REFERENCES

DECCW, (2010), *Reconnaissance soil and land resources of the Murray CMA*, NSW Department of Environment, Climate Change and Water, Sydney

Geoscience Australia, 2011, *Australian stratigraphic units database*, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int

Keith, D. A. 2004. *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, Hurstville, NSW Department of Environment and Conservation

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, OEH Sydney, [Accessed: 10 November 2014] www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

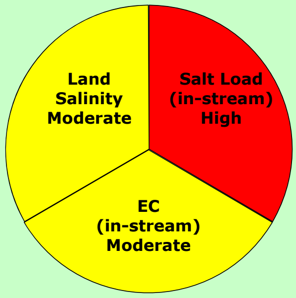
Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia

Stelling, F. 1998, *South west slopes revegetation guide (south of the Murrumbidgee River)*, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

Wooldridge, A., Nicholson, A., Muller R., Jenkins, B. R., Wilford, J. and Winkler, M. 2015, *Guidelines for managing salinity in rural areas*, NSW Office of Environment and Heritage, Sydney, NSW

24. Bald Hill Hydrogeological Landscape

LOCALITIES	**Bald Hill, Kyeamba Gap**
MAP SHEET	**Wagga Wagga 1:250 000**
CONFIDENCE LEVEL	**Low**



OVERVIEW

The Bald Hill Hydrogeological Landscape (HGL) is at the northern border of the catchment west of Little Billabong, and at Kyeamba (Figure 1). The HGL covers an area of 21 km^2 and receives 650 to 800 mm of rain per annum.

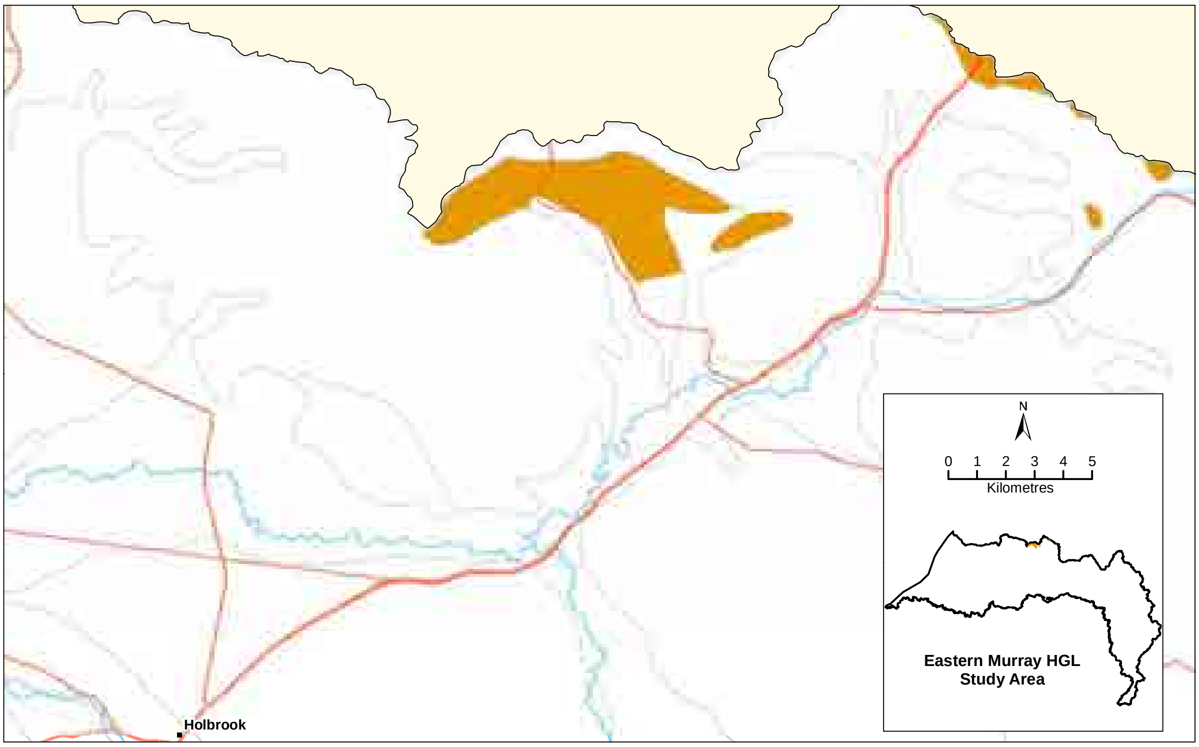


Figure 1: Bald Hill HGL distribution map.

The Bald Hill HGL is variably weathered and is characterised by steep, rolling and undulating hills with steep slopes and narrow to moderately broad crests and ridges; moderately long to long waning slopes; and moderately broad drainage depressions. Undulating hills have very long waxing foot-slopes (Figure 2). This HGL includes intrusive granitic rocks and associated sediments from the Silurian period. Unconsolidated Quaternary colluvial and alluvial gravel and sand derived from the surrounding rocks have been deposited on lower slopes and along streams that pass through. Soils are typically deep and moderately well-drained, and very deep and moderately well-drained on crests and slopes; shallow on the steeper parts of the landscape where rock comes close to the surface; moderate to very deep and imperfectly drained on upper foot-slopes; and deep and imperfectly drained on lower slopes and in drainage lines.

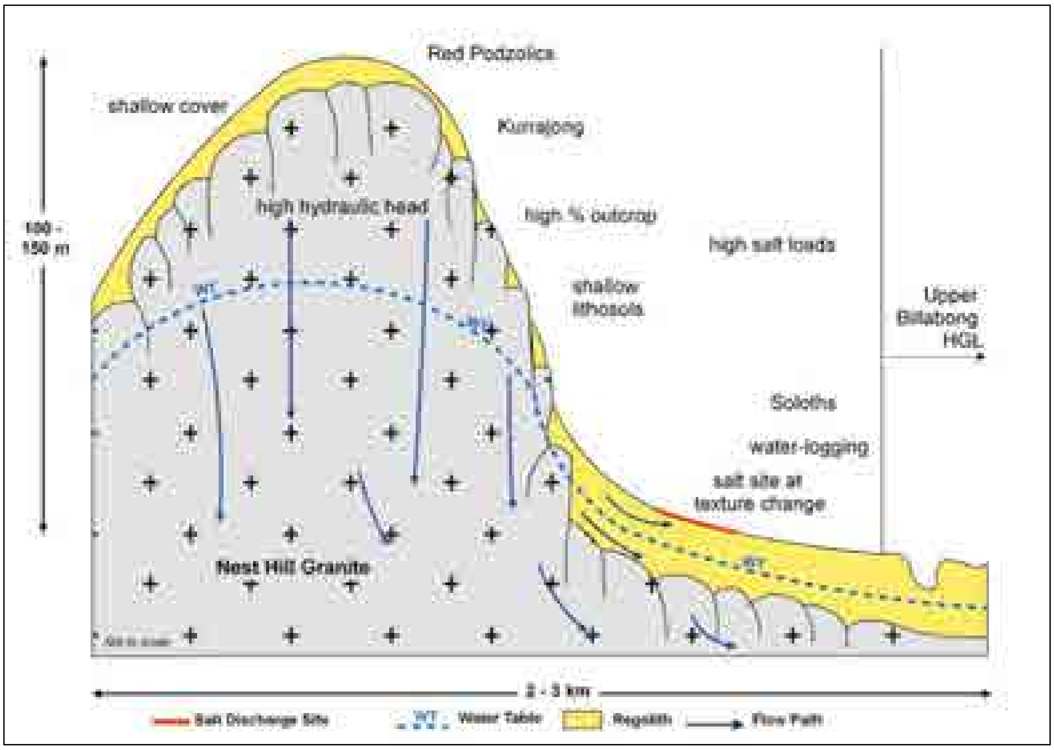


Figure 2: Conceptual cross-section for Bald Hill HGL showing the distribution of regolith and landforms, salt sites if present, and flow paths of water infiltrating the system.

Land salinity occurs at the margins of this HGL unit at the soil texture change on the lower colluvial slopes. The HGL generated high salt loads and moderate EC (Table 1).

Table 1: Bald Hill HGL salinity expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	Moderate – salt sites occur at margins of HGL unit at the soil texture change on the lower colluvial slopes
Salt Load (Export)	High – perennial streams carry large volumes of moderately saline water
EC (Water Quality)	Moderate – EC levels measured in streams on the boundary of this HGL were moderate

Salt stored within the Bald Hill HGL has moderate mobility. There is a moderate salt store that has moderate availability (Table 2).

Table 2: Bald Hill HGL salt store and availability.

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

The overall salinity hazard in the Bald Hill HGL is high. This is due to the high likelihood that salinity issues will occur that have potentially significant impacts (Table 3).

Table 3: Likelihood of salinity occurrence, potential impact and overall hazard of salinity for the Bald Hill HGL.

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

LANDSCAPE FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 4.

Photo 1: The rocky south-west faces of Bald Hill and Mt Stewart define the southern boundary of the Bald Hill HGL (Photo: University of Canberra/A Price).

Photo 2: The steep slope of Mt Stewart and the adjacent gently inclined colluvial plain are defining features of the Bald Hill HGL (Photo: University of Canberra/A Price).

Photo 3: On Mt Stewart, soil development is shallow and rock outcrop widespread. Kurrajongs are a common tree species on the south-west slope (Photo: University of Canberra/A Price).

Photo 4: To the north of Bald Hill, hill crests are broader and soil development much deeper. There is little rock outcrop in this part of the Bald Hill HGL (Photo: University of Canberra/A Price).

Table 4: Summary of information used to define the Bald Hill HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2011)*	This HGL comprises granitic rocks from the Silurian period. Unconsolidated Quaternary colluvial material occurs on lower slopes. Key lithologies include: • colluvium and/or residual deposits – boulders, gravel and sand • Kyeamba Suite – felsic, unfractionated granite • Nest Hill Granite – granite.
Annual Rainfall	650–800 mm
Regolith and Landforms	The Bald Hill HGL is slightly to moderately weathered and is characterised by rolling hills (90–150 m relief) some with steep crests but most with moderately broad crests and ridges, moderate to long colluvial slopes and broad drainage depressions, on Silurian granitic bedrock. Slopes are typically 2->30%, local relief is 5–150 m and this HGL is between 340–600 m elevation. This HGL features abundant (20–>50%) but irregularly distributed outcrop on crests and upper slopes, and numerous dissecting channels on colluvial slopes. Regolith materials are dominantly quartzose clayey sands with minor gravels and some sandy clays. On ridge crests and upper slopes there are some angular pebble and cobble-bearing coarse sandy gravels and gravelly sands.
Soil Landscapes *(DECCW 2010)*	This HGL contains a number of soil landscapes. The most commonly occurring soil landscapes are Clifton Hills, Mount Stewart and Forest Creek Headwater. A number of soil landscapes have minor occurrence, including Pulletop, Lloyd, Mount Flakney, Yarragundry and Veteran. Soils are typically: deep (1.0–1.5 m), moderately well-drained Red and Brown Kandosols (Red and Yellow Earths) and very deep (>1.5 m), moderately well-drained Red Chromosols (Red Podzolic Soils) on crests and slopes; shallow (<50 cm) Leptic Tenosols (Lithosols) occurring sporadically throughout the steeper parts of the landscape where rock comes close to the surface; moderate (0.5–1.0 m) to very deep (>1.5 m), imperfectly drained Grey and Brown Sodosols (Soloths) occur on upper foot-slopes; and deep (1.0–1.5 m), imperfectly drained Yellow Sodosols (Soloths) on lower slopes and drainage lines.
Land and Soil Capability *(OEH 2012)*	Class 6
Land Use	Grazing on volunteer, naturalised, native or sown, improved perennial pastures
Key Land Degradation Issues	• minor gully and sheet erosion (lower slopes) • severe gully erosion (mid to lower slopes) • mass movement (steep slopes) • salinity outbreaks on transition from Clifton Hills soil landscape to Forest Creek Headwaters soil landscape.

Native Vegetation *(Stelling 1998; Keith 2004)*	Vegetation on the hills and upper slopes tends to be red box and red stringybark dry forest, or scribbly gum/snap gum dry forest in some locations (such as around Nest Hill). Tree species on the upper slopes and hills include *Eucalyptus nortonii* (silver bundy) on dry rocky slopes, *E. polyanthemos* (red box) and *E. dwyeri* (Dwyer's red gum) on well drained soils, *E. melliodora* (yellow box), *E. albens* (white box), *Allocasuarina verticillata* (drooping sheoak), *Brachychiton populneus* (kurrajong), *Callitris endlicheri* (black cypress pine), *Acacia dealbata* (silver wattle) and *A. implexa* (hickory wattle) and *Exocarpos cupressiformis* (native cherry). Tree species of *E. rossii* (sribbly gum) and *E. macrorhyncha* (red stringybark) occur mainly on slopes with south and south-eastern aspects. Understorey species include *Leptospermum multicaule* (silver tea-tree) and *Pultenaea foliolosa* (bush-pea).

HYDROGEOLOGY

Aquifers within this landscape are unconfined with groundwater flow occurring primarily through fractures in bedrock and saprolite. Some flow occurs through colluvial and alluvial sediments on lower slopes and along flow lines. Hydraulic conductivity is moderate and transmissivity is low to moderate. Groundwater recharge rates are estimated to be moderate.

Groundwater systems are typically local with short flow lengths and are loosely defined by topographic catchments. Water quality within these systems is fresh to marginal. Watertable depths are shallow to intermediate.

Short to medium residence times are typical. These landscapes have a medium to fast response time to changes in land management.

Typical values for the hydrogeological parameters of this HGL are summarised in Table 5.

Table 5: Summary of values for typical hydrogeological parameters of the Bald Hill HGL.

Aquifer Type	Unconfined in fractured rock and saprolite Lateral flow through unconsolidated colluvial and alluvial sediments on lower slopes and in flow lines
Hydraulic Conductivity	Moderate Range: 10^{-2}–10 m/day
Aquifer Transmissivity	Low to moderate Range: <2–50 m^2/day
Specific Yield	Low to moderate Range: <5–15%
Hydraulic Gradient	Steep Range: >30%

Groundwater Salinity	Marginal Range: 800–1600 µS/cm
Depth to Watertable	Shallow to intermediate Range: <2–8 m
Typical Sub-Catchment Size	Small (<100 ha)
Scale (Flow Length)	Local Flow length: <5 km (short)
Recharge Estimate	Moderate
Residence Time	Short to medium (months to years)
Responsiveness to Change	Fast to medium (months to years)

MANAGEMENT OPTIONS

Overarching salinity management strategies have specific biophysical outcomes. These are achieved by implementing a series of targeted land management actions that take into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape to impact on salinity. Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Salinity is driven by interactions between water-use capacity of vegetation, physical soil properties and hydrogeological processes within the HGL.

Actions that influence the way water is used by vegetation or stored in the soil profile will have impacts on recharge. The influence of both continual and episodic recharge and the impacts of extreme weather events need to be considered when deciding on appropriate management actions. Short and long-term climate cycles also need to be considered as they have a bearing on salinity processes, particularly salt load and land salinity.

Landscape Salinity Functions – Bald Hill HGL

Functions this landscape provides within a catchment scale salinity context:

- **D.** The landscape generates salt loads which enter the streams and are redistributed in the catchment.
- **F.** The landscape generates high salinity concentration water.
- **G.** The landscape contains important land assets (including infrastructure and high value agricultural land) on which salinity processes impact.

Management Strategy Objectives – Bald Hill HGL

Appropriate strategies pertinent to this landscape:

- **Buffer the salt store – keep it dry and immobile (1):** There are stores of salt in discrete lower colluvial areas, which perennial vegetation can buffer, limiting the salinity impact.
- **Discharge rehabilitation and management (4):** The saline and waterlogged sites are small in size. Discharge management will reduce salt discharge to streams when vegetation is matched to salt sites.
- **Dry out the landscape with diffuse actions over most of the landscape (6):** Encourage plant growth and increase plant water use in order to use excess soil moisture and shallow groundwater. Healthy, actively growing vegetation will also act as a buffer to groundwater accessions in wet seasonal conditions.

Key Management Focus – Bald Hill HGL

Grazing management is the key focus for this unit. This should largely concern the colluvial parts of the landscape. The management should include pasture systems based on perennial plants on current and potential discharge areas and within wider mixed farming landscape.

Specific Land Management Opportunities

Specific opportunities for this HGL:

- Soils types in seasonal discharge areas can be well drained and fertile – this means pasture establishment and management will have immediate impacts.
- The potential salinity actions are targeted at a small area – the lower slopes colluvial.
- Salinity occurs during wet climatic periods. Dry times offer the opportunity for preventative land management actions to be taken.

Specific Land Management Constraints

Constraints for land management in this HGL include:

- Very rocky upper slopes and hills with shallow soils.

Specific Targeted Actions

Management areas for this HGL are illustrated in Figure 3. The specific management actions for these areas are described in Table 6.

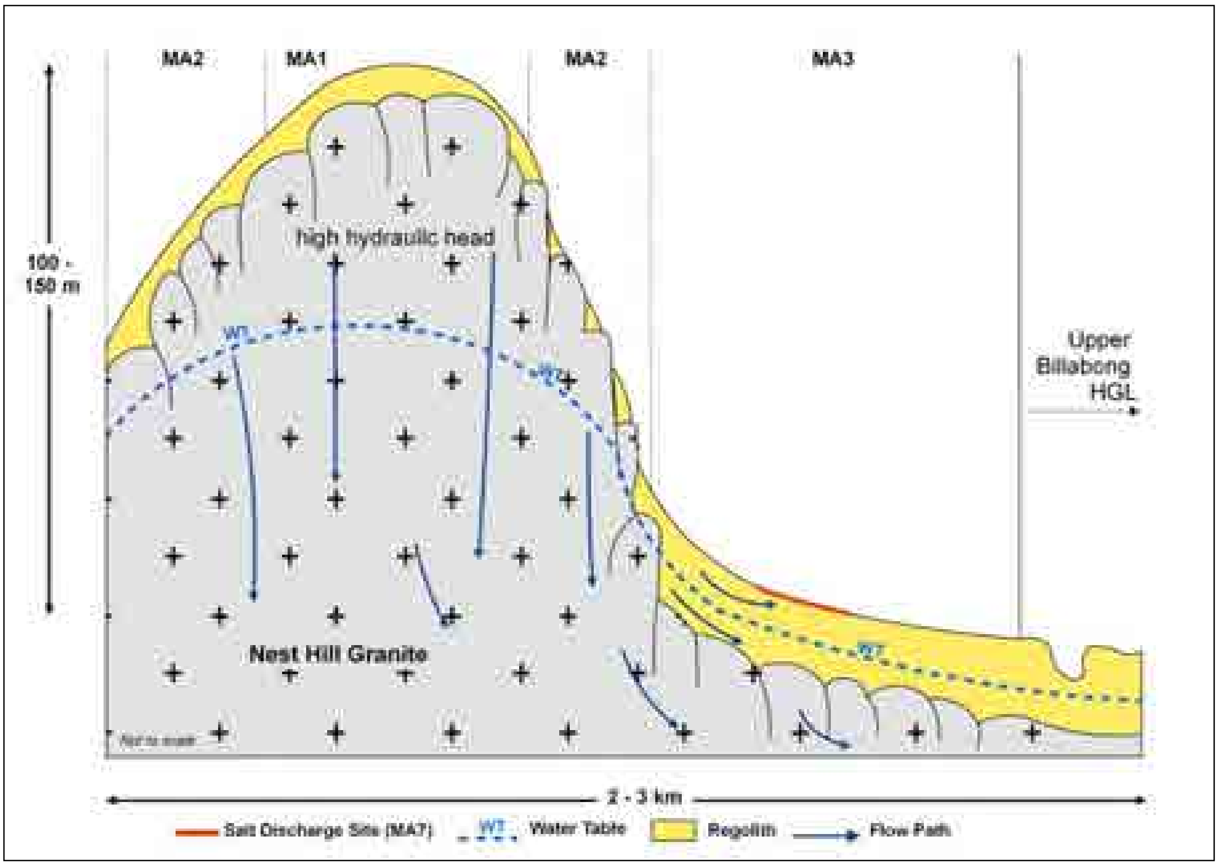


Figure 3: Management cross-section for Bald Hill HGL showing defined management areas.

Table 6: Specific management actions for management areas within the Bald Hill HGL.

Management Area (MA)	Action
MA1 (RIDGES)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**

Management Area (MA)	Action
MA2 (UPPER SLOPES – EROSIONAL)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**
MA3 (UPPER SLOPES – COLLUVIAL)	**Vegetation for ecosystem function** Establish and manage trees to intercept lateral groundwater flow **(VE2).** **Vegetation for production** Establish and manage perennial pastures to manage recharge (**VP2).** Establish and manage perennial pastures to intercept shallow lateral groundwater flow **(VP3).**
MA7 (SALINE SITES)	**Salt land rehabilitation** Fence and isolate salt land and discharge areas to promote revegetation **(SR1).** Establish and manage salt land pasture systems to improve productivity **(SR2).** Establish forestry systems on salt land to improve productivity **(SR3).** Mulch sites to reduce evaporation and promote pasture growth **(SR8).**

High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative impacts on salinity (Table 7).

Table 7: Management actions having negative salinity impacts in the Bald Hill HGL.

At Risk Management Areas	Action
MA1 (RIDGES)	Poor management of grazing pastures **(DLU2).** Clearing and poor management of native vegetation **(DLU4).**
MA2 (UPPER SLOPES – EROSIONAL)	Poor management of grazing pastures **(DLU2).** Clearing and poor management of native vegetation **(DLU4).**
MA3 (UPPER SLOPES – COLLUVIAL)	Annual cropping with annual plants **(DLU3).**
MA7 (SALINE SITES)	Deep ripping of soils to maximise water infiltration to subsoil **(DLU11).**

REFERENCES

DECCW, 2010, *Reconnaissance soil and land resources of the Murray CMA*, NSW Department of Environment, Climate Change and Water, Sydney

Geoscience Australia, 2011, *Australian stratigraphic units database*, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int

Keith, D. A. 2004, *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, Hurstville, NSW Department of Environment and Conservation

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, Office of Environment and Heritage, Sydney, [Accessed: 10 November 2014] www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia

Stelling, F. 1998, *South west slopes revegetation guide (south of the Murrumbidgee River)*, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

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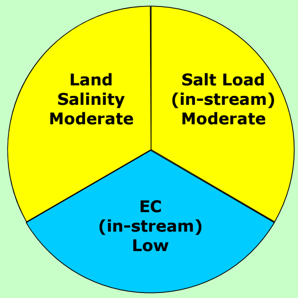
25. Lankeys Hydrogeological Landscape

LOCALITIES	**Lankeys Creek, Chinamans Gap, Yarara, Coppabella, Glenroy, Maginnitys Gap**
MAP SHEET	**Wagga Wagga 1:250 000**
CONFIDENCE LEVEL	**Medium**



OVERVIEW

The Lankeys Hydrogeological Landscape (HGL) extends from the northern boundary of the Murray CMA to the Murray River and from approximately Yarara in the west to Tumbarumba in the east (Figure 1). The HGL covers an area of 888 km^2 and receives 800 to 1100 mm of rain per annum.

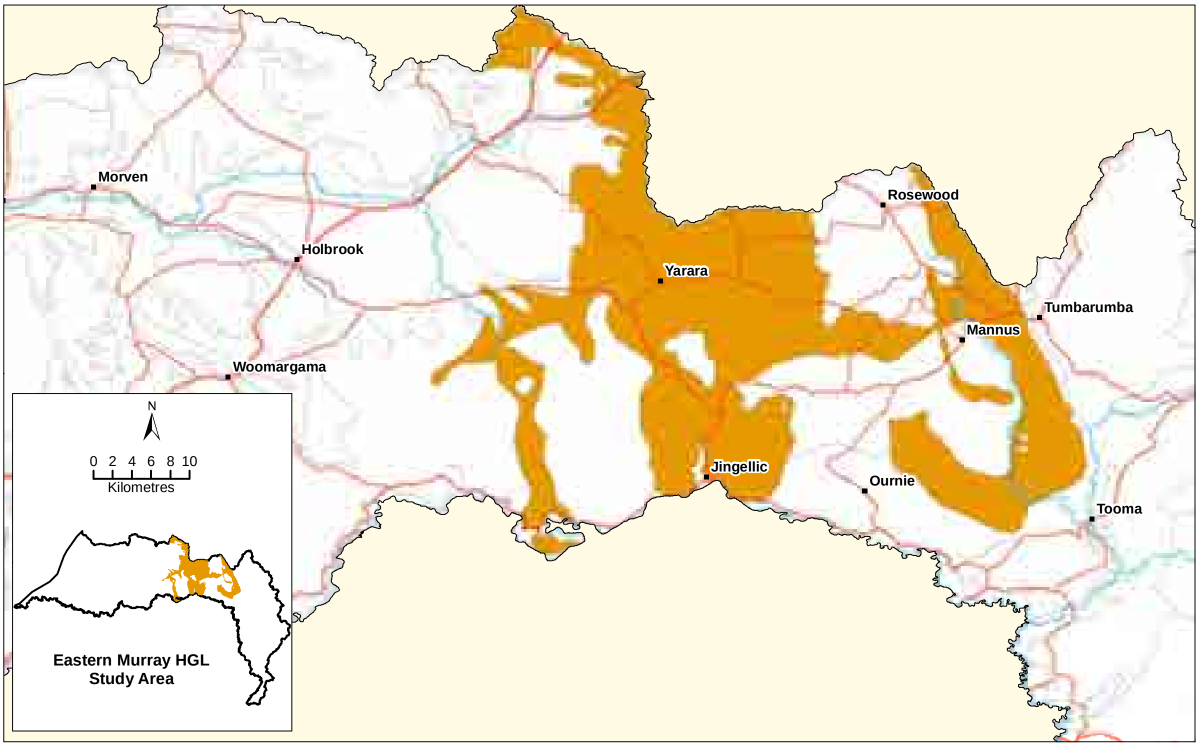


Figure 1: Lankeys HGL distribution map.

It is characterised by steep vegetated landforms decreasing in relief from precipitous, steep hills to rolling hills and steep low hills, and gently inclined foot-slopes of colluvium. The Lankeys HGL is predominantly an erosional environment characterised by steep hills, mountains, hills and rolling hills with narrow crests and ridges, short escarpment, moderately long waxing slopes and narrow drainage lines (Figure 2). The lower landform elements include gently inclined foot-slopes of colluvium derived from flanking metasediments. This HGL comprises locally metamorphosed consolidated sedimentary rocks from the Ordovician period. Unconsolidated Cenozoic sand plains (sand, gravel and clay) and Quaternary colluvium and alluvium occur on lower slopes and in river valleys. Soils are shallow and stony on crests, ridges and upper slopes; shallow to moderately deep in upper drainage lines; moderately deep and moderately well-drained on lower slopes; and moderately deep in lower drainage lines. Erosion on slopes, including sheet, rill, wind, gully erosion in drainage lines and terracetting (soil creep) on cleared slopes, are common landscape limitations. Lower landforms experience seasonal waterlogging and soil sodicity.

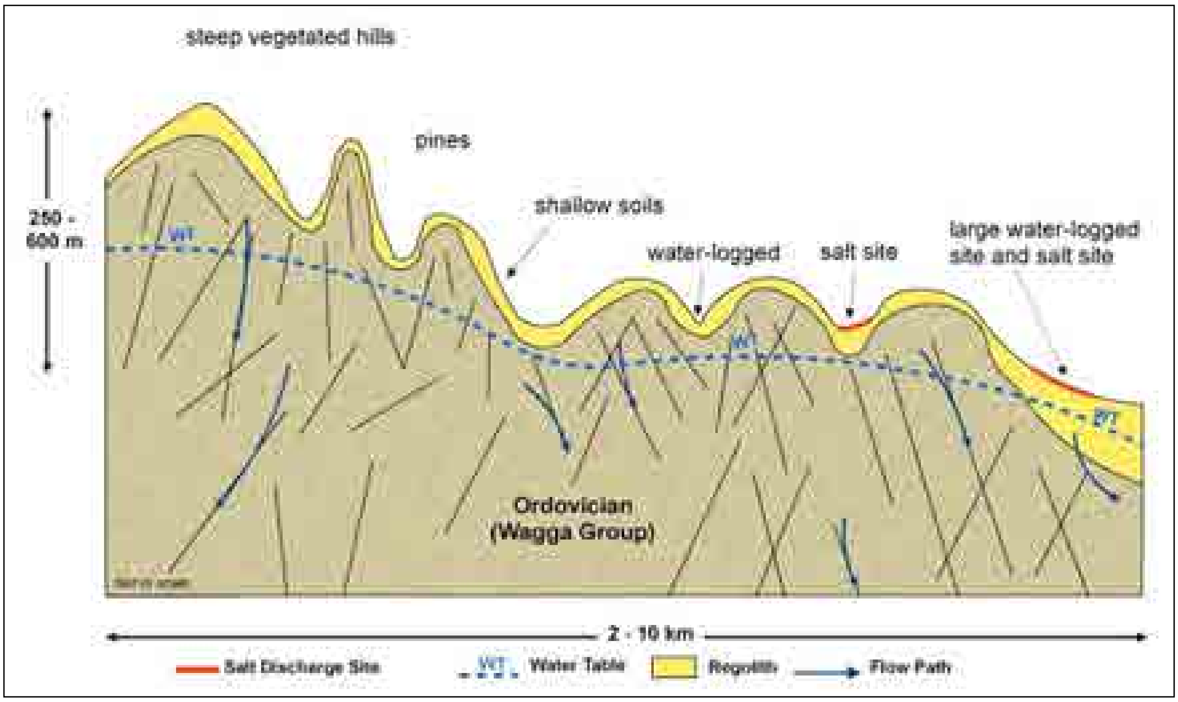


Figure 2: Conceptual cross-section for Lankeys HGL showing the distribution of regolith and landforms, salt sites if present, and flow paths of water infiltrating the system.

Isolated small areas of land salinity have been observed which show mainly waterlogging symptoms and are confined to the lower portion of the landscape. Moderate salt load and low EC levels are present (Table 1).

Table 1: Lankeys HGL salinity expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	Moderate – Isolated small areas have been observed which show mainly waterlogging symptoms and are confined to the lower portion of the landscape
Salt Load (Export)	Moderate – No evidence of export but low flow in perennial streams supplies continuous load
EC (Water Quality)	Low water EC was observed

Salt stored within the Lankeys HGL has moderate mobility. There is a low salt store that has high availability (Table 2).

Table 2: Lankeys HGL salt store and availability.

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

The overall salinity hazard in the Lankeys HGL is moderate. This is due to the high likelihood that salinity issues will occur that have potentially limited impacts (Table 3).

Table 3: Likelihood of salinity occurrence, potential impact and overall hazard of salinity for the Lankeys HGL.

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

LANDSCAPE FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 4.

Photo 1: The steeper, more elevated elements of the Lankeys HGL generally show some rock outcrop and are mostly vegetated with native forests (Photo: OEH/R Muller).

Photo 2: The rolling hills and low hills within the Lankeys HGL have broad crests with waxing slopes (Photo: OEH/R Muller).

Photo 3: The rolling hills and low hills within the Lankeys HGL near Chinamans Gap have broad crests with waxing slopes that are generally cleared (Photo: OEH/R Muller).

Photo 4:Tree decline and waterlogging are often associated with salinity in the lower parts of the Lankeys HGL (Photo: OEH/R Muller).

Photo 5: The rolling hills and low hills within the Lankeys HGL around Yarara have broad crests with long waxing slopes (Photo: OEH/R Muller).

Photo 6: The lower landform elements of the Lankeys HGL around Yarara are gently inclined and experience seasonal waterlogging and soil sodicity (Photo: OEH/R Muller).

Photo 7: Steep hills and hills with narrow crests and ridges, moderately long waxing slopes and narrow drainage lines occur in the more elevated areas of the Lankeys HGL (Photo: OEH/R Muller).

Photo 8: Vegetated precipitous slopes of Lankeys HGL with short escarpments and colluvium derived from flanking metasediments (Photo: OEH/R Muller).

Photo 9: Establishment of plantation forestry is becoming a significant land use in the Lankeys HGL around Coppabella (Photo: OEH/A Wooldridge).

Photo 10: Moderately long waxing lower slopes of the Lankeys HGL near Yarara (Photo: OEH/A Wooldridge).

Photo 11: Native forest, plantation forestry, grazing and cropping are all practiced within the Lankeys HGL (Photo: OEH/W Cook).

Photo 12: Steep vegetated hills with narrow drainage lines and sheet erosion on lower slopes of the Lankeys HGL (Photo: OEH/W Cook).

Photo 13: Lower elements of the Lankeys HGL experience seasonal waterlogging and soil sodicity, and are susceptible to gully erosion (Photo: OEH/W Cook).

Table 4: Summary of information used to define the Lankeys HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2011)*	This HGL comprises locally metamorphosed consolidated sedimentary rocks from the Ordovician period. Unconsolidated Cenozoic sand plains and Quaternary colluvium and alluvium occur on lower slopes and in river valleys. Key lithologies include: • channel and flood plain alluvium – gravel, sand, silt and clay • colluvium and/or residual deposits – boulders, gravel and sand • sand plains – sand dominant, gravel, clay; may include some residual alluvium • Wagga Group – quartzose siltstone, sandstone, quartz-mica schist, mudstone and chert. Minor quartzite, graphitic schist and hornfels.
Annual Rainfall	800–1100 mm
Regolith and Landforms	The Lankeys HGL is slightly to moderately weathered and is characterised by decreasing relief from steep to precipitous mountains (300–600 m relief) and hills (90–300 m relief) with narrow crests and ridges, short scarps, and moderately long colluvial slopes with narrow drainage lines, and rolling low hills (30–90 m) and rises (9–30 m) with gently inclined colluvial slopes, on Ordovician metasedimentary bedrock. Slopes are typically 5–40%, occasionally steeper, local relief is 5–600 m, and this HGL is between 180–900 m elevation. Rock outcrop is rare on low hills, but locally up to 50% on steep hill crests. Regolith materials are dominantly kaolinite-bearing quartzose clayey sands with minor gravels and some sandy clays. On ridge crests and upper slopes there are some angular tabular pebble and cobble-bearing coarse sandy gravels and gravelly sands with variable kaolinitic clay content.
Soil Landscapes *(DECCW 2010)*	This HGL contains a suite of metasedimentary derived soil landscapes. In decreasing relief and slope soil landscapes range from the mountainous Abrahams Bosom through to Veteran, Livingstone, Lloyd and finally the gently inclined Four Mile Creek. Soils include: shallow, stony Leptic Tenosols (Lithosols) and Lithic and Paralithic Leptic Rudosols (Lithosols) on crests, ridges and upper slopes; shallow Red Dermosols and Red Chromosols (structured Red Earths and Red Podzolic Soils); moderately deep (50–100cm) Mesotrophic Black Kandosols (Alluvial Soils, NSG) and Brown Kurosols (Yellow Podzolic Soils) in upper drainage lines; moderately deep (0.5–1.0 m), moderately well-drained Red Chromosols and Kurosols (Red Podzolic Soils) on lower slopes; and moderately deep (0.5–1.0 m) Yellow and Grey Sodosols (Soloths) in lower drainage lines. There are areas of severe salinity at the boundary between the colluvium and alluvium which occurs predominantly in the Four mile Creek soil landscape. In areas of rolling low hills and texture contrast soils (Chromosols and Kurosols), Lloyd soil landscape, localised saline outbreaks are found at breaks of slope.

Land and Soil Capability *(OEH 2012)*	Class 5
Land Use	Mostly native forest (Jingellic and Bogandyera Nature Reserves, Woomargama State Conservation Area and Mundaroo State Forest). Some grazing on volunteer, naturalised, native or sown, improved perennial pasture
Key Land Degradation Issues	• sheet erosion and terracettes (common on cleared slopes) • rill erosion (lower slopes) • wind erosion (crests and ridgelines) • compaction from grazing contributes to hard-setting • high recharge on crests and ridges • gully erosion (drainage lines) • salinity at boundary between colluvium/alluvium • sodicity.
Native Vegetation *(Stelling 1998; Keith 2004)*	Native vegetation in Lankeys HGL is typical of high rainfall and high altitude areas. Species include *Eucalyptus bicostata* (eurabbie) in sheltered, wet areas on fertile soils, *E. pauciflora* (snow gum), *E. mannifera* (brittle gum), *E. rossii* (inland scribbly gum) and *E. goniocalyx* (long-leaf box) on ridges, shallow rocky areas, well drained alluvium or poor shallow soils on rises, typically in high rainfall areas, and *E. viminalis* (ribbon gum), *E. dives* (broad-leaved peppermint), *E. rubida* (candle bark), *E. robertsonii* (Robertson's peppermint) and *E. stellulata* (black sallee) on deeper, more fertile, loam soils. All species tend to have some degree of frost tolerance and are able to withstand periods of snow as well as cold climate. Vegetation on the lower slopes additionally may include *E. bridgesiana* (apple box) where the soils are heavy but well drained; *E. melliodora* (yellow box) on light to heavy, well drained moist soils; and *E. microcarpa* (grey box) on heavy loamy soils. Vegetation communities tend to be grassy woodlands or dry sclerophyll forests, with some wet sclerophyll forests.

HYDROGEOLOGY

Aquifers within this landscape are unconfined to semi-confined with groundwater flow occurring primarily through fractures in bedrock and saprolite. Some flow occurs through sand plains on lower slopes and alluvial sediments in flow lines. Hydraulic conductivity and transmissivity are low. Groundwater recharge rates are estimated to be moderate to high.

Groundwater systems are typically local to intermediate with short to intermediate flow lengths, and are loosely defined by topographic catchments. Water quality within these systems is fresh to marginal. Watertable depths are intermediate to deep.

Medium residence times are typical. These landscapes have a medium to fast response time to changes in land management.

Typical values for the hydrogeological parameters of this HGL are summarised in Table 5.

Table 5: Summary of values for typical hydrogeological parameters of the Lankeys HGL.

Aquifer Type	Unconfined to semi-confined in fractured rock and saprolite Lateral flow through unconsolidated colluvial and alluvial sediments on lower slopes and in flow lines
Hydraulic Conductivity	Low Range: <10^{-2} m/day
Aquifer Transmissivity	Low Range: <2 m^2/day
Specific Yield	Low to moderate Range: <5–15%
Hydraulic Gradient	Moderate to steep Range: 10–>30%
Groundwater Salinity	Fresh to marginal Range: <800–1600 µS/cm
Depth to Watertable	Intermediate to deep Range: 2–>8 m
Typical Sub-Catchment Size	Small (<100 ha)
Scale (Flow Length)	Local to intermediate Flow length: <15 km (short to intermediate)
Recharge Estimate	Moderate to high
Residence Time	Medium (years)
Responsiveness to Change	Fast to medium (months to years)

MANAGEMENT OPTIONS

Overarching salinity management strategies have specific biophysical outcomes. These are achieved by implementing a series of targeted land management actions that take into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape to impact on salinity. Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Salinity is driven by interactions between water-use capacity of vegetation, physical soil properties and hydrogeological processes within the HGL.

Actions that influence the way water is used by vegetation or stored in the soil profile will have impacts on recharge. The influence of both continual and episodic recharge and the

impacts of extreme weather events need to be considered when deciding on appropriate management actions. Short and long-term climate cycles also need to be considered as they have a bearing on salinity processes, particularly salt load and land salinity.

Landscape Salinity Functions – Lankeys HGL

Functions this landscape provides within a catchment scale salinity context:

- **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
- **G.** The landscape contains important land assets (including infrastructure and high value agricultural land) on which salinity processes impact.

Management Strategy Objectives – Lankeys HGL

Appropriate strategies pertinent to this landscape:

- **Maintain or maximise runoff (10):** This HGL contributes significant fresh water as a resource and dilution flow to the system. The fresh runoff mitigates the salt load, stream salinity and EC concentration of local streams and the greater catchment.
- **Discharge rehabilitation and management (4):** The salt sites are small in size and isolated in the lower portion of the landscape, often associated with large waterlogged areas Discharge management will improve on-site and off-site salinity outcomes when vegetation is matched to salt sites.
- **Buffer the salt store – keep it dry and immobile (1):** There are minor stores of salt in the lower landform areas, which are highly available, and which vegetation can buffer, limiting the salinity impact. They are generally in the lower colluvial elements of the landscape associated with areas of waterlogging.

Key Management Focus – Lankeys HGL

Grazing management is the key focus for this unit. This includes management of pasture systems based on perennial plants on both waterlogged areas and the wider recharging landscape. Grazing management and infrastructure should consider wet areas as sensitive to grazing.

This landscape is a net dilution salinity landscape in a catchment context. Actions should aim to minimise salinity impacts but maintain runoff from this landscape. This landscape is important as it provides fresh water within the catchment. This means careful consideration and planning need to be given to land uses which reduce runoff. Large scale revegetation with trees is not recommended on this unit.

Specific Land Management Opportunities

Specific opportunities for this HGL:

- Waterlogged and seasonally wet areas exist in parts of this HGL. These areas offer potential for pastures/grazing systems based on pastures which have waterlogging tolerance.

Specific Land Management Constraints

Constraints for land management in this HGL include:

- Seasonal waterlogging occurs during low growth periods of the year.

Specific Targeted Actions

Management areas for this HGL are illustrated in Figure 3. The specific management actions for these areas are described in Table 6.

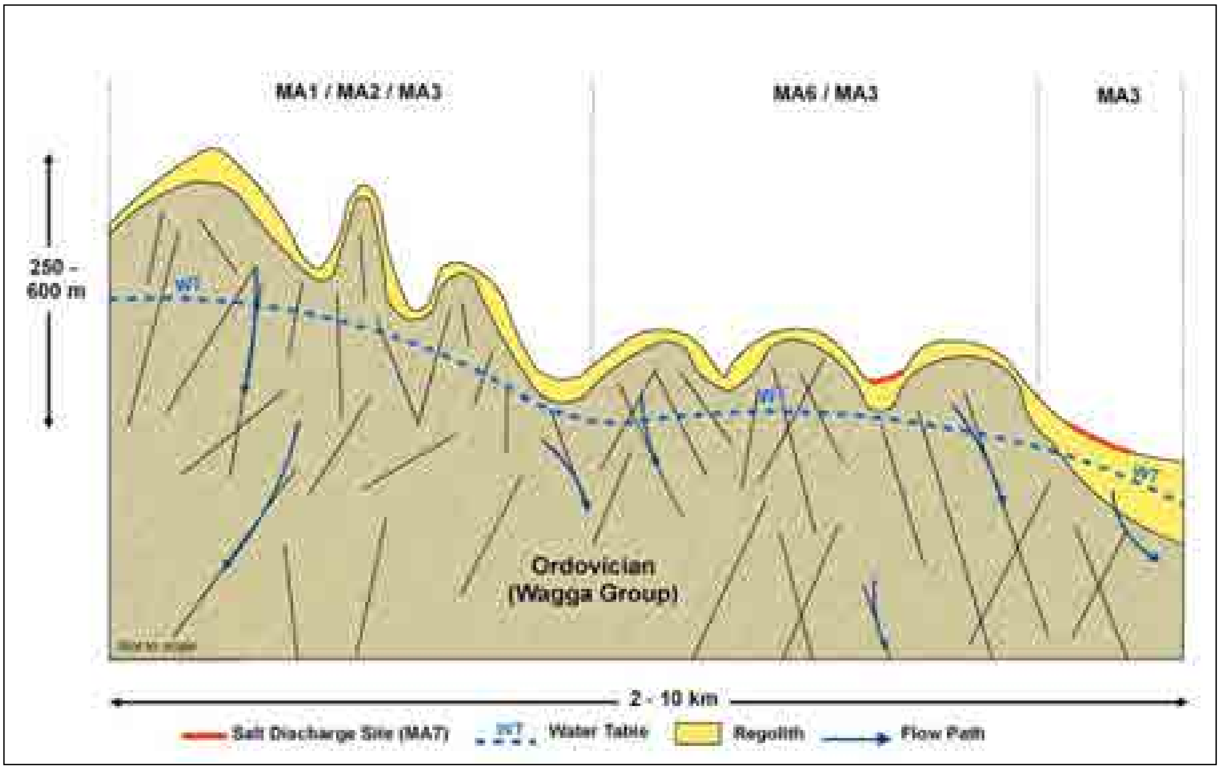


Figure 3: Management cross-section for Lankeys HGL showing defined management areas.

Table 6: Specific management actions for management areas within the Lankeys HGL.

Management Area (MA)	Action
MA1/2/3 (RIDGES & UPPER SLOPES – EROSIONAL & COLLUVIAL)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** Revegetate non-agricultural land with native species to manage recharge **(VE6).**
MA6/3 (RISES & UPPER SLOPES – COLLUVIAL)	**Vegetation for ecosystem function** Maintain and improve native woody vegetation **(VE3).** Revegetate non-agricultural land with native species to manage recharge **(VE6).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**
MA3 (UPPER SLOPES – COLLUVIAL)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**
MA7 (SALINE SITES)	**Salt land rehabilitation** Fence and isolate salt land and discharge areas to promote revegetation **(SR1).** Undertake rehabilitation to ameliorate land salinity processes and reduce land degradation **(SR4).** Reduce animal impact on scalds by providing mineral supplements to stock **(SR7).**

High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative impacts on salinity (Table 7).

Table 7: Management actions having negative salinity impacts in the Lankeys HGL.

At Risk Management Areas	Action
MA1/2/3 (RIDGES & UPPER SLOPES – EROSIONAL & COLLUVIAL)	Establish commercial forestry to manage recharge **(VP7).** Reducing runoff from fresh surface water catchments **(DLU6).**
MA6/3 (RISES & UPPER SLOPES – COLLUVIAL)	Establish commercial forestry to manage recharge **(VP7).** Reducing runoff from fresh surface water catchments **(DLU6).**

REFERENCES

DECCW, 2010, *Reconnaissance soil and land resources of the Murray CMA*, NSW Department of Environment, Climate Change and Water, Sydney

Geoscience Australia, 2011, *Australian stratigraphic units database*, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int

Keith, D. A. 2004, *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, Hurstville, NSW Department of Environment and Conservation

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, Office of Environment and Heritage, Sydney, [Accessed: 10 November 2014] http://www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

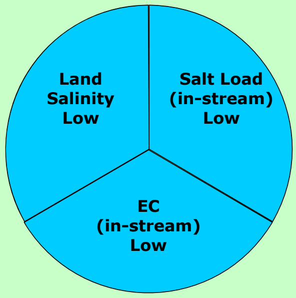
Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia

Stelling, F. 1998, *South west slopes revegetation guide (south of the Murrumbidgee River)*, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

Wooldridge, A., Nicholson, A., Muller R., Jenkins, B. R., Wilford, J. and Winkler, M. 2015, *Guidelines for managing salinity in rural areas*, NSW Office of Environment and Heritage, Sydney, NSW

26. Rosewood Hydrogeological Landscape

LOCALITIES	**Rosewood, Wolseley Park**
MAP SHEET	**Wagga Wagga 1:250 000**
CONFIDENCE LEVEL	**Medium**



OVERVIEW

The Rosewood Hydrogeological Landscape (HGL) is approximately centred on Rosewood along the northern boundary of the Murray CMA (Figure 1). The HGL covers an area of 139 km^2 and receives 900 to 1050 mm of rain per annum.

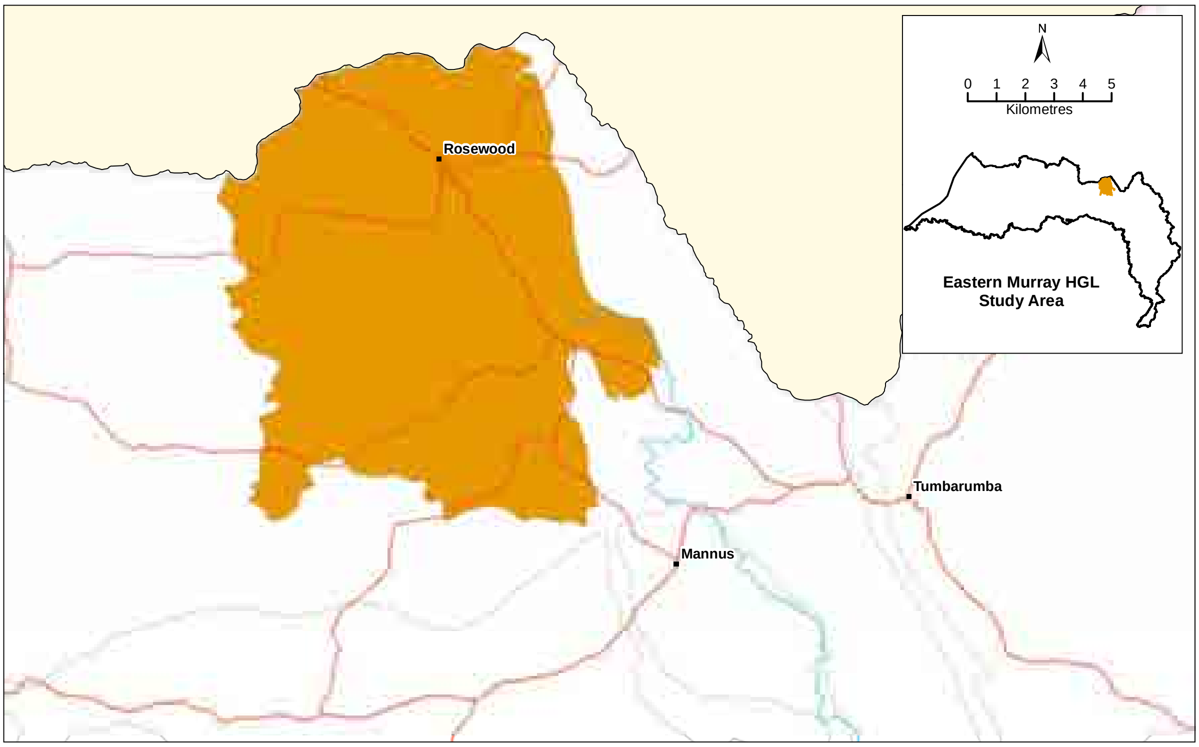


Figure 1: Rosewood HGL distribution map.

The Rosewood HGL is a residual environment characterised by gently undulating rises, long gently sloping ridges and crests, and numerous broad drainage plains (Figure 2). It features low relief, long gentle slopes and broad, often waterlogged, swampy drainage plains. This HGL comprises locally metamorphosed consolidated sedimentary rocks from the Ordovician period. Minor unconsolidated Quaternary alluvium (gravel, sand, silt and clay) occurs along river valleys. Soils are occasionally stony on crests and upper slopes; and moderately deep on lower slopes and in drainage depressions. Soils tend to be acid and seasonal waterlogging is common. Erosion is in the most part minimal providing groundcover is maintained but sheet erosion occurs more frequently on the rolling hills where cleared.

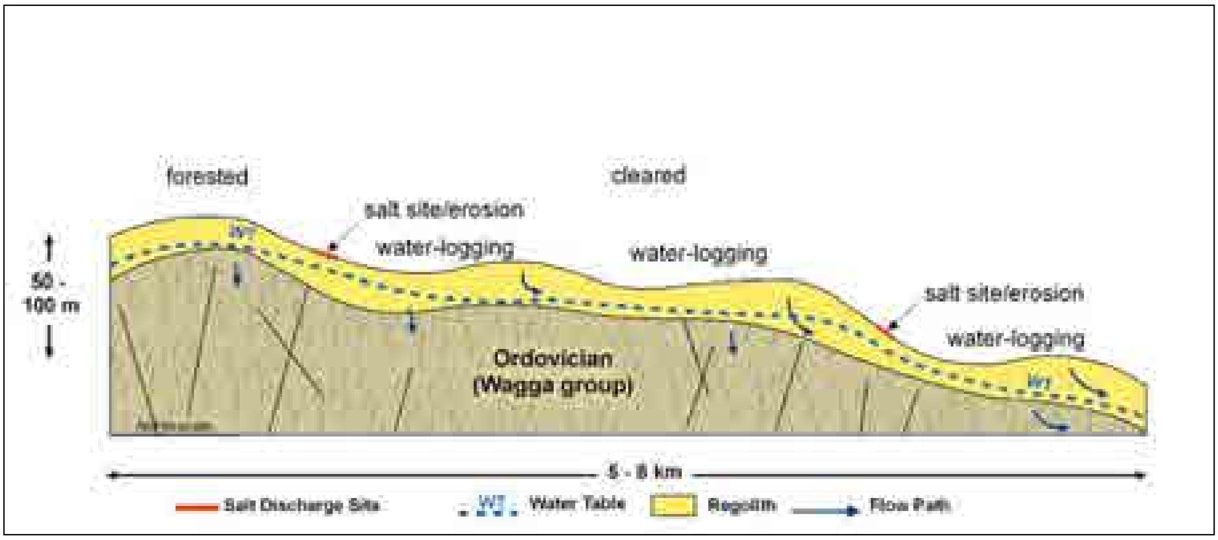


Figure 2: Conceptual cross-section for Rosewood HGL showing the distribution of regolith and landforms, salt sites if present, and flow paths of water infiltrating the system.

No land salinity or salinity indicator species have been observed but waterlogging with pin rush and tussocks is common. Some accumulation of saline material can feature in swampy depressions. Salt load and EC are low for this HGL (Table 1).

Table 1: Rosewood HGL salinity expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	Low – pin rush and tussocks are common but no salinity indicator species observed. Waterlogged areas are common in flow lines
Salt Load (Export)	Low – flow lines carry low flow and were consistently measured below 200 µS/cm
EC (Water Quality)	Low water EC was observed (measured below 200 µS/cm)

Salt stored within the Rosewood HGL has low mobility. There is a low salt store that has moderate availability (Table 2).

Table 2: Rosewood HGL salt store and availability.

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

The overall salinity hazard in the Rosewood HGL is moderate. This is due to the high likelihood that salinity issues will occur that have potentially limited impacts (Table 3).

Table 3: Likelihood of salinity occurrence, potential impact and overall hazard of salinity for the Rosewood HGL.

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

LANDSCAPE FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 4.

Photo 1: The low relief landscape of the Rosewood HGL with evidence of waterlogged areas (Photo: OEH/Andrew Wooldridge).

Photo 2:Long gentle slopes and broad drainage plains within the Rosewood HGL are susceptible to waterlogging, with tussocks being common in wet drainage lines (Photo: OEH/A Wooldridge).

Photo 3: Minor gully erosion in upper drainage lines of the Rosewood HGL. Broad and swampy drainage plain on lower slopes indicated by species change (Photo: OEH/W Cook).

Photo 4: Low relief and undulating rises are characteristic of Rosewood HGL. Species change is indicative of waterlogged areas (Photo: OEH/W Cook).

Photo 5: The broad, gently inclined slopes of the Rosewood HGL drain slowly, particularly after significant rainfall (Photo: OEH/R Muller).

Photo 6: Long gentle slopes and broad drainage plains within the Rosewood HGL are susceptible to waterlogging (Photo: OEH/R Muller).

Photo 7: Low relief landscapes in the Rosewood HGL contain numerous flow lines. Mountain swamp gums feature in swampy areas (Photo: OEH/R Muller).

Photo 8:Long, broad gentle slopes with gully erosion in drainage lines are evident in the Rosewood HGL. Species change is indicative of drainage lines (Photo: OEH/R Muller).

Photo 9: Waterlogging and seeps occur at slope changes in the Rosewood HGL, particularly following significant rainfall (Photo: OEH/R Muller).

Photo 10: The landscape has moderate relief change in the south-east of the Rosewood HGL (Photo: OEH/R Muller).

Table 4: Summary of information used to define the Rosewood HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2011)*	This HGL comprises locally metamorphosed consolidated sedimentary rocks from the Ordovician period. Minor unconsolidated Quaternary alluvium occurs along river valleys. Key lithologies include: • flood plain alluvium – gravel, sand, silt and clay • Wagga Group – quartzose siltstone, sandstone, quartz-mica schist, mudstone and chert. Minor quartzite, graphitic schist and hornfels.
Annual Rainfall	900–1050 mm
Regolith and Landforms	The Rosewood HGL is moderately weathered and is characterised by undulating rises with broad ridges and crests and numerous broad alluvial plains, formed on Ordovician metasedimentary bedrock. Slopes are typically <10%, local relief is <100 m, and this HGL is between 600–700 m elevation. Regolith materials are dominantly kaolinite-bearing quartzose clayey sands with minor gravels and some sandy clays.

Soil Landscapes *(DECCW 2010)*	Maginnitys Gap is the dominant soil landscape located within this HGL. There are minor occurrences of Lloyd, Veteran and Pulletop. Soils include: Red to Brown Dermosols (Brown Earths), Kurosols (Red and Brown Podzolic Soils) and minor stony Tenosols (Lithosols) on crests and upper slopes; moderately deep Brown and Yellow Dermosols (Structured Earths) and Kurosols (Podzolic Soils) on lower slopes and in drainage depressions. Minor degradation only. Some accumulation of saline material in swampy depressions.
Land and Soil Capability *(OEH 2012)*	Class 4
Land Use	Grazing on volunteer, naturalised, native or improved pastures, or sown, improved perennial pastures
Key Land Degradation Issues	• soil acidity • erosion.
Native Vegetation *(Stelling 1998; Keith 2004)*	Much of the native vegetation in Rosewood HGL has been cleared. Remnant native vegetation is typical of high altitude and rainfall conditions. Species include *Eucalyptus camphora* (mountain swamp gum) in open swampy flats, *E. pauciflora* (snow gum) on exposed cold sites above 700 m above sea level, *E. dives* (broad-leaved peppermint) with *E. mannifera* (brittle gum); and *E. rubida* (candle bark), *E. robertsonii* (Robertson's peppermint) and *E. stellulata* (black sallee) on deeper, more fertile, loamy soils at high altitudes. All species tend to have some degree of frost tolerance and are able to withstand periods of snow, high rainfall conditions as well as cold and wet climate. Understorey species can include *Pomaderris eriocephala, Leptospermum grandifolium, Acacia siculiformis, Cassinia aculeata, Kunzea ericoides* and *Grevillea rosmarinifolia.* The landscape tends to be an upper plateau landscape and species which are suited to fertile lower slopes are not typically present.

HYDROGEOLOGY

Aquifers within this landscape are unconfined to semi-confined with groundwater flow occurring primarily through fractures in bedrock and saprolite. Some flow occurs through colluvial and alluvial sediments on lower slopes and in flow lines. Hydraulic conductivity and transmissivity are low. Groundwater recharge rates are estimated to be moderate.

Groundwater systems are typically local with short flow lengths, and are loosely defined by topographic catchments. Water quality within these systems is fresh to marginal. Watertable depths are shallow to intermediate.

Medium to long residence times are typical. These landscapes have a medium response time to changes in land management.

Typical values for the hydrogeological parameters of this HGL are summarised in Table 5.

Table 5: Summary of values for typical hydrogeological parameters of the Rosewood HGL.

Aquifer Type	Unconfined to semi-confined in fractured rock and saprolite Lateral flow through unconsolidated colluvial and alluvial sediments on lower slopes and in flow lines
Hydraulic Conductivity	Low Range: <10^{-2} m/day
Aquifer Transmissivity	Low Range: <2 m^2/day
Specific Yield	Low Range: <5%
Hydraulic Gradient	Gentle to moderate Range: <10–30%
Groundwater Salinity	Fresh to marginal Range: <800–1600 µS/cm
Depth to Watertable	Shallow to intermediate Range: <8 m
Typical Sub-Catchment Size	Small (<100 ha)
Scale (Flow Length)	Local Flow length: <5 km (short)
Recharge Estimate	Moderate
Residence Time	Medium to long (years to decades)
Responsiveness to Change	Medium (years)

MANAGEMENT OPTIONS

Overarching salinity management strategies have specific biophysical outcomes. These are achieved by implementing a series of targeted land management actions that take into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape to impact on salinity. Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Salinity is driven by interactions between water-use capacity of vegetation, physical soil properties and hydrogeological processes within the HGL.

Actions that influence the way water is used by vegetation or stored in the soil profile will have impacts on recharge. The influence of both continual and episodic recharge and the

impacts of extreme weather events need to be considered when deciding on appropriate management actions. Short and long-term climate cycles also need to be considered as they have a bearing on salinity processes, particularly salt load and land salinity.

Landscape Salinity Functions – Rosewood HGL

Functions this landscape provides within a catchment scale salinity context:

- **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.

Management Strategy Objectives – Rosewood HGL

Appropriate strategies pertinent to this landscape:

- **Maintain or maximise runoff (10):** This HGL contributes significant amounts of fresh water runoff. The quantity and quality of the runoff water is important in the catchment salinity context. This water is important as both a source (quantity) and as a dilution flow (quality) to the catchment. The fresh runoff mitigates the salt load, stream salinity and EC concentration of the downstream landscapes.
- **Discharge rehabilitation and management (4):** Discharge sites appear as small numerous waterlogged areas. Discharge management will address the physical conditions of these areas. The effects of successful discharge management will be predominantly felt on site.

Key Management Focus – Rosewood HGL

Improved grazing management of existing perennial pastures is the major focus for this landscape. Improved grazing management particularly on discharge areas should be the focus of salinity management. Salt sites are minor, mainly waterlogged and have potential for increased pasture production. The salt sites do not exhibit high soil salinity. Grazing management should consider waterlogged areas as sensitive areas.

Specific Land Management Opportunities

Specific opportunities for this HGL:

- This landscape contains significant areas of native grass pastures. These provide an excellent base to build better management of native pastures into the future
- Improving grazing management of existing native pastures particularly on areas that are seasonally waterlogged
- Current land use is mainly grazing
- Remnant trees throughout provide good base for revegetation.

Specific Land Management Constraints

Constraints for land management in this HGL include:

- Climate conditions will restrict pasture growth – particularly in the winter with heavy frost. The climate will influence the ability of pasture systems to reduce recharge and manage discharge.

Specific Targeted Actions

Management areas for this HGL are illustrated in Figure 3. The specific management actions for these areas are described in Table 6.

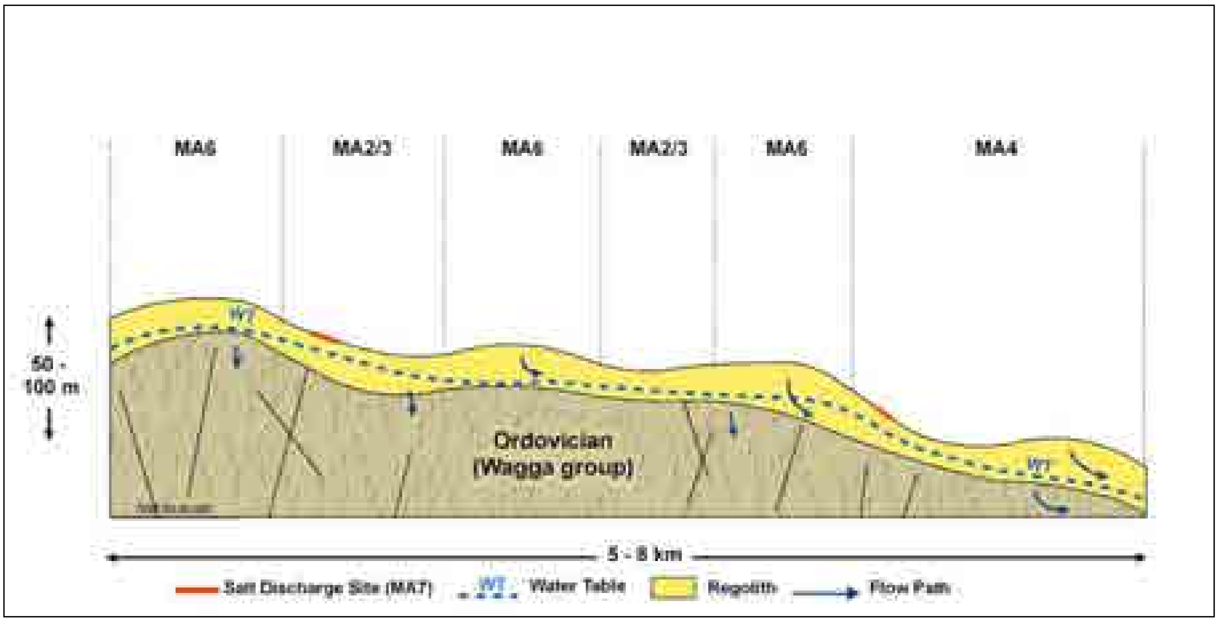


Figure 3: Management cross-section for Rosewood HGL showing defined management areas.

Table 6: Specific management actions for management areas within the Rosewood HGL.

Management Area (MA)	Action
MA6 (RISES)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).**
MA2/3 (UPPER SLOPES – EROSIONAL & COLLUVIAL)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge (**VP1).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**

Management Area (MA)	Action
MA4 (LOWER SLOEPS)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** Maintain and improve riparian native vegetation to reduce discharge to streams **(VE4).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge (**VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**

High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative impacts on salinity (Table 7).

Table 7: Management actions having negative salinity impacts in the Rosewood HGL.

At Risk Management Areas	Action
MA6 (RISES)	Annual cropping with annual plants **(DLU3).**
MA2/3 (UPPER SLOPES – EROSIONAL & COLLUVIAL)	Poor management of grazing pastures **(DLU2).** Annual cropping with annual plants **(DLU3).** Reducing runoff from fresh surface water catchments **(DLU6).**
MA4 (LOWER SLOEPS)	Poor management of grazing pastures **(DLU2).** Annual cropping with annual plants **(DLU3).** Farm dams in flow lines **(DLU5).** Reducing runoff from fresh surface water catchments **(DLU6).**

REFERENCES

DECCW, 2010, *Reconnaissance soil and land resources of the Murray CMA*, NSW Department of Environment, Climate Change and Water, Sydney

Geoscience Australia, 2011, *Australian stratigraphic units database*, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int

Keith, D. A. 2004, *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, Hurstville, NSW Department of Environment and Conservation

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, Office of Environment and Heritage, Sydney, [Accessed: 10 November 2014] www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia

Stelling, F. 1998, *South west slopes revegetation guide (south of the Murrumbidgee River)*, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

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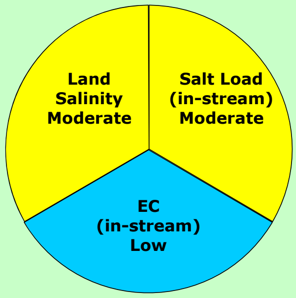
27. Mannus Hydrogeological Landscape

LOCALITIES	**Mundaroo, The Glen, Mannus**
MAP SHEET	**Wagga Wagga 1:250 000**
CONFIDENCE LEVEL	**Low**



OVERVIEW

The Mannus Hydrogeological Landscape (HGL) extends from Mannus to west of The Glenn along Jingellic Road and south towards Ournie (Figure 1). The HGL covers an area of 201 km^2 and receives 1000 to 1100 mm of rain per annum.

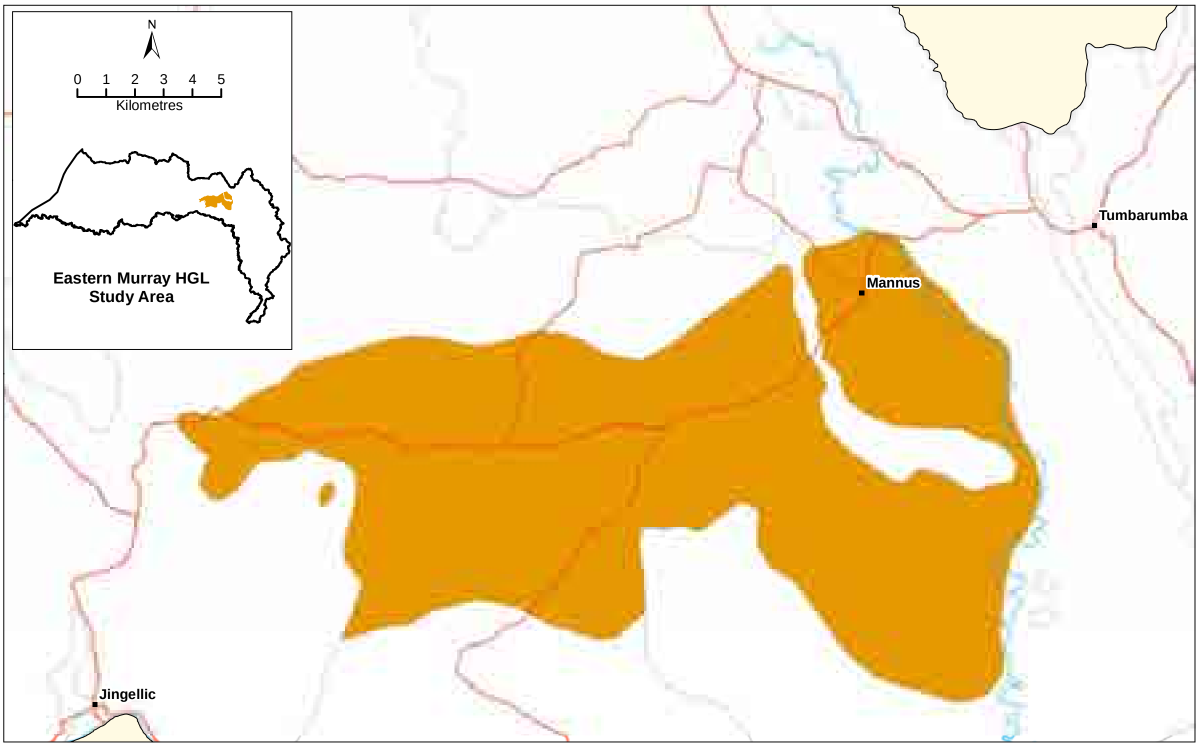


Figure 1: Mannus HGL distribution map.

Typically it features felsic granites and granodiorites.

The Mannus HGL is a residual environment characterised by undulating rises and rolling low hills with large waterlogged areas, plus erosional and colluvial elements characterised by steep hills with some tors and rock outcrop on higher slopes (Figure 2). It is characterised by waterlogging on undulating country, rolling low hills with rounded slopes and common local springs. The boundaries of Mannus HGL are steep hills with granite rock outcrops and high relief. This HGL comprises granitic rocks from the Silurian and Devonian periods and associated colluvial material. Soils are prone to erosion, especially on lower slopes and fans. Soils are shallow and sandy at rock outcrop and on rugged crests; deep on gentle crests and upper slopes. Sodic subsoils contribute to localised gully and some minor mass movement.

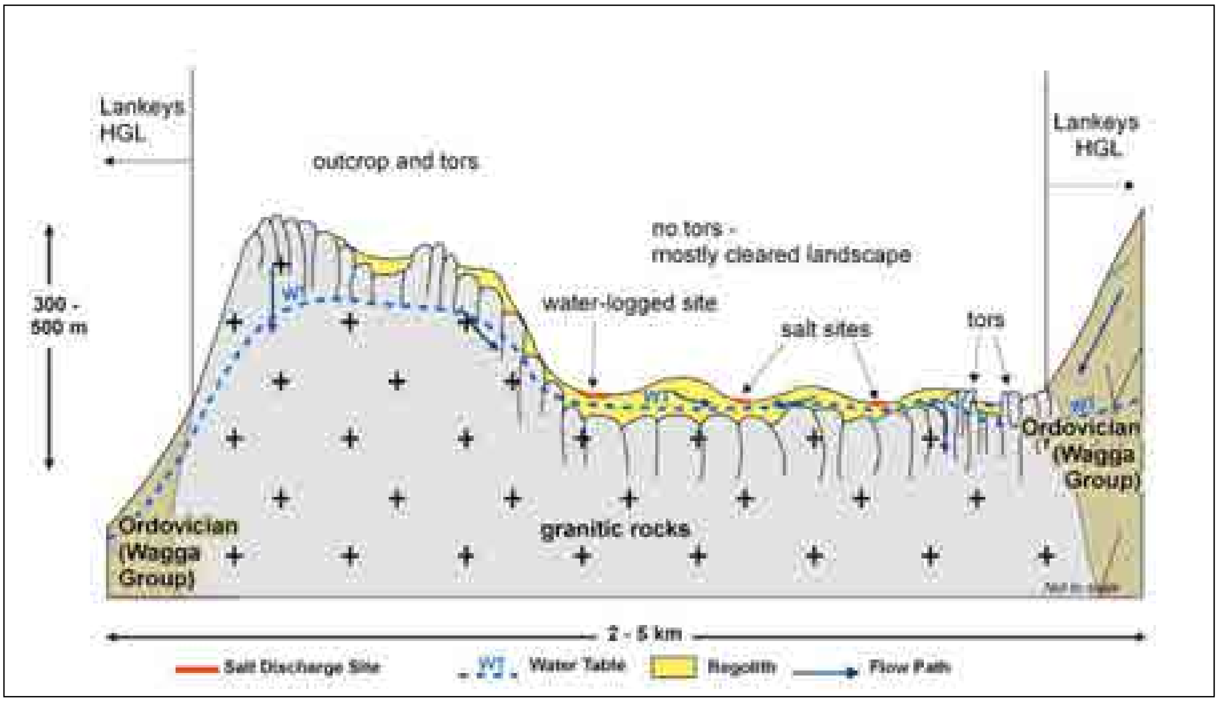


Figure 2: Conceptual cross-section for Mannus HGL showing the distribution of regolith and landforms, salt sites if present, and flow paths of water infiltrating the system.

Outbreaks of land salinity are small and minor in relation to large areas of waterlogging. Salt load is moderate and EC is low (Table 1).

Table 1: Mannus HGL salinity expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	Moderate – some small salt sites observed; large areas of waterlogging also present
Salt Load (Export)	Moderate – through flow and shallow ground water export consistent salt loads into surrounding units
EC (Water Quality)	Low water EC observed during study

Salt stored within the Mannus HGL has low mobility. There is a low salt store that has moderate availability (Table 2).

Table 2: Mannus HGL salt store and availability.

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

The overall salinity hazard in the Mannus HGL is moderate. This is due to the high likelihood that salinity issues will occur that have potentially limited impacts (Table 3).

Table 3: Likelihood of salinity occurrence, potential impact and overall hazard of salinity for the Mannus HGL.

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

LANDSCAPE FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 4.

Photo 1: The central areas of the Mannus HGL have broad undulating plains that fall away to the south (Photo: OEH/R Muller).

Photo 2: Hills within the central parts of the Mannus HGL have broad crests with occasional low outcrop and long, undulating slopes (Photo: OEH/R Muller).

Photo 3: The slopes in the central parts of the Mannus HGL are long and undulating running down to undulating plains (Photo: OEH/R Muller).

Photo 4: Sodic soils can lead to minor gully erosion or mass movement on low hills in the Mannus HGL (Photo: OEH/A Wooldridge).

Photo 5: Rock in the upper landscape of Mannus HGL is often exposed along drainage lines (Photo: OEH/W Cook).

Photo 6: Wide waterlogged drainage channel within the rolling country of Mannus HGL. The high tree covered hill in the background is Lankeys HGL (Photo: OEH/W Cook).

Table 4: Summary of information used to define the Mannus HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2011)*	This HGL comprises granitic rocks from the Silurian and Devonian periods and associated colluvial material. The key lithologies include: • Munderoo Granodiorite – felsic, unfractionated granite • Bogandyera Granite – felsic, unfractionated granite • Prison Farm Granodiorite – felsic, unfractionated granite • Green Hills Granodiorite – medium to coarse-grained biotite granodiorite, fine to medium-grained biotite-muscovite granodiorite/granite; biotite granodiorite and tonalite commonly containing cordierite, common metasedimentary xenoliths.
Annual Rainfall	1000–1100 mm
Regolith and Landforms	The Mannus HGL is slightly to moderately weathered and is characterised by steep mountains (300–500 m relief) and hills (90–300 m relief) with rounded crests and steep colluvial slopes, to rolling low hills (30–90 m relief) and undulating rises (20–30 m relief) with flat crests, moderate colluvial slopes and narrow drainage lines, on Siluro-Devonian granitic bedrock. Slopes are typically 3–50%, local relief is 20–500 m. This HGL is between 300–1200 m elevation. This HGL features rock outcrops as tors, clusters of tors and rock bars on crests and upper slopes of mountains and hills and as isolated tors or clusters of boulders on crests and upper slopes of the low hills and rises. Locally there are springs on the mid and lower colluvial slopes. Regolith materials are dominantly quartzose clayey sands with minor gravels and some sandy clays. On ridge crests and upper slopes there are some angular pebble and cobble-bearing coarse sandy gravels and gravelly sands.
Soil Landscapes *(DECCW 2010*	This HGL contains a suite of soil landscapes on granitic rocks. They are distinguished by relief and slope. Pilot Hill soil landscape occupies steep hills, Rippling Water rolling hills and low hills, Nacki Nacki rises and Munderoo gently undulating rises and floodplain. Soils include: shallow sandy Rudosols and Tenosols (Siliceous Sands, Earthy Sands) associated with rock outcrop and rugged crests; deep Red Chromosols (Red Podzolic Soils/Structured Red Earths) occur on gentle crests and upper slopes; Yellow Kandosols (Yellow Earths) and Red Kurosols (Red Earths and Red Podzolic Soils) on mid-slopes; Natric Kurosols and Sodosols (Soloths) and Yellow Kandosols (Yellow Earths) on lower slopes and drainage lines; and, Grey Sodosols (Soloths) in positions of restricted drainage on lower slopes and in drainage lines. Localised gully erosion, with some minor mass movement. Soils are prone to erosion, especially on lower slopes and fans.
Land and Soil Capability *(OEH 2012)*	Class 6

Land Use	Grazing on naturalised or improved pasture is the dominant land use. Native forest on the slopes also occurs within Bogandyera Nature Reserve and State Forest
Key Land Degradation Issues	• sheet erosion (steep slopes if soil is disturbed) • sodic subsoils (lower slopes) • gully erosion (localised).
Native Vegetation *(Stelling 1998; Keith 2004)*	Native vegetation in Mannus HGL is typical of high rainfall and high altitude areas. Species include *Eucalyptus camphora* (mountain swamp gum) and Mountain Swamp Gum Forest and other moist open forest types are typical. Other dominant tree species include *E. pauciflora* (snow gum) and *E. mannifera* (brittle gum) on ridges, shallow rocky areas, well drained alluvium or poor shallow soils on rises, typically of high rainfall areas, and *E. robertsonii* (Robertson's peppermint) and *E. stellulata* (black sallee) on deeper, more fertile, loamy soils. Vegetation on the lower slopes additionally may include *E. bridgesiana* (apple box) where the soils are heavy but well drained. Understorey species can include *Lomatia myricoides* and *Hakea microcarpa.*

HYDROGEOLOGY

Aquifers within this landscape are unconfined with groundwater flow occurring primarily through fractures in bedrock and saprolite. Some flow occurs through colluvial and alluvial sediments on lower slopes and along flow lines. Hydraulic conductivity is low to moderate and transmissivity is low. Groundwater recharge rates are estimated to be moderate to high.

Groundwater systems are typically local with short flow lengths and are loosely defined by topographic catchments. Water quality within these systems is fresh. Watertable depths are intermediate.

Short to medium residence times are typical. These landscapes have a medium to fast response time to changes in land management.

Typical values for the hydrogeological parameters of this HGL are summarised in Table 5.

Table 5: Summary of values for typical hydrogeological parameters of the Mannus HGL.

Aquifer Type	Unconfined in fractured rock and saprolite Lateral flow through unconsolidated colluvial and alluvial sediments on lower slopes and in flow lines
Hydraulic Conductivity	Low to moderate Range: <10^{-2}–10 m/day
Aquifer Transmissivity	Low Range: <2 m^2/day
Specific Yield	Low to moderate Range: <5–15%

Hydraulic Gradient	Gentle to moderate Range: <10–30%
Groundwater Salinity	Fresh Range: <800 µS/cm
Depth to Watertable	Intermediate Range: 2–8 m
Typical Sub-Catchment Size	Small (<100 ha)
Scale (Flow Length)	Local Flow length: <5 km (short)
Recharge Estimate	Moderate to high
Residence Time	Short to medium (months to years)
Responsiveness to Change	Fast to medium (months to years)

MANAGEMENT OPTIONS

Overarching salinity management strategies have specific biophysical outcomes. These are achieved by implementing a series of targeted land management actions that take into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape to impact on salinity. Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Salinity is driven by interactions between water-use capacity of vegetation, physical soil properties and hydrogeological processes within the HGL.

Actions that influence the way water is used by vegetation or stored in the soil profile will have impacts on recharge. The influence of both continual and episodic recharge and the impacts of extreme weather events need to be considered when deciding on appropriate management actions. Short and long-term climate cycles also need to be considered as they have a bearing on salinity processes, particularly salt load and land salinity.

Landscape Salinity Functions – Mannus HGL

Functions this landscape provides within a catchment scale salinity context:

- **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.
- **G.** The landscape contains important land assets (including infrastructure and high value agricultural land) on which salinity processes impact.

Management Strategy Objectives – Mannus HGL

Appropriate strategies pertinent to this landscape:

- **Maintain or maximise runoff (10):** This HGL contributes significant fresh water as a resource and dilution flow to the system. The fresh runoff mitigates the salt load, stream salinity and EC concentration of the local streams.
- **Discharge rehabilitation and management (4):** The saline and waterlogged sites are small in size but waterlogged areas can be large. Discharge management will reduce salt discharge to streams when vegetation is matched to salt sites.
- **Buffer the salt store – keep it dry and immobile (1):** There are minor stores of salt in the lower landform areas, which are moderately available, and which vegetation can buffer, limiting the salinity impact. They are generally in the lower colluvial elements of the landscape associated with areas of waterlogging.

Key Management Focus – Mannus HGL

Grazing management is the key focus for this HGL. This includes management of pasture systems based on perennial plants on both discharge areas and the wider recharging landscape. Grazing infrastructure and management should consider saline and sodic sites as sensitive areas.

Specific Land Management Opportunities

Specific opportunities for this HGL:

- Currently this is mainly a grazing landscape. Continuing and improving grazing management of existing native pastures is an opportunity, particularly on areas which are seasonally waterlogged
- This landscape contains significant areas of native grass pastures. These provide an excellent base to build better management of native pastures into the future.

Specific Land Management Constraints

Constraints for land management in this HGL include:

- Shallow soils, particularly on the upper erosional landscape elements where rock outcrop occurs
- Climate conditions will restrict pasture growth – particularly in the winter
- Management change will impact on the amount of fresh water runoff from this fresh water source.

Specific Targeted Actions

Management areas for this HGL are illustrated in Figure 3. The specific management actions for these areas are described in Table 6.

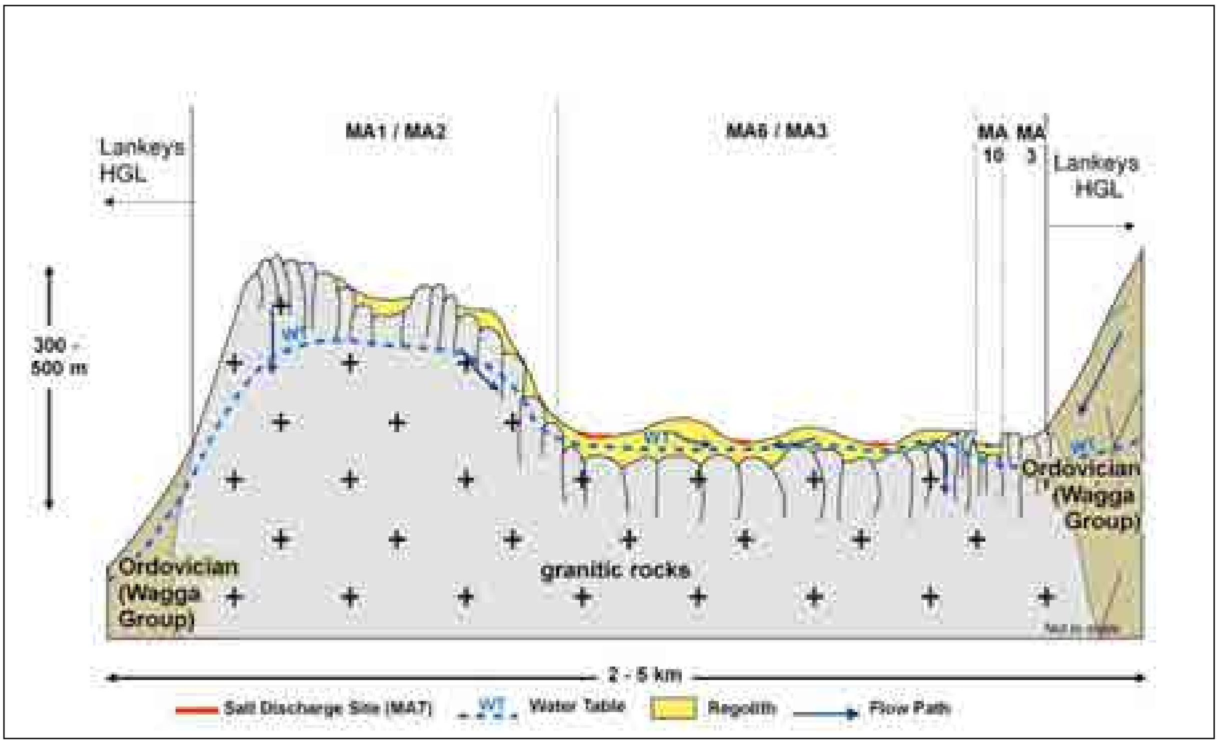


Figure 3: Management cross-section for Mannus HGL showing defined management areas.

Table 6: Specific management actions for management areas within the Mannus HGL.

Management Area (MA)	Action
MA1/2 (RIDGES & UPPER SLOPES – EROSIONAL)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).**
MA6/3 (RISES & UPPER SLOPES – COLLUVIAL)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**
MA3 (UPPER SLOPES – COLLUVIAL)	**Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**

Management Area (MA)	Action
MA10 (ALLUVIAL CHANNEL)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** Maintain and improve riparian native vegetation to reduce discharge to streams **(VE4).**
MA7 (SALINE SITES)	**Salt land rehabilitation** Fence and isolate salt land and discharge areas to promote revegetation **(SR1).** Reduce animal impact on scalds by providing mineral supplements to stock **(SR7).** Mulch sites using tactical animal impact **(SR9).**

High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative impacts on salinity (Table 7).

Table 7: Management actions having negative salinity impacts in the Mannus HGL.

At Risk Management Areas	Action
MA1/2 (RIDGES & UPPER SLOPES – EROSIONAL)	Clearing and poor management of native vegetation **(DLU4).** Reducing runoff from fresh surface water catchments **(DLU6).**
MA6/3 (RISES & UPPER SLOPES – COLLUVIAL)	Annual cropping with annual plants **(DLU3).** Clearing and poor management of native vegetation **(DLU4).** Farm dams in flow lines **(DLU5).** Reducing runoff from fresh surface water catchments **(DLU6).**
MA10 (ALLUVIAL CHANNEL)	Clearing and poor management of native vegetation **(DLU4).** Farm dams in flow lines **(DLU5).**

REFERENCES

DECCW, 2010, *Reconnaissance soil and land resources of the Murray CMA*, NSW Department of Environment, Climate Change and Water, Sydney

Geoscience Australia, 2011, *Australian stratigraphic units database*, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int

Keith, D. A. 2004, *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, Hurstville, NSW Department of Environment and Conservation

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, Office of Environment and Heritage, Sydney, [Accessed: 10 November 2014] www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

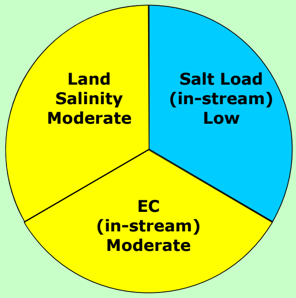
Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia

Stelling, F. 1998, *South west slopes revegetation guide (south of the Murrumbidgee River)*, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

Wooldridge, A., Nicholson, A., Muller R., Jenkins, B. R., Wilford, J. and Winkler, M. 2015, *Guidelines for managing salinity in rural areas*, NSW Office of Environment and Heritage, Sydney, NSW

28. Ournie Hydrogeological Landscape

LOCALITIES	**Ournie, Mount Welaregang**
MAP SHEET	**Tallangatta 1:250 000** **Wagga Wagga 1:250 000**
CONFIDENCE LEVEL	**Low**



OVERVIEW

The Ournie Hydrogeological Landscape (HGL) is centred on Ournie on the southern boundary of the Murray CMA near the Murray River (Figure 1). The HGL covers an area of 124 km^2 and receives 700 to 1000 mm of rain per annum.

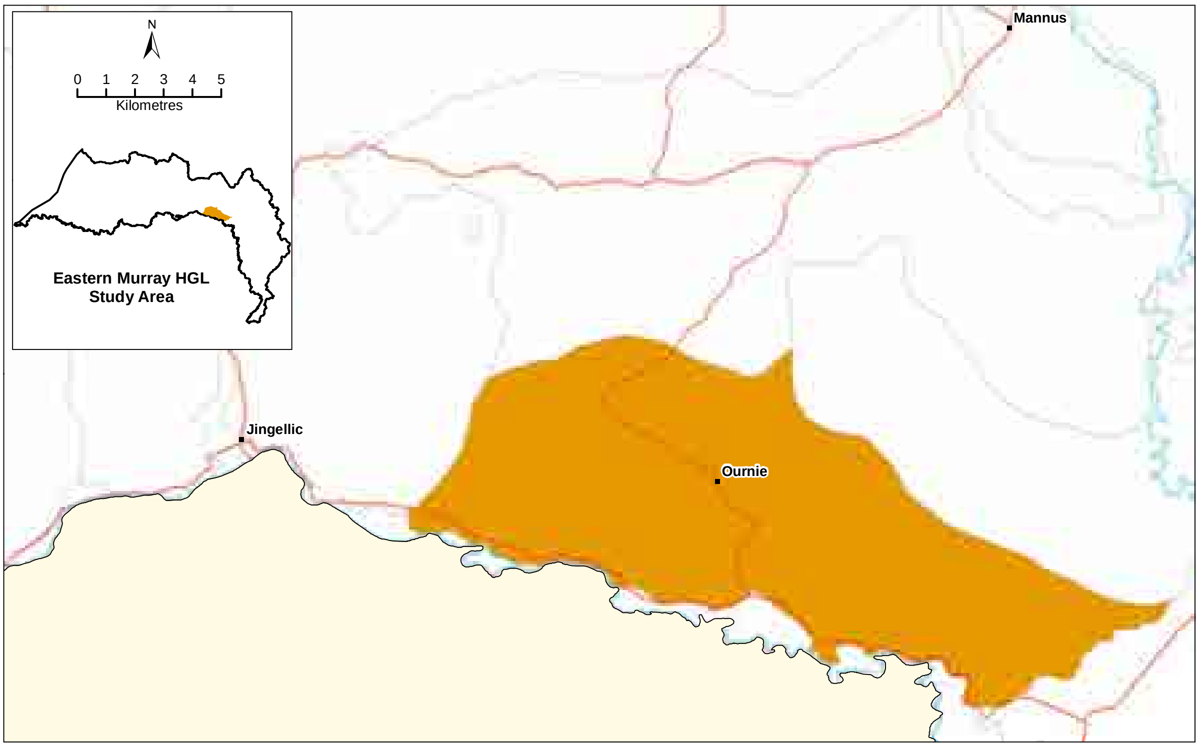


Figure 1: Ournie HGL distribution map.

The Ournie HGL is an erosional and colluvial environment characterised by frequent rock outcrop on steep to precipitous rocky hills and mountains covered with native vegetation, plus gently rolling to rolling low hills which are often cleared. The lower colluvial and transferral landscape features gently rolling hills and low hills (Figure 2). This HGL comprises granitic rocks from the Silurian period and associated colluvial material. The soils are commonly shallow, sandy and have weakly structured B horizons. There is evidence of serious land degradation including gullies up to 5 m deep, active stream bank erosion and sheet and rill erosion. Terracetting is common on cleared slopes.

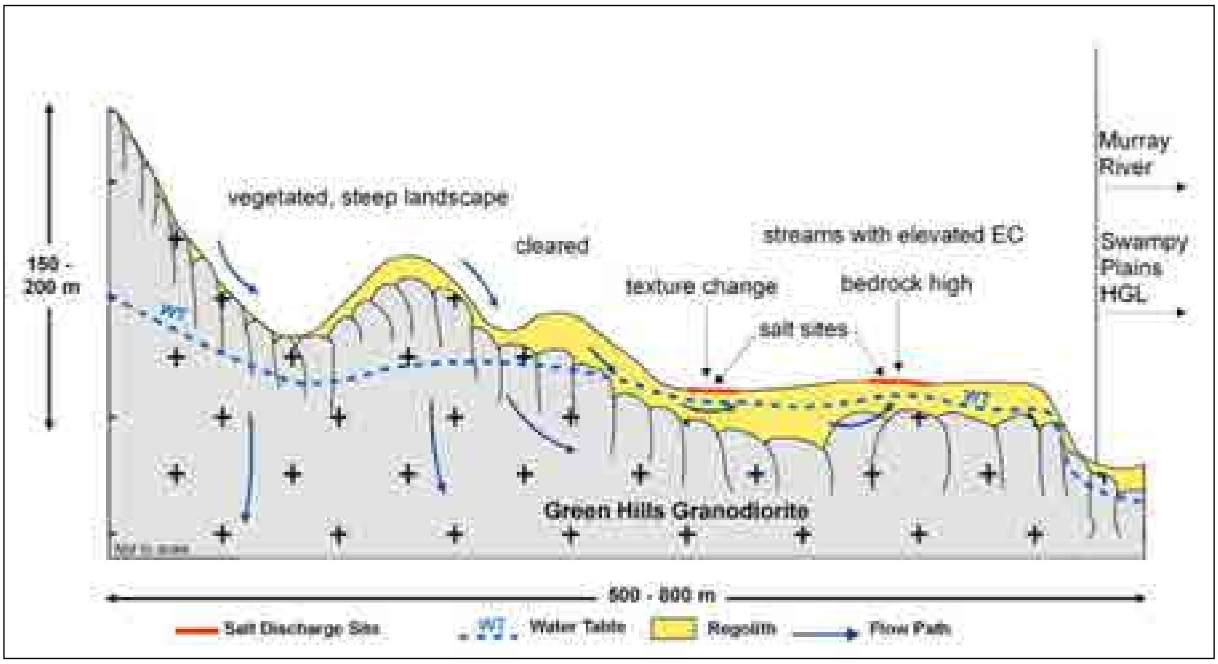


Figure 2: Conceptual cross-section for Ournie HGL showing the distribution of regolith and landforms, salt sites if present, and flow paths of water infiltrating the system.

Outbreaks of land salinity are uncommon but minor salt symptoms have been observed at locations where soil texture changes. Salt load is low and EC is moderate (Table 1).

Table 1: Ournie HGL salinity expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	Moderate – sites observed with minor salt symptoms observed at texture changes
Salt Load (Export)	Low
EC (Water Quality)	Moderate – spikes of EC up to 1700 µS/cm observed during study

Salt stored within the Ournie HGL has low mobility. There is a low salt store that has moderate availability (Table 2).

Table 2: Ournie HGL salt store and availability.

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

The overall salinity hazard in the Ournie HGL is moderate. This is due to the high likelihood that salinity issues will occur that have potentially limited impacts (Table 3).

Table 3: Likelihood of salinity occurrence, potential impact and overall hazard of salinity for the Ournie HGL.

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

LANDSCAPE FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 4.

Photo 1: Adjacent to the Murray River near Jingellic, the Ournie HGL is characterised by rolling hills with tors outcropping (Photo: OEH/R Muller).

Photo 2: Terracetting can occur on the steeper slopes that are cleared such as north of River Road near Ournie (Photo: OEH/A Nicholson).

Photo 3: Elements of the northern part of the Ournie HGL are quite mountainous (Photo: OEH/A Nicholson).

Photo 4: The Ournie HGL landscape with vegetated rocky erosional granite hills and rolling lower colluvial foot-slopes (Photo: OEH/A Nicholson).

Photo 5: Characteristic Ournie HGL landscape with vegetated rocky erosional hills and rolling lower colluvial slopes (Photo: OEH/A Nicholson).

Photo 6: Steep rocky hills with tors and rock outcrop on slopes of the south-east part of Ournie HGL (Photo: OEH/R Muller).

Photo 7: Mt Welaregang is typical of the steeper component of the Ournie HGL. Swampy Plains HGL is in foreground (Photo: OEH/R Muller).

Table 4: Summary of information used to define the Ournie HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2011)*	This HGL comprises granitic rocks from the Silurian period and associated colluvial material. The key lithology is: • Green Hills Granodiorite – Medium to coarse-grained biotite granodiorite, fine to medium-grained biotite-muscovite granodiorite/granite; biotite granodiorite and tonalite commonly containing cordierite, common metasedimentary xenoliths.
Annual Rainfall	700–1000 mm
Regolith and Landforms	The Ournie HGL is variably weathered and is characterised by steep to precipitous, rocky hills (90–200 m relief) with rocky crests and upper slopes, and rolling hills (90 m+ relief) and low hills (30–90m relief) with flat crests and moderate colluvial slopes, on Silurian granitic bedrock. Slopes are typically >30%, local relief 30–200 m, and this HGL is between 200–1000m elevation. The HGL features rock outcrop on crests and upper slopes as rock bars, scarps and tors on higher elements and as isolated tors or clusters of boulders on crests and upper slopes of the rolling hills and low hills. Soil creep is common on cleared colluvial slopes, and narrow drainage lines incise to bedrock. Regolith materials are dominantly quartzose clayey sands with minor gravels and some sandy clays. On ridge crests and upper slopes there are some angular pebble and cobble-bearing coarse sandy gravels and gravelly sands.

Soil Landscapes *(DECCW 2010)*	This HGL contains a suite of soil landscapes on granitic rock. They are distinguished by relief and slope. Tipperary soil landscape occupies steep hills and mountains, Rippling Water rolling hills and low hills, Welaregang foot-slopes and fans. There are minor areas of Nacki Nacki on rises. Soils include: shallow, sandy, discontinuous Tenosols and Rudosols (Lithosols, Siliceous Sands and Earthy Sands) typically with little subsoil development on crests and near rock outcrop; Yellow Kandosols (Yellow Earths) and Red Kurosols (Red Earths and Red Podzolic Soils) on mid slopes; Natric Kurosols and Sodosols (Soloths) and Yellow Kandosols (Yellow Earths) on lower slopes and drainage lines; and, Red and Brown Chromosols (Red and Brown Podzolic Soils) on foot-slopes. There is evidence of serious land degradation including gullies up to 5 m deep, active stream bank erosion and sheet and rill erosion.
Land and Soil Capability *(OEH 2012)*	Class 7
Land Use	Dominant land use is grazing on volunteer, naturalised, native or improved pastures. Edges of the HGL are within Bogandyera Nature Reserve.
Key Land Degradation Issues	• gully erosion (localised) • some minor mass movement • erosion (upper slopes if disturbed, lower slopes and fans) • terracettes (soil creep) (common in disturbed areas) • sheet erosion (common in disturbed areas) • sheet and rill erosion if cropped.
Native Vegetation *(Stelling 1998; Keith 2004)*	Native vegetation in the Ournie HGL includes species typical of lower slopes and fertile soils or alluvial soils which can be classified in river red gum woodlands, red box and Blakely's red gum woodlands and sclerophyll forests. Species include *Eucalyptus melliodora* (yellow box) on sandy soils or alluvium where soils are most, light to heavy and well-drained; *E. blakelyi* (Blakely's red gum), *E. polyanthemos* (red stringybark) and *E. camaldulensis* (river red gun) on lower landform elements and floodplains, and *E. dives* (broad-leaved peppermint) on south-south-east facing slopes and *E. nortonii* (silver bundy) on north-north-west facing slopes. Some *E. viminalis* (manna gum), *E. rubida* (candle bark), and the Kurrajong tree *Brachychiton populneus* are also present in Ournie HGL.

HYDROGEOLOGY

Aquifers within this landscape are unconfined with groundwater flow occurring primarily through fractures in bedrock and saprolite. Some flow occurs through colluvial and alluvial sediments on lower slopes and along flow lines. Hydraulic conductivity and transmissivity are low to moderate. Groundwater recharge rates are estimated to be moderate.

Groundwater systems are typically local with short flow lengths and are loosely defined by topographic catchments. Water quality within these systems is fresh. Watertable depths are deep.

Short to medium residence times are typical. These landscapes have a medium to fast response time to changes in land management.

Typical values for the hydrogeological parameters of this HGL are summarised in Table 5.

Table 5: Summary of values for typical hydrogeological parameters of the Ournie HGL.

Aquifer Type	Unconfined in fractured rock and saprolite Lateral flow through unconsolidated colluvial and alluvial sediments on lower slopes and in flow lines
Hydraulic Conductivity	Low to moderate Range: <10^{-2}–10 m/day
Aquifer Transmissivity	Low to moderate Range: <2–50 m^2/day
Specific Yield	Low to moderate Range: <5–15%
Hydraulic Gradient	Moderate to steep Range: 10–>30%
Groundwater Salinity	Fresh Range: <800 µS/cm
Depth to Watertable	Deep Range: >8 m
Typical Sub-Catchment Size	Small (<100 ha)
Scale (Flow Length)	Local Flow length: <5 km (short)
Recharge Estimate	Moderate
Residence Time	Short to medium (months to years)
Responsiveness to Change	Fast to medium (months to years)

MANAGEMENT OPTIONS

Overarching salinity management strategies have specific biophysical outcomes. These are achieved by implementing a series of targeted land management actions that take into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape to impact on salinity. Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Salinity is driven by interactions between water-use capacity of vegetation, physical soil properties and hydrogeological processes within the HGL.

Actions that influence the way water is used by vegetation or stored in the soil profile will have impacts on recharge. The influence of both continual and episodic recharge and the impacts of extreme weather events need to be considered when deciding on appropriate management actions. Short and long-term climate cycles also need to be considered as they have a bearing on salinity processes, particularly salt load and land salinity.

Landscape Salinity Functions – Ournie HGL

Functions this landscape provides within a catchment scale salinity context:

- **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.

Management Strategy Objectives – Ournie HGL

Appropriate overall strategies pertinent to this landscape:

- **Maintain or maximise runoff (10):** The landscape receives high amounts of rainfall and generates significant fresh water runoff as a dilution flow to the system. The fresh runoff mitigates the salt load in the local streams and the broader catchment.
- **Discharge rehabilitation and management (4):** The salt sites are small in size and uncommon, but observed to coincide with soil texture changes. Discharge management targeted in appropriate landscape locations will reduce salt discharge to streams.

Key Management Focus – Ournie HGL

This landscape provides high volumes of water and is a net dilution landscape. Management of current and future land use should consider the impacts of action on water runoff. Salt site management is also important in areas where salt sites are observed

Specific Land Management Opportunities

Specific opportunities for this HGL:

- There are significant areas of remnant vegetation left in this landscape to act as a seed source and basis for remnant vegetation management and biodiversity conservation.
- This landscape contains significant areas of native grass pastures. These provide an excellent base to build better management of native pastures into the future.

Specific Land Management Constraints

Constraints for land management in this HGL include:

- This landscape is generally steep to precipitous with frequent rock outcrop with high potential for erosion when cleared
- While the overall load of salinity exported in streams is low, occasional spikes of high EC water can occur.

Specific Targeted Actions

Management areas for this HGL are illustrated in Figure 3. The specific management actions for these areas are described in Table 6.

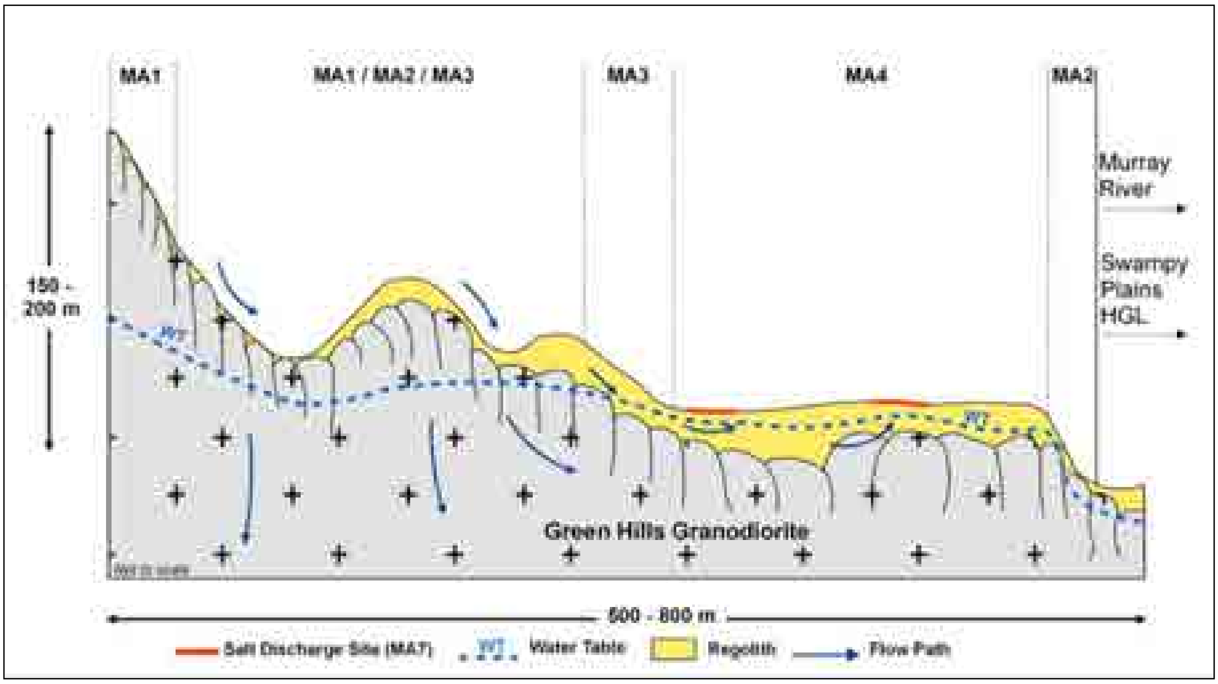


Figure 3: Management cross-section for Ournie HGL showing defined management areas.

Table 6: Specific management actions for management areas within the Ournie HGL.

Management Area (MA)	Action
MA1/2/3 & MA2 (RIDGES & UPPER SLOPES – EROSIONAL & COLLUVIAL) AND (UPPER SLOPES – EROSIONAL)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).**
MA3 (UPPER SLOPES – COLLUVIAL)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**
MA4 (MID-SLOPES)	**Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**
MA7 (SALINE SITES)	**Salt land rehabilitation** Fence and isolate salt land and discharge areas to promote revegetation **(SR1).** Establish and manage salt land pasture systems to improve productivity **(SR2).** Mulch sites to reduce evaporation and promote pasture growth **(SR8).**

High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative impacts on salinity (Table 7).

Table 7: Management actions having negative salinity impacts in the Ournie HGL.

At Risk Management Areas	Action
MA1/2/3 & MA2 (RIDGES & UPPER SLOPES – EROSIONAL & COLLUVIAL) AND (UPPER SLOPES – EROSIONAL)	Clearing and poor management of native vegetation **(DLU4).** Reducing runoff from fresh surface water catchments **(DLU6).**
MA3 & MA4 (UPPER SLOPES – COLLUVIAL) AND (MID – SLOPES)	Poor management of grazing pastures **(DLU2).** Clearing and poor management of native vegetation **(DLU4).** Reducing runoff from fresh surface water catchments **(DLU6).**
MA7 (SALINE SITES)	Poor soil management – loss of surface soil layers **(DLU10).**

REFERENCES

DECCW, 2010, *Reconnaissance soil and land resources of the Murray CMA*, NSW Department of Environment, Climate Change and Water, Sydney

Geoscience Australia, 2011, *Australian stratigraphic units database*, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int

Keith, D. A. 2004, *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, Hurstville, NSW Department of Environment and Conservation

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, Office of Environment and Heritage, Sydney, [Accessed: 10 November 2014] www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

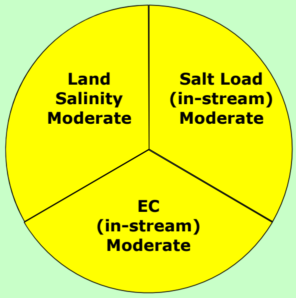
Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia

Stelling, F. 1998, *South west slopes revegetation guide (south of the Murrumbidgee River)*, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

Wooldridge, A., Nicholson, A., Muller R., Jenkins, B. R., Wilford, J. and Winkler, M. 2015, *Guidelines for managing salinity in rural areas*, NSW Office of Environment and Heritage, Sydney, NSW

29. Welaregang Hydrogeological Landscape

LOCALITIES	**Welaregang, Warbrook, Pipeclay Hill**
MAP SHEET	**Tallangatta 1:250 000** **Wagga Wagga 1:250 000**
CONFIDENCE LEVEL	**Low**



OVERVIEW

The Welaregang Hydrogeological Landscape (HGL) extends from Welaregang to Warbrook along River and Tintaldra Roads beside the Murray River, and north to Tooma (Figure 1). The HGL covers an area of 102 km^2 and receives 700 to 850 mm of rain per annum. Extensive clearing is a major feature of the landscape.

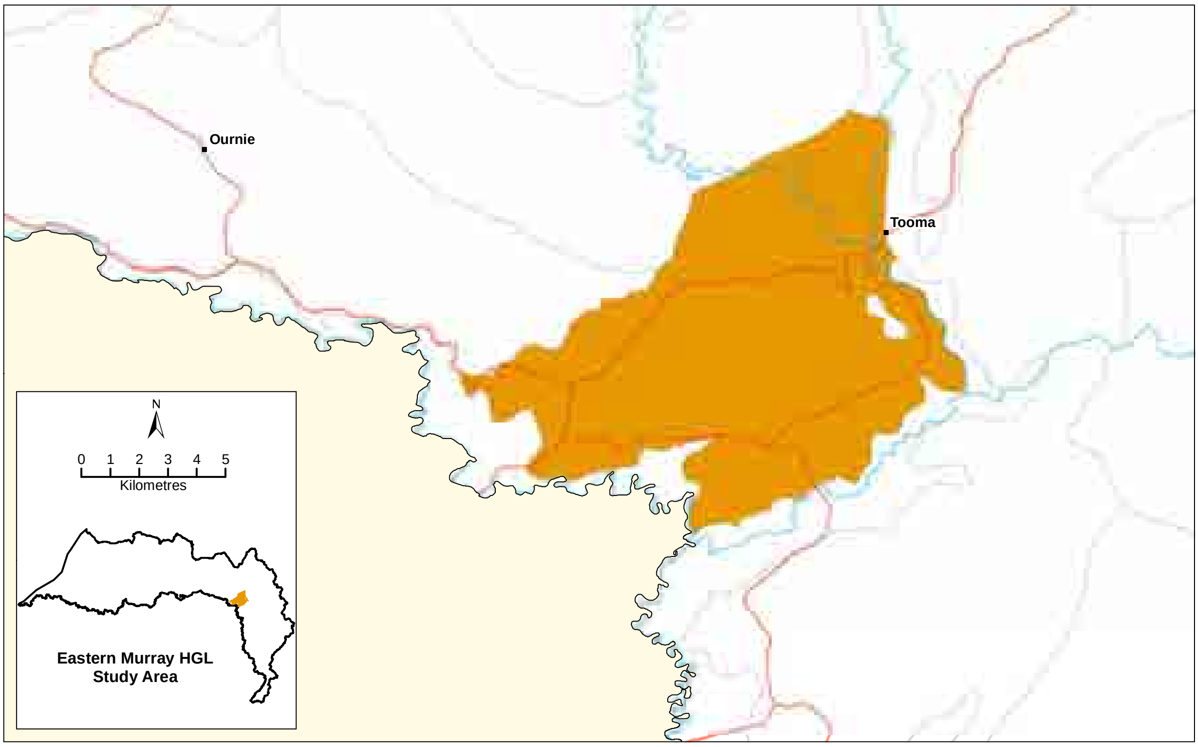


Figure 1: Welaregang HGL distribution map.

The Welaregang HGL is an erosional environment characterised by moderately weathered granodiorite forming low hills and hills with rounded crests. Transferral environments occur on the lower landform elements (Figure 2). This HGL comprises granitic rocks from the Silurian period and associated colluvial material. Soils are deep on gentle crests and upper slopes. Terracetting occurs on lower colluvial slopes but no appreciable erosion occurs on slopes if ground cover is well managed.

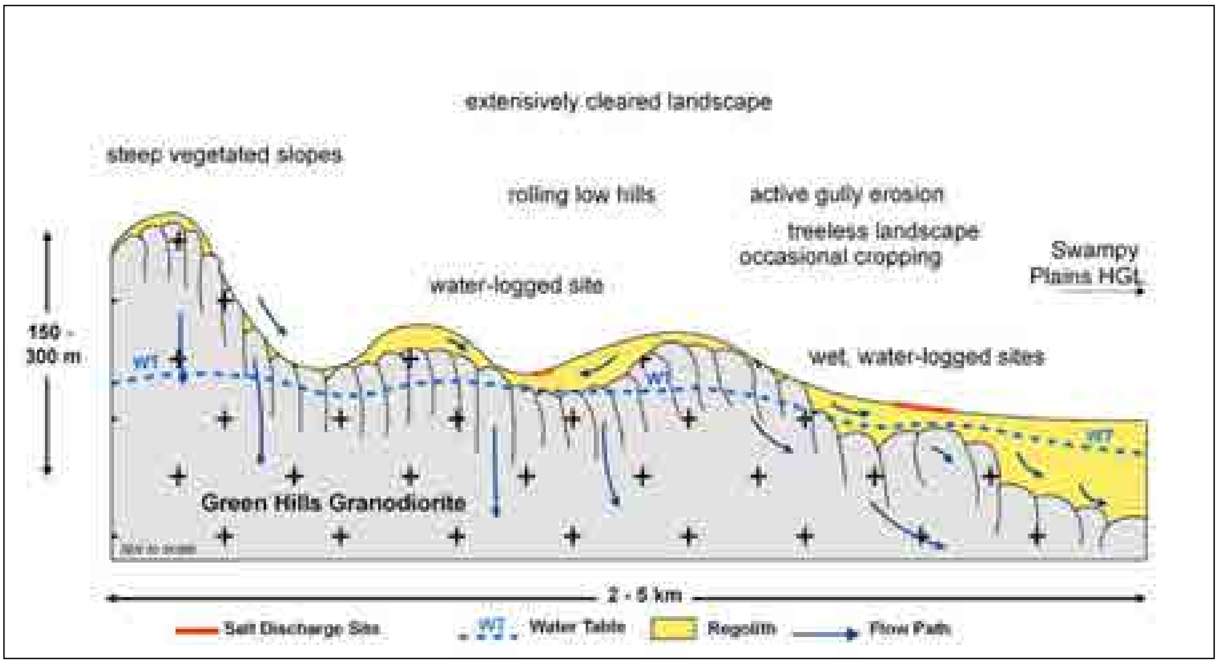


Figure 2: Conceptual cross-section for Welaregang HGL showing the distribution of regolith and landforms, salt sites if present, and flow paths of water infiltrating the system.

Outbreaks of land salinity were observed in locations subject to seasonal waterlogging. There is a history of moderate water quality (high EC) recorded in the area. Salt load is moderate for this HGL (Table 1).

Table 1: Welareganag HGL salinity expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	Moderate – seasonally waterlogged sites with observed salt sites
Salt Load (Export)	Moderate – perennial streams with moderate water EC
EC (Water Quality)	Moderate – history of high water EC recorded in this area

Salt stored within the Welaregang HGL has moderate mobility. There is a moderate salt store that has moderate availability (Table 2).

Table 2: Welaregang HGL salt store and availability.

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

The overall salinity hazard in the Welaregang HGL is moderate. This is due to the moderate likelihood that salinity issues will occur that have potentially significant impacts (Table 3).

Table 3: Likelihood of salinity occurrence, potential impact and overall hazard of salinity for the Welaregang HGL.

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

LANDSCAPE FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 4.

Photo 1: Cleared Welaregang HGL transferral environment of the Welaregang HGL near Welaregang (Photo: OEH/R Muller).

Photo 2: Cleared slopes of Welaregang HGL show some terracetting near Welaregang. Ournie HGL is in the distance (Photo: OEH/R Muller).

Photo 3: Heavily cleared hills are common in the southern areas of the Welaregang HGL (Photo: OEH/A Nicholson).

Photo 4: Low hills and broad drainage depression in the Welaregang HGL near Warbrook (Photo: OEH/A Nicholson).

Photo 5: Welaregang HGL - note saline discharge area in foreground (Photo: OEH/A Nicholson).

Photo 6: Planted tree lines on deep soils within Welaregang HGL (Photo: OEH/A Nicholson).

Photo 7: Rolling low hills of Welaregang HGL in proximity to the Murray River alluvials showing waterlogged lower landform (Photo: OEH/A Nicholson).

Photo 8: Cleared landscape of Welaregang HGL and deep red soils shown in distant right of photo (Photo: OEH/A Nicholson).

Photo 9: The higher and steeper elements of the northern part of the Welaregang HGL have some tree cover (Photo: OEH/R Muller).

Table 4: Summary of information used to define the Welaregang HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2011)*	This HGL comprises granitic rocks from the Silurian period and associated colluvial material. The key lithology is: • Green Hills Granodiorite – Medium to coarse-grained biotite granodiorite, fine to medium-grained biotite-muscovite granodiorite/granite; biotite granodiorite and tonalite commonly containing cordierite, common metasedimentary xenoliths.
Annual Rainfall	700–850 mm
Regolith and Landforms	The Welaregang HGL is slightly to moderately weathered and is characterised by hills (90–300 m relief) and low hills (30–90 m relief) with rounded crests and steep colluvial slopes, on Silurian granitic bedrock. Slopes are typically 10–30%, local relief is 30–300 m, and this HGL is between 560–870 m elevation. The HGL features limited rock outcrop as tors or clusters of tors, but there can be more outcrop on crests and upper slopes. Locally there are springs on the mid and lower colluvial slopes. Regolith materials are dominantly quartzose clayey sands with minor gravels and some sandy clays. On ridge crests and upper slopes there are some angular pebble and cobble-bearing coarse sandy gravels and gravelly sands.

Soil Landscapes *(DECCW 2010)*	The major soil landscape in this HGL is Nacki Nacki. The remainder of the HGL is occupied by a suite of soil landscapes on granitic rock. Tipperary soil landscape occupies steep hills and mountains, Rippling Water rolling hills and low hills, Welaregang foot-slopes and fans. Soils include: deep Red Chromosols (Red Podzolic Soils/Structured Red Earths) on gentle crests and upper slopes; mottled red and brown Chromosols (Red and Brown Podzolic Soils) and Red Kurosols (Red Earths and Red Podzolic Soils) on mid slopes; bleached mottled yellow and brown Chromosols (Solodic Soils) on lower slopes and Stratic Rudosols (Alluvial Soils) in drainage lines. Localised areas of land degradation including gullies up to 5 m deep, active stream-bank erosion and sheet and rill erosion.
Land and Soil Capability *(OEH 2012)*	Class 5
Land Use	Grazing on volunteer, naturalised, native or improved perennial pasture
Key Land Degradation Issues	• sheet erosion (localised) • gully erosion • terracettes (soil creep).
Native Vegetation *(Stelling 1998; Keith 2004)*	Native vegetation in Welaregang HGL has been predominantly cleared for agriculture and native trees are typically rare in the landscape. Native species may have been typical of river red gum woodlands, red box and Blakely's red gum woodland, and sclerophyll forest. Species can include *Persoonia rigida* and *Grevillea lanigera*.

HYDROGEOLOGY

Aquifers within this landscape are unconfined with groundwater flow occurring primarily through fractures in bedrock and saprolite. Some flow occurs through colluvial and alluvial sediments on lower slopes and along flow lines. Hydraulic conductivity and transmissivity are low to moderate. Groundwater recharge rates are estimated to be moderate.

Groundwater systems are typically local to intermediate with short to intermediate flow lengths and are loosely defined by topographic catchments. Water quality within these systems is fresh to marginal. Watertable depths are intermediate to deep.

Medium residence times are typical. These landscapes have a medium to fast response time to changes in land management.

Typical values for the hydrogeological parameters of this HGL are summarised in Table 5.

Table 5: Summary of values for typical hydrogeological parameters of the Welaregang HGL.

Aquifer Type	Unconfined in fractured rock and saprolite Lateral flow through unconsolidated colluvial and alluvial sediments on lower slopes and in flow lines
Hydraulic Conductivity	Low to moderate Range: <10^{-2}–10 m/day
Aquifer Transmissivity	Low to moderate Range: <2–50 m^2/day
Specific Yield	Low to moderate Range: <5–15%
Hydraulic Gradient	Moderate Range: 10–30%
Groundwater Salinity	Fresh to marginal Range: <800–1600 µS/cm
Depth to Watertable	Intermediate to deep Range: 2–>8 m
Typical Sub-Catchment Size	Small (<100 ha)
Scale (Flow Length)	Local to intermediate Flow length: <15 km (short to intermediate)
Recharge Estimate	Moderate
Residence Time	Medium (years)
Responsiveness to Change	Fast to medium (months to years)

MANAGEMENT OPTIONS

Overarching salinity management strategies have specific biophysical outcomes. These are achieved by implementing a series of targeted land management actions that take into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape to impact on salinity. Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Salinity is driven by interactions between water-use capacity of vegetation, physical soil properties and hydrogeological processes within the HGL.

Actions that influence the way water is used by vegetation or stored in the soil profile will have impacts on recharge. The influence of both continual and episodic recharge and the impacts of extreme weather events need to be considered when deciding on appropriate management actions. Short and long-term climate cycles also need to be considered as they have a bearing on salinity processes, particularly salt load and land salinity.

Landscape Salinity Functions – Welaregang HGL

Functions this landscape provides within a catchment scale salinity context:

- **B.** The landscape provides fresh water runoff as an important dilution flow source
- **C.** The landscape provides important base flows to local streams
- **F.** The landscape generates high salinity concentration water.

Management Strategy Objectives – Welaregang HGL

Appropriate strategies pertinent to this landscape:

- **Discharge rehabilitation and management (4):** The saline and waterlogged sites are seasonal. Discharge management will reduce salt discharge to streams when vegetation is matched to salt sites.
- **Dry out the landscape with diffuse actions over most of the landscape (6):** Encourage plant growth and increase plant water use in order to use excess soil moisture across most of the landscape. Healthy, actively growing vegetation will also act as a buffer to groundwater accessions in wet seasonal conditions.
- **Maintain or maximise runoff (10):** The landscape receives high amounts of rainfall and generates significant fresh water runoff as a dilution flow to the system. The fresh runoff mitigates the salt load in the local streams and the broader catchment.

Key Management Focus – Welaregang HGL

Grazing management is the key focus. This includes management of pasture systems based on perennial plants on both waterlogged areas and the wider recharging landscape. Grazing management and infrastructure should consider wet areas as sensitive to grazing, however waterlogged sites have the potential for increased pasture production.

Specific Land Management Opportunities

Specific opportunities for this HGL:

- The landscape contains soils which are reasonably deep and fertile and can support pasture production.

Specific Land Management Constraints

Constraints for land management in this HGL include:

- Climate conditions will restrict pasture growth – cold climate and high rainfall influences the ability of pasture systems to reduce recharge and manage discharge
- Seasonal waterlogging occurs during low growth periods of the year.

Specific Targeted Actions

Management areas for this HGL are illustrated in Figure 3. The specific management actions for these areas are described in Table 6.

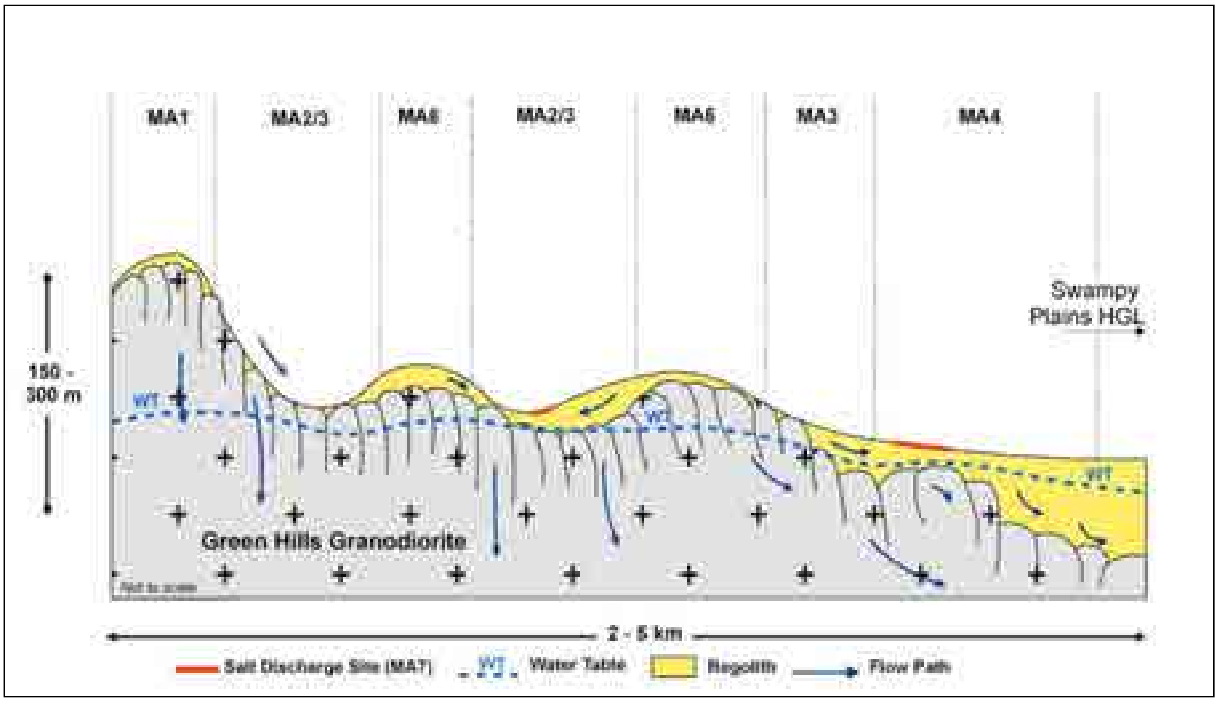


Figure 3: Management cross-section for Welaregang HGL showing defined management areas.

Table 6: Specific management actions for management areas within the Welaregang HGL.

Management Area (MA)	Action
MA1 (RIDGES) MA2/3 (UPPER SLOPES – EROSIONAL & COLLUVIAL)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).**
MA3 (UPPER SLOPES – COLLUVIAL)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**

Management Area (MA)	Action
MA4 (MID-SLOPES)	**Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Establish and manage perennial pastures to manage recharge (**VP2).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**
MA6 (RISES)	**Vegetation for ecosystem function** Establish and manage blocks of trees to reduce recharge **(VE1).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).**
MA7 (SALINE SITES)	**Salt land rehabilitation** Fence and isolate salt land and discharge areas to promote revegetation **(SR1).** Establish and manage salt land pasture systems to improve productivity **(SR2).**

High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative impacts on salinity (Table 7).

Table 7: Management actions having negative salinity impacts in the Welaregang HGL.

At Risk Management Areas	Action
MA1 & MA6 (RIDGES & RISES) AND MA2/3 (UPPER SLOPES – EROSIONAL & COLLUVIAL)	Poor management of grazing pastures **(DLU2).** Clearing and poor management of native vegetation **(DLU4).**
MA3 (UPPER SLOPES – COLLUVIAL) & MA4 (MID-SLOPES)	Annual cropping with annual plants **(DLU3).** Clearing and poor management of native vegetation **(DLU4).**

At Risk Management Areas	Action
MA7 (SALINE SITES)	Deep ripping of soils to maximise water infiltration to subsoil **(DLU11).**

REFERENCES

DECCW, 2010, *Reconnaissance soil and land resources of the Murray CMA*, NSW Department of Environment, Climate Change and Water, Sydney

Geoscience Australia, 2011, *Australian stratigraphic units database*, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int

Keith, D. A. 2004, *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, Hurstville, NSW Department of Environment and Conservation

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, Office of Environment and Heritage, Sydney, [Accessed: 10 November 2014] www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

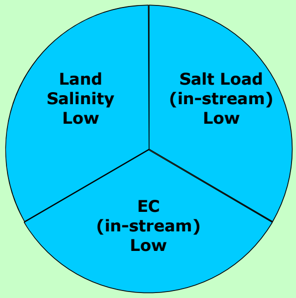
Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia

Stelling, F. 1998, *South west slopes revegetation guide (south of the Murrumbidgee River)*, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

Wooldridge, A., Nicholson, A., Muller R., Jenkins, B. R., Wilford, J. and Winkler, M. 2015, *Guidelines for managing salinity in rural areas*, NSW Office of Environment and Heritage, Sydney, NSW

30. Tumbarumba Hydrogeological Landscape

LOCALITIES	**Tumbarumba, Maragle, Tooma, Greg Greg, Hardys Mill, Mount Blackjack**
MAP SHEET	**Tallangatta 1:250 000 Wagga Wagga 1:250 000**
CONFIDENCE LEVEL	**Medium**



OVERVIEW

The Tumbarumba Hydrogeological Landscape (HGL) covers a large area in the uplands of Murray CMA. It extends from the northern boundary of the CMA at Laurel Hill and Tumbarumba to the southern boundary of the CMA near the Murray River at Greg Greg, and east-west from Worlds End to Tooma, excluding pockets of other HGLs within this region (Figure 1). The HGL covers an area of 666 km^2 and receives 800 to 1300 mm of rain per annum.

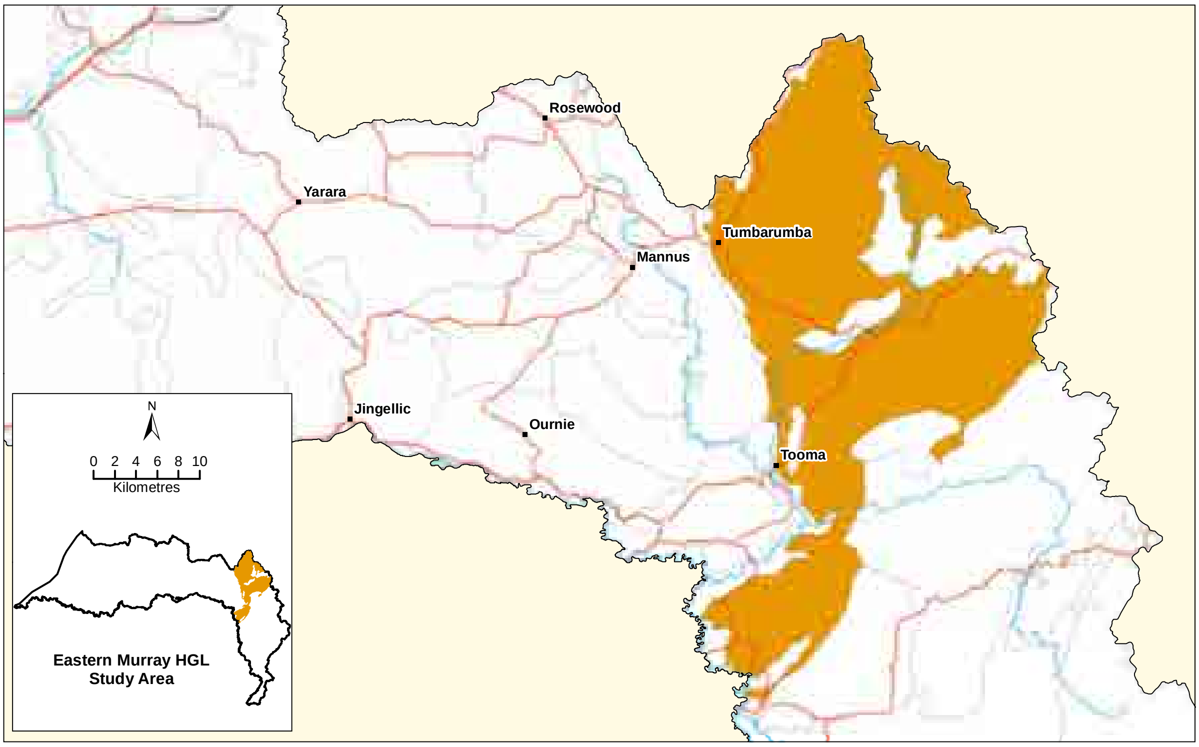


Figure 1: Tumbarumba HGL distribution map.

The Tumbarumba HGL is an erosional and colluvial environment characterised by steep slopes on deeply weathered granite and granodiorite with frequent tors; elevated, undulating to rolling low hills and rises with moderately inclined slopes; and lower gradient lower slopes with seasonal waterlogging (Figure 2). This HGL comprises granitic rocks from the Silurian period and associated colluvial material. Sheet, rill and minor gully erosion can occur following disturbance of vegetation.

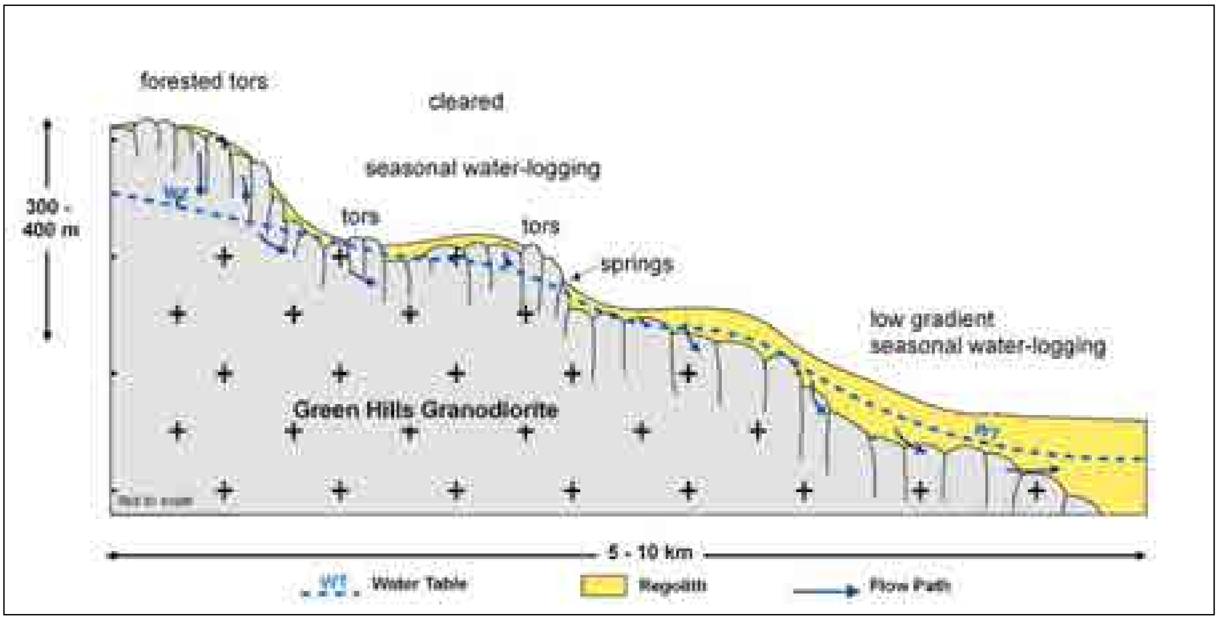


Figure 2: Conceptual cross-section for Tumbarumba HGL showing the distribution of regolith and landforms, salt sites if present, and flow paths of water infiltrating the system.

No land salinity is observed in these landscapes and streams are fresh due to the greater than 1100 mm annual rainfall across most of the area. Salt loads are consequently minor (Table 1).

Table 1: Tumbarumba HGL salinity expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	Low – no salt land observed or mapped
Salt Load (Export)	Low – high rainfall and high quality runoff
EC (Water Quality)	Low water EC

Salt stored within the Tumbarumba HGL has low mobility. There is a low salt store that has moderate availability (Table 2).

Table 2: Tumbarumba HGL salt store and availability.

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

The overall salinity hazard in the Tumbarumba HGL is low. This is due to the moderate likelihood that salinity issues will occur that have potentially limited impacts (Table 3).

Table 3: Likelihood of salinity occurrence, potential impact and overall hazard of salinity for the Tumbarumba HGL.

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

LANDSCAPE FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 4.

Photo 1: Tumbarumba HGL landscape with tors in all landscape positions (Photo: OEH/R Muller).

Photo 2: The Tumbarumba HGL landscape including steep slopes and lower gradient undulating slopes in high rainfall areas (Photo: OEH/R Muller).

Photo 3:The rolling Tumbarumba HGL landscape near Maragle. Native vegetation is on the steeper Khancoban HGL (Photo: OEH/A Wooldridge).

Photo 4:Undulating to rolling hills and rises with moderately inclined slopes near Maragle are characteristic of the Tumbarumba HGL (Photo: OEH/R Muller).

Photo 5: Granite tors are commonly exposed in flow lines in the Tumbarumba HGL (Photo: OEH/A Marchand).

Photo 6: The steeper, rocky hills within the Tumbarumba HGL are often covered with native vegetation (Photo: University of Canberra/K Harvey).

Photo 7: Granite tors are commonly exposed along flow lines in the Tumbarumba HGL (Photo: University of Canberra/K Harvey).

Photo 8: Granite tors are commonly exposed along flow lines in the Tumbarumba HGL (Photo: University of Canberra/K Harvey).

Photo 9: The steeper slopes of the Tumbarumba HGL are susceptible to gully erosion when native vegetation has been removed (Photo: OEH/R Muller).

Photo 10: The steeper slopes of the Tumbarumba HGL are rocky and unproductive when native vegetation has been removed (Photo: OEH/R Muller).

Photo 11: Seeps occur at slope changes on colluvial slopes during wet climatic periods in the Tumbarumba HGL (Photo: OEH/R Muller).

Table 4: Summary of information used to define the Tumbarumba HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2011)*	This HGL comprises granitic rocks from the Silurian period and associated colluvial material. The key lithologies include: • Green Hills Granodiorite – Medium to coarse-grained biotite granodiorite, fine to medium-grained biotite-muscovite granodiorite/granite; biotite granodiorite and tonalite commonly containing cordierite, common metasedimentary xenoliths.

Annual Rainfall	800–1300 mm
Regolith and Landforms	The Tumbarumba HGL is slightly to moderately weathered and is characterised by hills (90–300 m relief) and rolling low hills (30–90 m relief) and rises (20–30m relief) with rounded crests and steep colluvial slopes, forming an undulating landscape, on Silurian granitic bedrock. Rock outcrop is rare and soils are deep. Slopes are typically 3–>30%, local relief 20–300 m, and this HGL is between 300–1290 m elevation. The HGL features limited rock outcrop as tors or clusters of tors but there can be area with more outcrop throughout this landscape. Locally there are springs on the mid and lower colluvial slopes. Regolith materials are dominantly quartzose clayey sands with minor gravels and some sandy clays. In areas of outcrop there are some angular pebble and cobble-bearing coarse sandy gravels and gravelly sands.
Soil Landscapes *(DECCW 2010)*	The major soil landscapes in this HGL are Nacki Nacki, Cabramurra and their respective soil landscape variants. Minor soil landscapes present include Pilot Hill, Mother Wilson and Wolseleys Gap. Soils include: deep Red Chromosols (Red Podzolic Soils/Structured Red Earths) on gentle crests and upper slopes; mottled Red and Brown Chromosols (Red and Brown Podzolic Soils), Red Kandosols (Red Earths) and Yellow Kandosols (Yellow Earths) on mid slopes; bleached mottled yellow and brown Chromosols (Solodic Soils) on lower slopes; and, Stratic Rudosols (Alluvial Soils) in drainage lines. There are localised areas of land degradation, particularly sheet and rill erosion.
Land and Soil Capability *(OEH 2012)*	Class 6
Land Use	Mostly nature conservation and state forest. Bago State Forest, Clarkes Hill Nature Reserve and part of Kosciuszko National Park. Some grazing
Key Land Degradation Issues	• sheet, rill and minor gully erosion (following disturbance of vegetation).
Native Vegetation *(Stelling 1998; Keith 2004)*	Native vegetation in Tumbarumba HGL includes *Eucalyptus polyanthemos* (red stringybark), *E. dives* (broad-leaved peppermint) and *E. blakelyi* (Blakely's red gum). Clarkes Hill Nature Reserve is within Tumbarumba HGL. Vegetation communities are characteristic of mountain swamp gum forest, open forest, tall wet forest, river red gum woodland, Blakely's red gum woodland, box woodland, stringybark-broad leafed peppermint forest and dry sclerophyll forest.

HYDROGEOLOGY

Aquifers within this landscape are unconfined with groundwater flow occurring primarily through fractures in bedrock and saprolite. Some flow occurs through colluvial and alluvial sediments on lower slopes and along flow lines. Hydraulic conductivity and transmissivity are low to moderate. Groundwater recharge rates are estimated to be moderate.

Groundwater systems are typically local to intermediate with short to intermediate flow lengths and are loosely defined by topographic catchments. Water quality within these systems is fresh to marginal. Watertable depths are intermediate to deep.

Short to medium residence times are typical. These landscapes have a medium to fast response time to changes in land management.

Typical values for the hydrogeological parameters of this HGL are summarised in Table 5.

Table 5: Summary of values for typical hydrogeological parameters of the Tumbarumba HGL.

Aquifer Type	Unconfined in fractured rock and saprolite Lateral flow through unconsolidated colluvial and alluvial sediments on lower slopes and in flow lines
Hydraulic Conductivity	Low to moderate Range: <10^{-2}–10 m/day
Aquifer Transmissivity	Low to moderate Range: <2–50 m^2/day
Specific Yield	Low to moderate Range: <5–15%
Hydraulic Gradient	Steep Range: >30%
Groundwater Salinity	Fresh to marginal Range: <800–1600 µS/cm
Depth to Watertable	Intermediate to deep Range: 2–>8 m
Typical Sub-Catchment Size	Small to medium (<1000 ha)
Scale (Flow Length)	Local to intermediate Flow length: <15 km (short to intermediate)
Recharge Estimate	Moderate
Residence Time	Short to medium (months to years)
Responsiveness to Change	Fast to medium (months to years)

MANAGEMENT OPTIONS

Overarching salinity management strategies have specific biophysical outcomes. These are achieved by implementing a series of targeted land management actions that take into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape to impact on salinity. Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Salinity is driven by interactions between water-use capacity of vegetation, physical soil properties and hydrogeological processes within the HGL.

Actions that influence the way water is used by vegetation or stored in the soil profile will have impacts on recharge. The influence of both continual and episodic recharge and the impacts of extreme weather events need to be considered when deciding on appropriate management actions. Short and long-term climate cycles also need to be considered as they have a bearing on salinity processes, particularly salt load and land salinity.

Landscape Salinity Functions – Tumbarumba HGL

Functions this landscape provides within a catchment scale salinity context:

- **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.

Management Strategy Objectives – Tumbarumba HGL

Appropriate strategies pertinent to this landscape:

- **Maintain or maximise runoff (10):** The landscape receives high amounts of rainfall and generates significant fresh water runoff as a dilution flow to the system. The fresh runoff mitigates the salt load in the local streams and the broader catchment.
- **Discharge rehabilitation and management (4):** The waterlogged sites on the cleared lower slopes are small in size and springs can be seasonal. Discharge management will reduce any salt discharge to streams when vegetation is matched to conditions.

Key Management Focus – Tumbarumba HGL

This landscape provides high volumes of water and is an important water supply landscape. Management of current and future land use should consider the impacts of action on water runoff.

Conserving native vegetation to protect fresh water supply and preserve biodiversity is important.

Specific Land Management Opportunities

Specific opportunities for this HGL:

- There are significant areas of native vegetation left in this landscape within preserved remnants and conservation areas which both carry biodiversity value. They act as a seed source and basis for remnant vegetation management as well as biodiversity conservation.

- Grazing management on cleared lower slopes can affect waterlogged areas.
- Revegetation in gullies can reduce gully erosion on lower gradient slopes.

Specific Land Management Constraints

Constraints for land management in this HGL include:

- Climate conditions will restrict pasture growth – cold climate and high rainfall will influence the ability of pasture systems to reduce recharge and manage discharge
- This is an important water supply landscape. Land use will affect the quality of this water.

Specific Targeted Actions

Management areas for this HGL are illustrated in Figure 3. The specific management actions for these areas are described in Table 6.

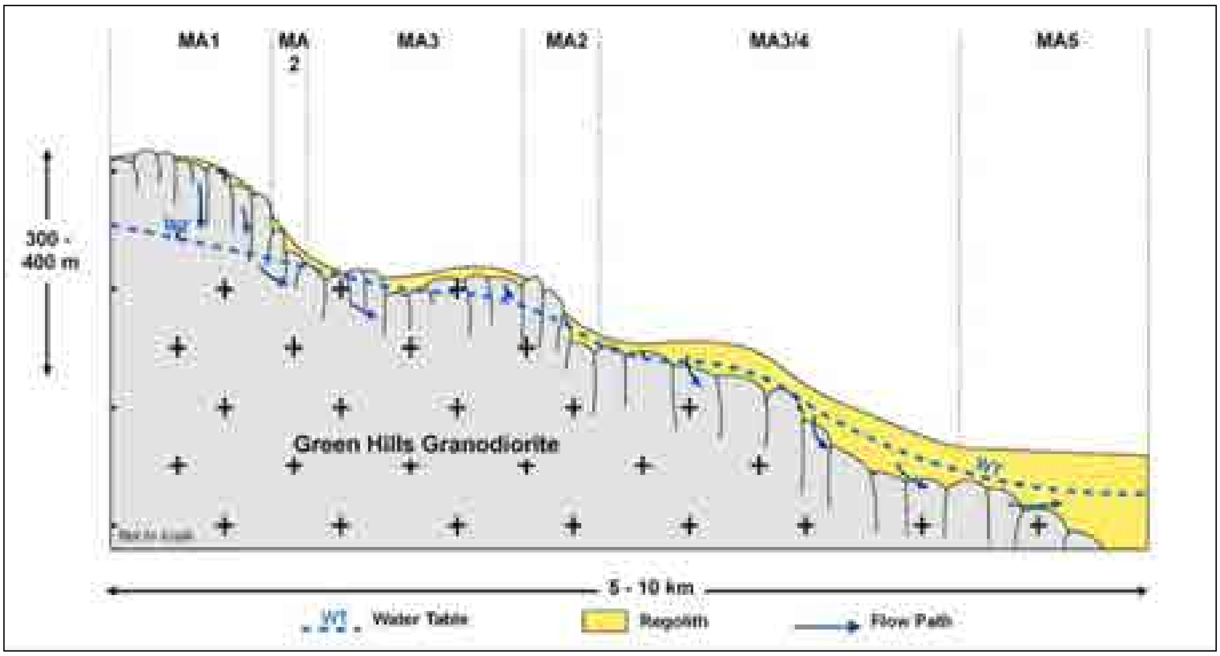


Figure 3: Management cross-section for Tumbarumba HGL showing defined management areas.

Table 6: Specific management actions for management areas within the Tumbarumba HGL.

Management Area (MA)	Action
MA1 (RIDGES) AND MA2 & MA3 (UPPER SLOPES – EROSIONAL & COLLUVIAL)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).**
MA4 (MID-SLOPES)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**
MA5 (LOWER SLOPES)	**Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**

High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative impacts on salinity (Table 7).

Table 7: Management actions having negative salinity impacts in the Tumbarumba HGL.

At Risk Management Areas	Action
MA1, 2, 3, 4 & 5	Reducing runoff from fresh surface water catchments **(DLU6).**

REFERENCES

DECCW, 2010, *Reconnaissance soil and land resources of the Murray CMA*, NSW Department of Environment, Climate Change and Water, Sydney

Geoscience Australia, 2011, *Australian stratigraphic units database*, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int

Keith, D. A. 2004, *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, Hurstville, NSW Department of Environment and Conservation

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, Office of Environment and Heritage, Sydney [Accessed: 10 November 2014] www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

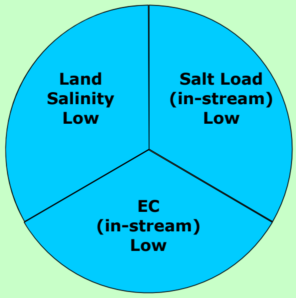
Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia

Stelling, F. 1998, *South west slopes revegetation guide (south of the Murrumbidgee River)*, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

Wooldridge, A., Nicholson, A., Muller R., Jenkins, B. R., Wilford, J. and Winkler, M. 2015, *Guidelines for managing salinity in rural areas*, NSW Office of Environment and Heritage, Sydney, NSW

31. Nine Mile Hydrogeological Landscape

LOCALITIES	**The Nine Mile, The Sisters**
MAP SHEET	**Wagga Wagga 1:250 000**
CONFIDENCE LEVEL	**Low**



OVERVIEW

The Nine Mile Hydrogeological Landscape (HGL) has a patchy distribution within the upland areas of the Murray CMA near to The Nine Mile, Paddys River, The Racecourse and The Sisters (Figure 1). The HGL covers a combined area of 108 km^2 and receives 1000 to 1600 mm of rain per annum.

Figure 1: Nine Mile HGL distribution map.

Nine Mile HGL is an erosional landscape characterised by flat topped basalt hills and moderately inclined slopes (Figure 2). Undulating to rolling low hills, undulating rises and plateaus are typical. Alpine vegetation occurs where native trees remain uncleared. This HGL comprises consolidated volcanic rocks from the Cenozoic era. This HGL contains a number of soil landscapes of basaltic origin and some derived from the underlying country rock (mainly granite). Minimal land degradation is apparent as soils are very stable.

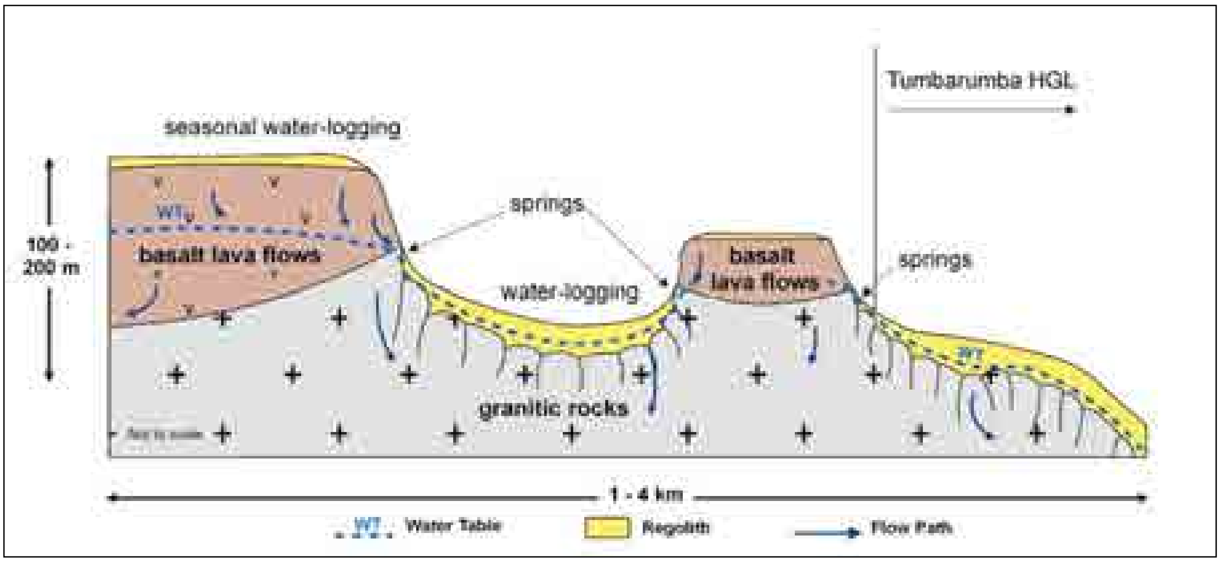


Figure 2:Conceptual cross-section for Nine Mile HGL showing the distribution of regolith and landforms, salt sites if present, and flow paths of water infiltrating the system.

Outbreaks of land salinity were not observed. Minor salinity may be found at the boundaries between Cenozoic basalt flows and underlying geology. Water in Nine Mile HGL is generally fresh (Table 1).

Table 1: Nine Mile HGL salinity expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	Low – no salt sites or seeps observed
Salt Load (Export)	Low – high rainfall and high quality runoff
EC (Water Quality)	Low water EC observed

Salt stored within the Nine Mile HGL has low mobility. There is a low salt store that has moderate availability (Table 2).

Table 2: Nine Mile HGL salt store and availability.

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

The overall salinity hazard in the Nine Mile HGL is low. This is due to the moderate likelihood that salinity issues will occur that have potentially limited impacts (Table 3).

Table 3: Likelihood of salinity occurrence, potential impact and overall hazard of salinity for the Nine Mile HGL.

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

LANDSCAPE FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 4.

Photo 1: The Nine Mile HGL is characterised low rolling plateaus with steep slopes down to drainage lines (Photo: OEH/R Muller).

Photo 2: On the Great Dividing Range, the flat nature of the Nine Mile HGL lends itself to the formation of alpine meadows with broad drainage lines (Photo: OEH/R Muller).

Photo 3: The flat nature of plateaus and steep slopes in the Nine Mile HGL are well illustrated in the Tooma area (Photo: OEH/R Muller).

Photo 4: The deeply incised drainage lines the cut through the level basalt plateaus of the Nine Mile HGL can be clearly seen when looking south from Southern Cloud Lookout (Photo: OEH/R Muller).

Photo 5: The basalt flows that make up, the Nine Mile HGL, as seen at Paddy's River Falls, are thick and can form precipitous scarps around the edges of the HGL where erosional processes are active (Photo: University of Canberra/K Harvey).

Photo 6: Successive basalt lava flows with level surfaces and steep erosional slopes overly older granites in the Nine Mile HGL. This feature can be clearly seen to the west of Maragle (Photo: OEH/A Marchand).

Photo 7: The relatively flat landscape of the Nine Mile HGL at Southern Cloud Lookout drops away sharply into the Maragle valley (Photo: OEH/R Muller).

Photo 8: The flat nature of plateaus and steep slopes are a feature of the Nine Mile HGL in the Tooma area (Photo: OEH/R Muller).

Table 4: Summary of information used to define the Nine Mile HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2011)*	This HGL comprises consolidated volcanic rocks from the Cenozoic era. The key lithology is: • unnamed mafic volcanic rocks – basalt, trachyte, trachybasalt, trachyandesite, leucitite, basanite, nephelinite, limburgite, rhyolite, tuff.
Annual Rainfall	1000–1600 mm
Regolith and Landforms	The Nine Mile HGL is slightly to moderately weathered and is characterised by rolling hills (90–200 m relief) and low hills (30–90 m relief), and undulating rises (20–30 m relief) and elevated elongate plateaus on Cenozoic basalt bedrock. Slopes are typically 3–15%, local relief is 20–200 m, and this HGL is between 1100–1660 m elevation. Regolith materials are derived from basalt and basaltic colluvium and are dominantly deep sandy clays and clays, with some lithic gravels in areas of outcrop.
Soil Landscapes *(DECCW 2010)*	This HGL contains a number of soil landscapes of basaltic origin and some derived from the underlying country rock (mainly granite). Kiandra soil landscape is the most prominent. Other soil landscapes include Courabyra, Pine View, McPhersons Plain, Cabramurra and Toolong. Soils for most of the HGL are derived from basalt and basaltic colluvium and include: Red and Brown Ferrosols (Kraznozems) over most of the landscape; Brown Dermosols and Chromosols (Chocolate Soils) generally in drier areas; and, Hydrosols (Wiesenboden) on the poorly-drained valley flats. Soils for the areas of granite include: Red Kandosols (Red Earths) with sandy loam and clay loam textures on upper slopes; and Red Kandosols (Red Earths) and Yellow Kandosols (Yellow Earths) on lower slopes. Minimal land degradation, as soils are very stable. Minor salinity may be found at the boundaries between flows and geology.
Land and Soil Capability *(OEH 2012)*	Class 4
Land Use	State forest, grazing and national park
Key Land Degradation Issues	• minimal land degradation as soils are very stable.

Native Vegetation *(Stelling 1998; Keith 2004)*	Native vegetation of Nine Mile HGL follows a transect across the slopes and tops of the plateau landforms. Pockets on slopes with different aspects may contain discreet vegetation communities however the general vegetation communities contain *E. pauciflora* (snow gum) forest on the plateau top (where trees are shorter in the exposed, crest areas), *E. rubida* (candle bark), and *E. mannifera* (brittle gum) in association with *E. pauciflora* where soils are shallow and potentially stony. *Eucalyptus dalrympleana* (mountain gum) and *E. camphora* (mountain swamp gum) have also been observed at high elevations, and *E. delegatensis* (alpine ash) can be found on eastern facing slopes in moist pockets. *Eucalyptus blakelyi* (Blakely's red gum) tends to feature on slopes or plateau tops at lower altitudes, such as at The Sisters.

HYDROGEOLOGY

Aquifers in this HGL are unconfined, with flow along structures (basalt flow boundaries, joints, faults) in fractured basaltic rocks. Minor flow occurs through unconsolidated colluvial and alluvial sediments on lower slopes and along flow lines. Springs occur at contacts between the basalt flows and underlying bedrock. These result in wet or waterlogged areas. Localised perching of watertables occur above clay lenses during wetter periods. Hydraulic conductivity is moderate to high and transmissivity is moderate. Groundwater recharge rates are estimated to be moderate.

Groundwater systems are typically local with short flow lengths. Water quality within these systems is fresh. Watertable depths are shallow to intermediate, with seasonal localised perching.

Residence times are short to medium. These landscapes have a medium to fast response time to changes in land management.

Typical values for the hydrogeological parameters of this HGL are summarised in Table 5.

Table 5: Summary of values for typical hydrogeological parameters of the Nine Mile HGL.

Aquifer Type	Unconfined in fractured rock Minor flow through unconsolidated colluvial and alluvial sediments on lower slopes and along flow lines Local perching above clay-rich layers (seasonal)
Hydraulic Conductivity	Moderate to high Range: 10^{-2}–>10 m/day
Aquifer Transmissivity	Moderate Range: 2–50 m^2/day
Specific Yield	Moderate Range: 5–15%

Hydraulic Gradient	Moderate Range: 10–30%
Groundwater Salinity	Fresh Range: <800 µS/cm
Depth to Watertable	Shallow to intermediate (seasonal localised perching) Range: <2–8 m
Typical Sub-Catchment Size	Small (<100 ha)
Scale (Flow Length)	Local Flow length: <5 km (short)
Recharge Estimate	Moderate
Residence Time	Short to medium (months to years)
Responsiveness to Change	Fast to medium (months to years)

MANAGEMENT OPTIONS

Overarching salinity management strategies have specific biophysical outcomes. These are achieved by implementing a series of targeted land management actions that take into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape to impact on salinity. Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Salinity is driven by interactions between water-use capacity of vegetation, physical soil properties and hydrogeological processes within the HGL.

Actions that influence the way water is used by vegetation or stored in the soil profile will have impacts on recharge. The influence of both continual and episodic recharge and the impacts of extreme weather events need to be considered when deciding on appropriate management actions. Short and long-term climate cycles also need to be considered as they have a bearing on salinity processes, particularly salt load and land salinity.

Landscape Salinity Functions – Nine Mile HGL

Functions this landscape provides within a catchment scale salinity context:

- **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.

Management Strategy Objectives – Nine Mile HGL

Appropriate strategies pertinent to this landscape:

- **Maintain or maximise runoff (10):** The landscape receives very high amounts of rainfall and generates significant fresh water runoff as a dilution flow to the system. The fresh runoff mitigates the salt load in the local streams and the broader catchment.
- **Discharge rehabilitation and management (4):** The springs and waterlogged sites can be readily targeted. Discharge management will reduce any salt discharge to local streams when vegetation is matched to conditions.

Key Management Focus – Nine Mile HGL

Grazing management is the key focus. This includes management of pasture systems based on perennial plants in waterlogged areas and the recharging landscape. Grazing management and infrastructure should consider wet areas as sensitive to grazing.

This landscape also provides high volumes of water and is an important fresh water source. Management of current and future land use should consider the impacts of action on water runoff.

Specific Land Management Opportunities

Specific opportunities for this HGL:

- The landscape contains soils which are stable and reasonably fertile. These “better soils” support pasture production.
- This landscape contains significant areas of native grass pastures. These provide an excellent base to build better management of native pastures into the future.

Specific Land Management Constraints

Constraints for land management in this HGL include:

- Climate conditions will restrict pasture growth – cold climate and high rainfall will influence the ability of pasture systems to reduce recharge and manage discharge.

Specific Targeted Actions

Management areas for this HGL are illustrated in Figure 3. The specific management actions for these areas are described in Table 6.

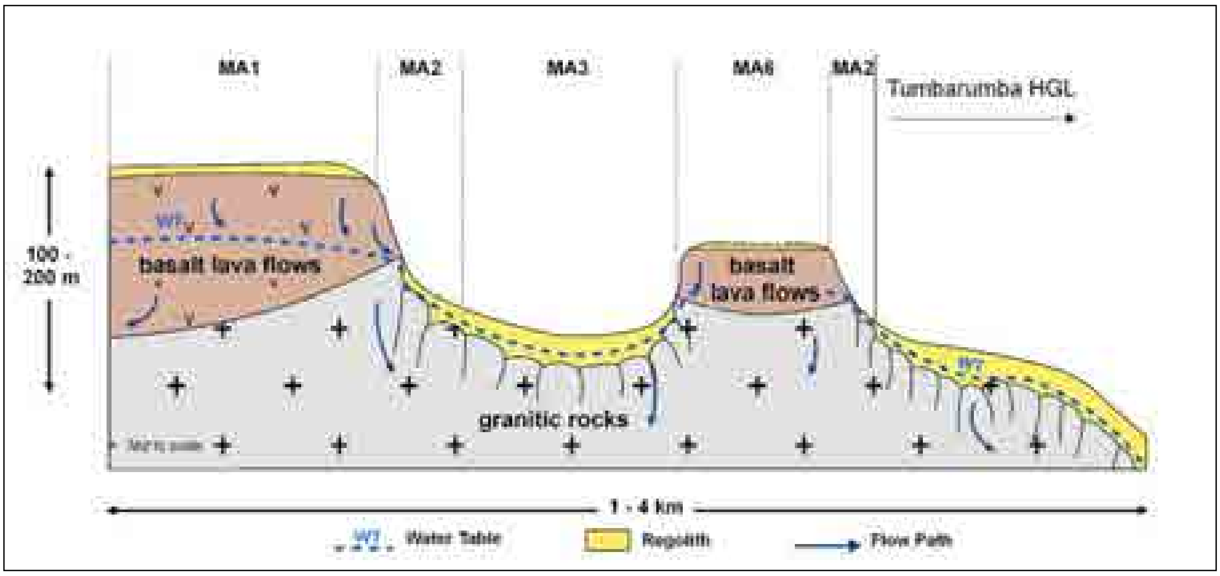


Figure 3: Management cross-section for Nine Mile HGL showing defined management areas.

Table 6: Specific management actions for management areas within the Nine Mile HGL.

Management Area (MA)	Action
MA1 & MA6 (RIDGES & RISES) AND MA2 & MA3 (UPPER SLOPES – EROSIONAL & COLLUVIAL)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** **Vegetation for production** Improve grazing management of existing perennial pastures to manage recharge **(VP1).** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5).**

High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative impacts on salinity (Table 7).

Table 7: Management actions having negative salinity impacts in the Nine Mile HGL.

At Risk Management Areas	Action
MA1,2,3 & 6	Clearing and poor management of native vegetation **(DLU4).** Reducing runoff from fresh surface water catchments **(DLU6).**

REFERENCES

DECCW, 2010, *Reconnaissance soil and land resources of the Murray CMA*, NSW Department of Environment, Climate Change and Water, Sydney

Geoscience Australia, 2011, *Australian stratigraphic units database*, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int

Keith, D. A. 2004, *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, Hurstville, NSW Department of Environment and Conservation

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, Office of Environment and Heritage, Sydney, [Accessed: 10 November 2014] www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

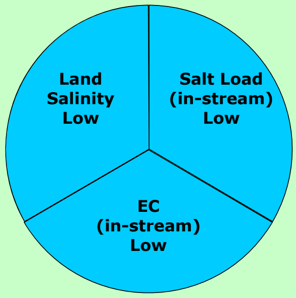
Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia

Stelling, F. 1998, *South west slopes revegetation guide (south of the Murrumbidgee River)*, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

Wooldridge, A., Nicholson, A., Muller R., Jenkins, B. R., Wilford, J. and Winkler, M. 2015, *Guidelines for managing salinity in rural areas*, NSW Office of Environment and Heritage, Sydney, NSW

32. Khancoban Hydrogeological Landscape

LOCALITIES	**Khancoban, Old Geehi Camp, China Walls, Pilot Reef Mountain, Bringenbrong**
MAP SHEET	**Tallangatta 1:250 000** **Wagga Wagga 1:250 000**
CONFIDENCE LEVEL	**High**



OVERVIEW

The Khancoban Hydrogeological Landscape (HGL) is in the alpine areas of the upper Murray Catchment. The western boundary extends along the Murray River from near Bringenbrong to Murray Gorge and the landscape extends east into the alpine areas around Geehi and Thiess (Figure 1). The HGL covers an area of 556 km^2 and receives 1000 to 1900 mm of rain per annum. It is characterised by high rainfall conditions, steep to precipitous mountains and high elevation.

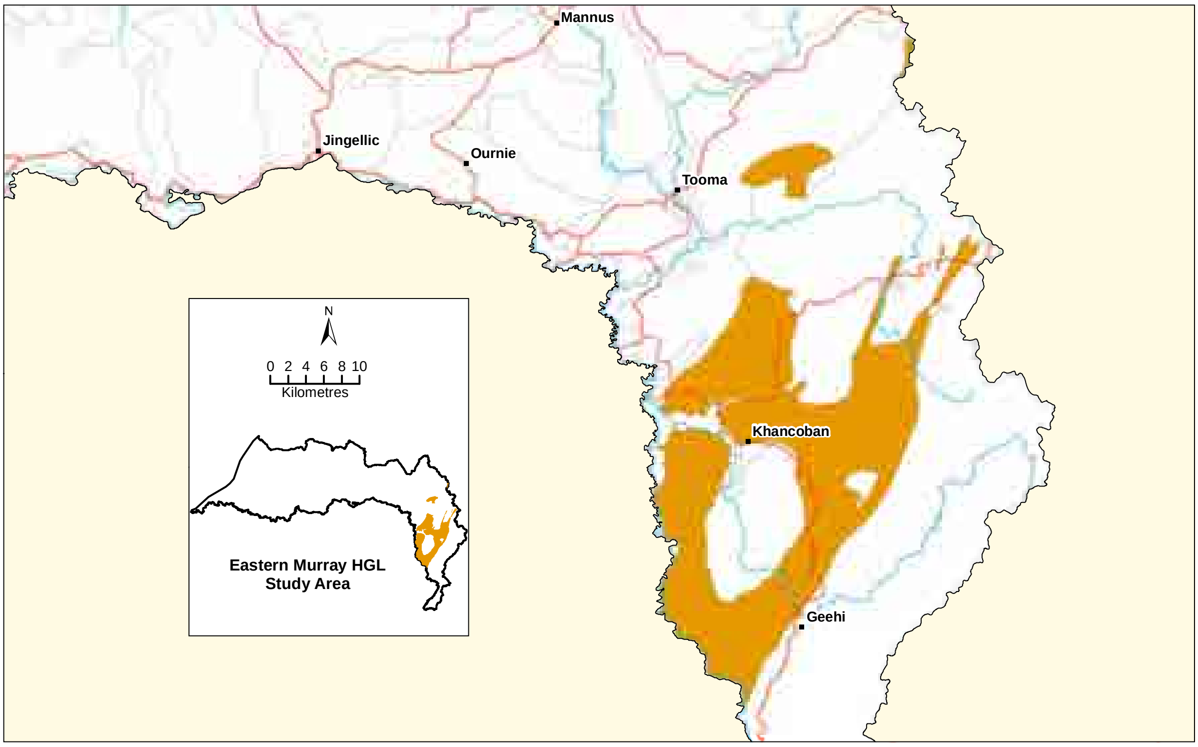


Figure 1: Khancoban HGL distribution map.

The Khancoban HGL is a colluvial environment characterised by mountainous steep slopes with shallow alpine soils (Figure 2). Steep to precipitous mountains and hills dominate. Drainage lines are incised. This HGL comprises consolidated sedimentary and low-grade metamorphic rocks from the Ordovician period. Land degradation issues include erosion where vegetation has been disturbed.

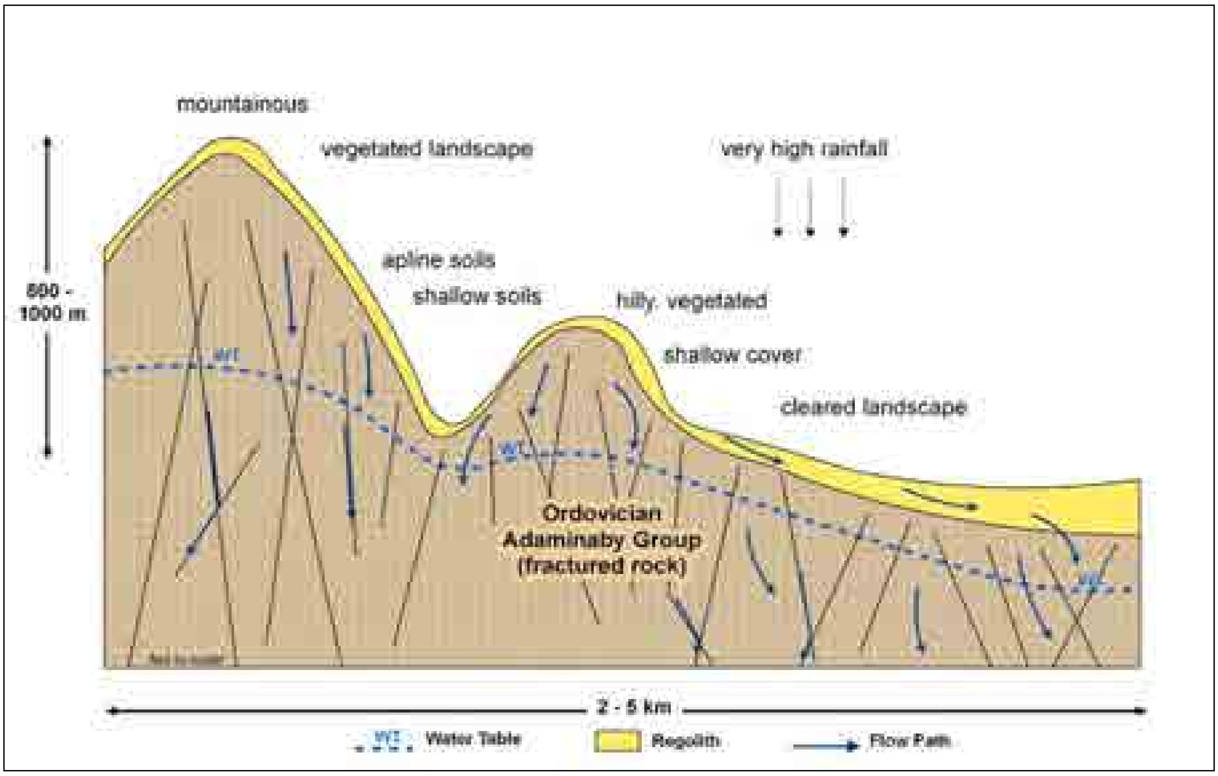


Figure 2: Conceptual cross-section for Khancoban HGL showing the distribution of regolith and landforms, salt sites if present, and flow paths of water infiltrating the system.

No land salinity is observed. Water quality is very high and freshwater runoff is a significant feature of this HGL (Table 1).

Table 1: Khancoban HGL salinity expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	Low – no land salinity observed
Salt Load (Export)	Low – high quality runoff and very high rainfall
EC (Water Quality)	Low water EC observed

Salt stored within the Khancoban HGL has moderate mobility. There is a low salt store that has high availability (Table 2).

Table 2: Khancoban HGL salt store and availability.

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

The overall salinity hazard in the Khancoban HGL is very low. This is due to the low likelihood that salinity issues will occur that have potentially limited impacts (Table 3).

Table 3: Likelihood of salinity occurrence, potential impact and overall hazard of salinity for the Khancoban HGL.

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

LANDSCAPE FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 4.

Photo 1: The lower elements of the Khancoban HGL near Swampy Plain Creek have gentler slopes and have been partially cleared for agriculture. Drainage lines are susceptible to gully erosion. The steep, precipitous range in the background is Kosciuszko HGL (Photo: OEH/R Muller).

Photo 2: The lower elements of the Khancoban HGL near Swampy Plain Creek have gentler slopes and have been partially cleared for agriculture. Drainage lines are susceptible to gully erosion (Photo: OEH/R Muller).

Photo 3: Typical Khancoban landscape (Photo: OEH/A Nicholson).

Photo 4: At Maragle, the steep terrain of Khancoban HGL (background) is covered with native vegetation and has higher elevation than the more rolling Tumbarumba HGL (foreground) which is being used for plantation forestry and traditional agriculture (Photo: OEH/R Muller).

Photo 5: South of Khancoban, the landscape of the Khancoban HGL becomes steep and mountainous (Photo: OEH/A Nicholson).

Photo 6: South of Khancoban, the landscape of the Khancoban HGL becomes steep and mountainous with incised drainage lines (Photo: OEH/R Muller).

Photo 7: The steep slopes and high relief of the Khancoban HGL are advantageous for the generation of hydro-electricity in the Khancoban region (Photo: OEH/R Muller).

Table 4: Summary of information used to define the Khancoban HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2011)*	This HGL comprises consolidated sedimentary and low-grade metamorphic rocks from the Ordovician period. Minor unconsolidated Quaternary alluvium occurs in river valleys. Key lithologies include: • flood plain alluvium – gravel, sand, silt and clay • Adaminaby Group – sequence of sandstone, mudstone, shale, carbonaceous shale, greywacke; chert, quartzite, phyllite, slate.
Annual Rainfall	1000–1900 mm

Regolith and Landforms	The Khancoban HGL is slightly to moderately weathered and is characterised by steep to precipitous mountains and hills on Ordovician metasedimentary bedrock. Slopes are typically 20–70%, local relief is 100–1000 m, and this HGL is between 330–1516 m elevation. The HGL features rock outcrop (2–10%) mostly on crests and upper slopes. Drainage lines are incised. Regolith materials are dominantly kaolinite-bearing quartzose clayey sands with minor gravels and some sandy clays. On ridge crests and upper slopes there are some angular tabular pebble and cobble-bearing coarse sandy gravels and gravelly sands with variable kaolinitic clay content.
Soil Landscapes *(DECCW 2010)*	Scammels Lookout and Indi Range are the major soil landscapes on this HGL. The remainder is covered by numerous soil landscapes including, but not limited to, Wolseleys Gap, Toolong, Strumbo, Nacki Nacki, Veteran, Tom Groggin, Greg, Greg and Tongue Bend. Soils include: Leptic Tenosols (Lithosols) on crests or where bedrock is near the surface, often associated with rock outcrop; Red and Yellow Kandosols (Red Earths and Yellow Earths) and Red Dermosols (structured Red Earths) on hill-slopes; shallow to moderately deep Red and Brown Kandosols (Red Earths and Brown Earths) and Red Kurosols (Red Podzolic Soils) on drier slopes; moderately deep Red and Brown Dermosols (structured Red Earths and Brown Earths) on moister hill-slopes, generally eastern or southern aspects; and Sapric Organosols (Alpine Humus Soils) above 1,500 m elevation.
Land and Soil Capability *(OEH 2012)*	Class 7
Land Use	Kosciuszko National Park, grazing, Snowy Hydro power stations and related infrastructure
Key Land Degradation Issues	• sheet erosion (where groundcover is poor on drier slopes) • terracetting on some cleared lower slopes used for grazing • gully erosion on lower cleared slopes.
Native Vegetation *(Stelling 1998; Keith 2004)*	Vegetation within Khancoban HGL can include species typical of high altitude, cold climates and high rainfall conditions. Dominant tree species typically withstand frosts, periodic snow fall. Dominant tree species on lower landforms include *Eucalyptus blakelyi* (Blakely's red gum) and *E. rossii* (inland scribbly gum). The vegetation communities on these lower slopes are frequently characteristic of river red gum woodland (close to the Murray River), Blakely's red gum woodland, red stringybark dry sclerophyll forest and peppermint moist open forest.

HYDROGEOLOGY

Aquifers within this landscape are unconfined to semi-confined with groundwater flow occurring primarily through fractures in bedrock and saprolite and through connected pore spaces in sandstone units. Some flow occurs through colluvial sediments on lower slopes. Hydraulic conductivity is low to moderate and transmissivity is low. Groundwater recharge rates are estimated to be moderate.

Groundwater systems are typically local to intermediate with short to intermediate flow lengths and are loosely defined by topographic catchments. Water quality within these systems is fresh to marginal. Watertable depths are intermediate to deep.

Medium to long residence times are typical. These landscapes have a medium response time to changes in land management.

Typical values for the hydrogeological parameters of this HGL are summarised in Table 5.

Table 5: Summary of values for typical hydrogeological parameters of the Khancoban HGL.

Aquifer Type	Unconfined to semi-confined in fractured rock and saprolite, and through pore spaces in sandstone (dual porosity) Lateral flow through unconsolidated colluvial sediments on lower slopes
Hydraulic Conductivity	Low to moderate Range: $<10^{-2}$–50 m/day
Aquifer Transmissivity	Low Range: <2 m^2/day
Specific Yield	Low to moderate Range: <5–15%
Hydraulic Gradient	Moderate to steep Range: 10–30%
Groundwater Salinity	Fresh to marginal Range: <800–1600 µS/cm
Depth to Watertable	Intermediate to deep Range: 2–>8 m
Typical Sub-Catchment Size	Small (<100 ha)
Scale (Flow Length)	Local to intermediate Flow length: <15 km (short to intermediate)
Recharge Estimate	Moderate
Residence Time	Medium to long (years to decades)
Responsiveness to Change	Medium (years)

MANAGEMENT OPTIONS

Overarching salinity management strategies have specific biophysical outcomes. These are achieved by implementing a series of targeted land management actions that take into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape to impact on salinity. Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Salinity is driven by interactions between water-use capacity of vegetation, physical soil properties and hydrogeological processes within the HGL.

Actions that influence the way water is used by vegetation or stored in the soil profile will have impacts on recharge. The influence of both continual and episodic recharge and the impacts of extreme weather events need to be considered when deciding on appropriate management actions. Short and long-term climate cycles also need to be considered as they have a bearing on salinity processes, particularly salt load and land salinity.

Landscape Salinity Functions – Khancoban HGL

Functions this landscape provides within a catchment scale salinity context:

- **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.

Management Strategy Objectives – Khancoban HGL

Appropriate strategies pertinent to this landscape:

- **Maintain or maximise runoff (10):** The landscape receives very high amounts of rainfall and generates significant fresh water runoff as a dilution flow to the system. The fresh runoff mitigates the salt load in the broader catchment.
- **Discharge rehabilitation and management (4):** The landscape can express small areas of seasonal discharge on lower slopes where vegetation has been cleared. Discharge management will minimise any salt loads discharging into local streams.

Key Management Focus – Khancoban HGL

This landscape provides very high volumes of fresh water and is an important water supply landscape. Management of current and future land use should balance water supply with water needs and consider impacts of action on water runoff.

Native vegetation for biodiversity conservation and maintenance of soil stability is important in this landscape.

Specific Land Management Opportunities

Specific opportunities for this HGL:

- There are significant areas of native vegetation in this landscape within National Park and conservation areas. They are important for biodiversity conservation but also provide a seed source for remnant vegetation management.

- This landscape contains native grass pastures. Continuing and improving grazing management of existing native pastures is an opportunity to capitalise on the existing pasture base.
- Revegetation of riparian zones will prevent further gully erosion and provide wildlife corridors between native habitats.

Specific Land Management Constraints

Constraints for land management in this HGL include:

- Climate conditions will restrict pasture growth – cold climate and high rainfall will influence the growth of pasture and the ability of these systems to reduce soil moisture and recharge on lower slopes.
- Access to some areas is hindered by steep slopes, vegetation and road closures during winter months.

Specific Targeted Actions

Management areas for this HGL are illustrated in Figure 3. The specific management actions for these areas are described in Table 6.

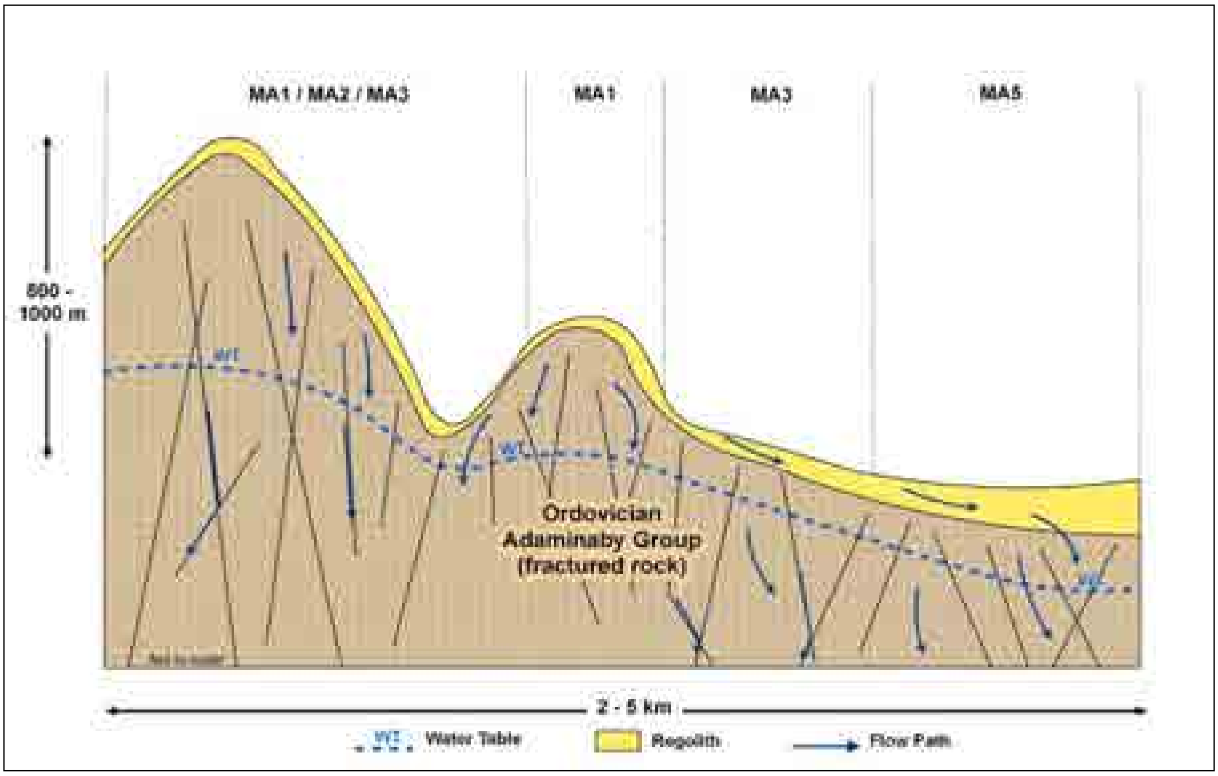


Figure 3: Management cross-section for Khancoban HGL showing defined management areas.

Table 6: Specific management actions for management areas within the Khancoban HGL.

Management Area (MA)	Action
MA1/2/3 (RIDGES & UPPER SLOPES – EROSIONAL & COLLUVIAL)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).**
MA3 (UPPER SLOPES – COLLUVIAL) AND MA5 (LOWER SLOPES – COLLUVIAL)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3).** **Vegetation for production** Establish and manage trees that are integrated into farming logistics to reduce recharge **(VP5).**

High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative impacts on salinity (Table 7).

Table 7: Management actions having negative salinity impacts in the Khancoban HGL.

At Risk Management Areas	Action
MA1/2/3 (RIDGES & UPPER SLOPES – EROSIONAL & COLLUVIAL) AND MA5 (LOWER SLOPES – COLLUVIAL)	Clearing and poor management of native vegetation **(DLU4).**

REFERENCES

DECCW, 2010, *Reconnaissance soil and land resources of the Murray CMA*, NSW Department of Environment, Climate Change and Water, Sydney

Geoscience Australia, 2011, *Australian stratigraphic units database*, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int

Keith, D. A. 2004, *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, Hurstville, NSW Department of Environment and Conservation

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, Office of Environment and Heritage, Sydney, [Accessed: 10 November 2014] www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

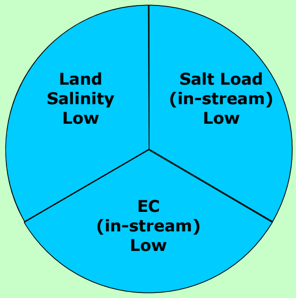
Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia

Stelling, F. 1998, *South west slopes revegetation guide (south of the Murrumbidgee River)*, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

Wooldridge, A., Nicholson, A., Muller R., Jenkins, B. R., Wilford, J. and Winkler, M. 2015, *Guidelines for managing salinity in rural areas*, NSW Office of Environment and Heritage, Sydney, NSW

33. Kosciuszko–Welumba Hydrogeological Landscape

LOCALITIES	**Geehi, Indi Camp, Toolong Plain, The Dargals, Mount Kosciuszko**
MAP SHEET	**Tallangatta 1:250 000** **Wagga Wagga 1:250 000**
CONFIDENCE LEVEL	**High**



OVERVIEW

The Kosciuszko–Welumba Hydrogeological Landscape (HGL) extends from east of Tooma and Khancoban eastwards to the Great Dividing Range (Figure 1). The HGL covers an area of 1266 km^2 and receives 1700–1900 mm of rain per annum.

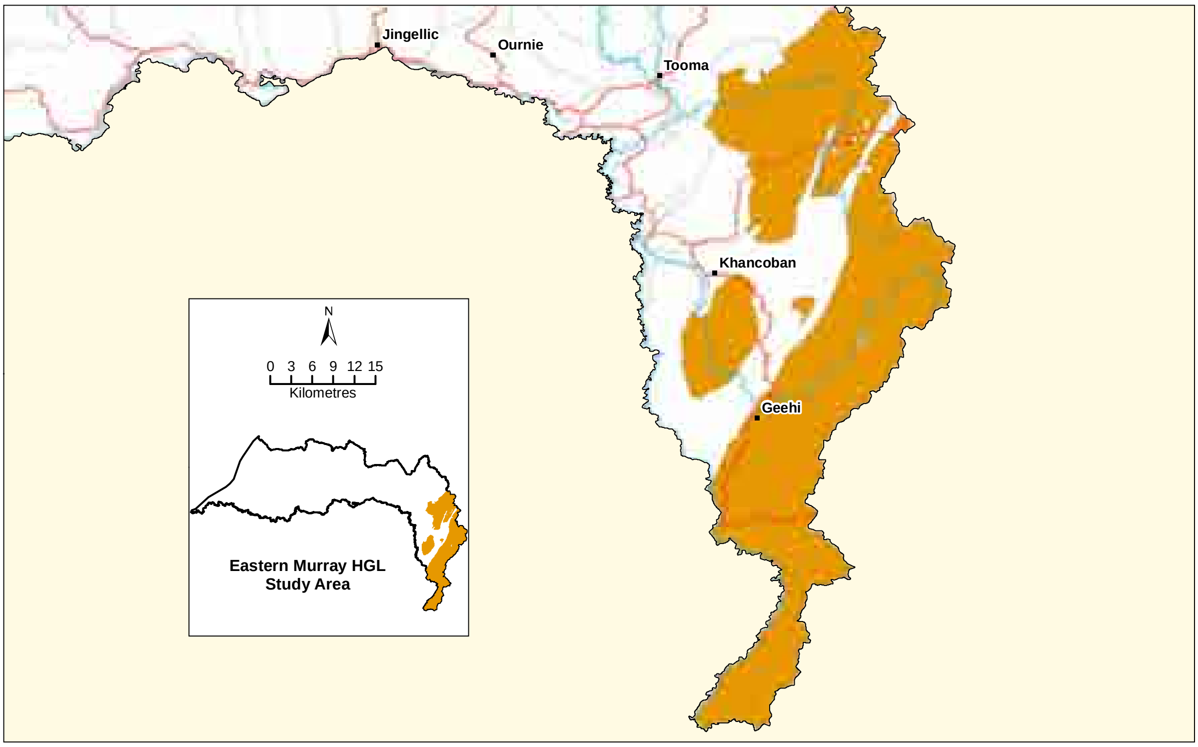


Figure 1: Kosciuszko–Welumba HGL distribution map.

The majority of this HGL falls within the Kosciuszko National Park and is considered to be a very low overall salinity hazard. Management in these areas is largely outside the control of the Murray CMA. A significant number of varied lithologies and landscapes have been combined to define the HGL. For this reason, the Kosciuszko–Welumba HGL is only discussed in general terms for this unit description.

The Kosciuszko–Welumba HGL is dominated by the mountainous landforms with broad rock plateaus and very steep slopes down to the upper tributaries of the Murray River. Lithologically, this HGL is very diverse and includes locally metamorphosed consolidated sedimentary rocks from the Ordovician period that have been intruded by granitic rocks from the Silurian period. Minor exposures of consolidated Devonian sedimentary rocks also occur. Unconsolidated colluvial and alluvial sediments derived from the surrounding rocks have been deposited on lower slopes and along streams that pass through. There is little or no soil related degradation.

Salt sites have not been observed, but localised waterlogging occurs in alpine regions. Salt loads and EC are low (Table 1).

Table 1: Kosciuszko–Welumba HGL salinity expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	Low – not observed, but localised waterlogging occurs in alpine regions
Salt Load (Export)	Low
EC (Water Quality)	Low

Salt stored within the Kosciuszko–Welumba HGL has low mobility. There is a low salt store that has moderate availability (Table 2).

Table 2: Kosciuszko–Welumba HGL salt store and availability.

SALT MOBILITY			
	Low availability	**Moderate** availability	**High** availability
High salt store			
Moderate salt store			
Low salt store		**Kosciuszko–Welumba**	

The overall salinity hazard in the Kosciuszko–Welumba HGL is very low. This is due to the low likelihood that salinity issues will occur that have potentially limited impacts (Table 3).

Table 3: Likelihood of salinity occurrence, potential impact and overall hazard of salinity for the Kosciuszko–Welumba HGL.

OVERALL SALINITY HAZARD			
	Limited potential impact	**Significant** potential impact	**Severe** potential impact
High likelihood of occurrence			
Moderate likelihood of occurrence			
Low likelihood of occurrence	**Kosciuszko-Welumba**		

LANDSCAPE FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 4.

Photo 1: The Kosciuszko–Welumba HGL is dominated by steep to very steep hills and mountains covered by native vegetation. The pines in the foreground are on the Tumbarumba HGL (Photo: OEH/A Wooldridge).

Photo 2: The Kosciuszko–Welumba HGL is dominated by steep to very steep hills and mountains that have steep slopes running down to the upper tributaries of the Murray River(Photo: OEH/R Muller).

Table 4: Summary of information used to define the Kosciuszko–Welumba HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2011)*	This HGL is very diverse and includes locally metamorphosed consolidated sedimentary rocks from the Ordovician period that have been intruded by granitic rocks from the Silurian period. Minor exposures of consolidated Devonian sedimentary rocks also occur. Unconsolidated colluvial and alluvial sediments derived from the surrounding rocks have been deposited on lower slopes and along streams that pass through. Snowy River Volcanics – sub-aerial volcanics, including rhyolitic lava, porphyry dykes, sediments.
Annual Rainfall	1700–1900 mm
Regolith and Landforms	The Kosciuszko–Welumba HGL is slightly to moderately weathered and is characterised by mountainous landforms (300 m+ relief) forming broad rock plateaus and rolling landscapes in the alpine regions with very steep colluvial slopes running down to the upper tributaries of the Murray River, on Ordovician metasedimentary, and Siluro-Devonian granitic and sedimentary bedrock. Slopes are typically 40–70%, local relief is >300m and this HGL is between 400 and 2228 m elevation. Regolith materials are dominantly quartzose clayey sands with minor gravels and some sandy clays. On ridge crests and upper slopes there are some angular pebble and cobble-bearing coarse sandy gravels and gravelly sands with variable clay content.
Soil Landscapes *(DECCW 2010)*	This HGL incorporates a large number of high altitude soil landscapes including, but not limited to, Wolseleys Gap, Toolong, Tom Groggin, Scammels Lookout, Pilot Hill, Free Damper Creek, Jimmies Lookout, Crackenback Peak, Bella Vista, Mount Youngal Fire Trail, Mother Wilson Hill, Read Ridge and Strawberry Hills. Soils include: Leptic Tenosols (Lithosols) on crests or where bedrock is near the surface, often associated with rock outcrop; Red and Yellow Kandosols (Red Earths and Yellow Earths) and Red and Brown Dermosols (structured Red Earths) on hill-slopes; and, Sapric and Hemic Organosols (Alpine Humus Soils) above 1500 m elevation.
Land and Soil Capability *(OEH 2012)*	Class 7
Land Use	Kosciuszko National Park. Grazing in cleared areas
Key Land Degradation Issues	• little or no soil related degradation.
Native Vegetation *(Stelling 1998; Keith 2004)*	Kosciuszko–Welumba HGL is thickly vegetated with species typical of high altitude, cold climates and high rainfall conditions. Dominant tree species are typically able to withstand frosts, periodic (and in many locations prolonged) snow fall, and often prefer loamy or highly fertile soils. Distinctive tree species include *Eucalyptus bicostata* (eurabbie) in wetter areas and sheltered sites amongst wet forest, *E. viminalis* (ribbon gum) which is tolerant of frost and snow and prefers loamy, fertile soil, *E. stellulata* (black sallee) in some locations and *E. robertsonii* (Robertson's peppermint).

HYDROGEOLOGY

Aquifers within this landscape are unconfined to semi-confined with groundwater flow occurring primarily through fractures in bedrock and saprolite and through connected pore spaces in sandstone units. Some flow occurs through colluvial sediments on lower slopes. Groundwater recharge rates are estimated to be moderate to high. Groundwater systems are typically local to intermediate with short to intermediate flow lengths and are loosely defined by topographic catchments. Water quality within these systems is fresh. Watertable depths are intermediate to deep, although waterlogging and perched watertables are common on the alpine plateaus.

MANAGEMENT OPTIONS

Overarching salinity management strategies have specific biophysical outcomes. These are achieved by implementing a series of targeted land management actions that take into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape to impact on salinity. Further explanation of land management functions, strategies and actions can be found in Wooldridge *et al.* (2015).

Salinity is driven by interactions between water-use capacity of vegetation, physical soil properties and hydrogeological processes within the HGL.

Actions that influence the way water is used by vegetation or stored in the soil profile will have impacts on recharge. The influence of both continual and episodic recharge and the impacts of extreme weather events need to be considered when deciding on appropriate management actions. Short and long-term climate cycles also need to be considered as they have a bearing on salinity processes, particularly salt load and land salinity.

Landscape Salinity Functions – Kosciuszko HGL

Functions this landscape provides within a catchment scale salinity context:

- **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.

Management Strategy Objectives – Kosciuszko HGL

Appropriate strategies pertinent to this landscape:

- **Maintain or maximise runoff (10):** The landscape receives very high amounts of rainfall and generates significant fresh water runoff as a dilution flow to the entire system.
- **Discharge rehabilitation and management (4):** Waterlogged sites can occur as localised features in the alpine regions.

Key Management Focus – Kosciuszko HGL

Native vegetation for biodiversity conservation is of prime important in this landscape. Preserving a balance between conservation and water yield issues is a management concern for this HGL.

Specific Land Management Opportunities

Specific opportunities for this HGL:

- The native habitat, flora and fauna are currently preserved within National Park in most of this area. Ongoing protection of current natural assets and biodiversity is under State management.

Specific Land Management Constraints

Constraints for land management in this HGL include:

- Climate conditions of cold and very high amounts of rainfall may influence pasture growth (where established) and other vegetation in their ability to reduce soil moisture and recharge on lower slopes.

REFERENCES

DECCW, 2010, *Reconnaissance soil and land resources of the Murray CMA*, NSW Department of Environment, Climate Change and Water, Sydney

Geoscience Australia, 2011, *Australian stratigraphic units database*, Canberra, Australia, [Accessed: 10 November 2014] http://dbforms.ga.gov.au/www/geodx.strat_units.int

Keith, D. A. 2004, *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, Hurstville, NSW Department of Environment and Conservation

OEH, 2012, *The land and soil capability assessment scheme second approximation, a general rural land evaluation system for New South Wales*, Office of Environment and Heritage, Sydney, [Accessed: 10 November 2014] www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

Raymond, O.L., Lui, S., Kilgour, P., Retter, A.J., Stewart, A.J. and Stewart, G. 2007, *Surface geology of Australia 1:1,000,000 scale, New South Wales – 2nd edition*, Geoscience Australia, Canberra, Australia

Stelling, F. 1998, *South west slopes revegetation guide (south of the Murrumbidgee River)*, Murray Catchment Management Committee / NSW Department of Land and Water Conservation, Albury

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Appendix C: Data Sources

The boundaries for each Hydrogeological Landscape unit have been derived from a number of data sources. All data is based on the GDA94 coordinate system.

The details of the data sets used and the supplying agencies follow:

Agency	Data set	Description
NSW OEH	Reconnaissance Soil and Land Resources of the Murray CMA	A DVD product comprising reconnaissance level natural resource mapping for the Murray CMA. It integrates numerous soil mapping datasets into a single seamless coverage and provides access to many layers of spatial information. It reports on soil types, terrain and physical constraints to use for the 151 map units.
	Soil Landscapes of the Holbrook-Tallangatta 1:100,000 Sheet (8326-8325) *Metadata File Identifier: {BB2DB4AD-C009-4B1C-8D74-B3B3CAA170A9}*	The soil landscape mapping program provides a compendium of natural resource information designed to help land managers to make informed environmental planning decisions. The mapping of soil landscapes through the investigation and collection of detailed soil and landscape profiles and analysis of both soil physical and chemical properties provides a powerful natural resource database on which to base informed environmental decisions. Soil landscape mapping also provides an overview of soil and/or landscape limitations for land use practices, and an assessment of both urban and rural land capabilities.
	NSW Soil and Land Information System (SALIS) *Metadata File Identifier: {15BF7C54-4F28-4BAB-AFEA-F7A08FE18B3E}*	State-wide dataset of soil profiles, comprising (at time of writing) ~70,000 separate observations of soil physical and chemical characteristics, along with, in most cases, information about the landscape in which they occur (including landform, geology, vegetation, hydrology, land use and land degradation). Data are added by NSW Government agencies and members of the wider community using standardised Soil Data Cards.
	BIOCLIM 2009	35 bioclimatic layers have been generated for NSW using supplied climate surfaces at 250 m. They are based on the Geoscience Australia 9 second DEM. These layers were generated using ANUCLIM Beta Version in November 2009.

Agency	Data set	Description
Geoscience Australia	GEODATA TOPO 250K Series 3	Major topographic features appearing on the 1:250 000 scale including cartography, elevation, framework, habitation, hydrography, infrastructure, terrain, transport, utility and vegetation.
	1:1 million Geology of Eastern Australia	The NSW component of this dataset is a detailed seamless geology coverage for the State. The dataset was compiled primarily from the NSW Department of Mineral Resources statewide 1:250 000 and 1:100 000 database, as well as several broader scale regional datasets in the Broken Hill and Murray Basin areas. The work involved edge-matching over 40 individual maps and applying a consistent stratigraphic and regolith classification scheme across the state and into Qld and Vic.
Geological Survey of NSW	Wagga Wagga 1:250 000 Geological Sheet SI/55-15, 1st edition (1966)	Geological Survey of NSW published hard copy geological maps that form part of the 'standard series' maps published at 1:250 000 and 1:100 000 scale. Modern maps have good detail and comprehensive depictions of geology. Note that sheets published prior to 1980 may lack the detail present in later maps.
	Tallangatta 1:250 000 Geological Sheet SJ/55-3, first edition (1966)	
	Jerilderie 1:250 000 Geological Sheet SI/55-14, 2nd edition (1976)	
Land and Property Information	NSW DTDB Landform Theme 50K Digital Terrain Models *(ANZLIC Identifier: ANZNS0404000846)*	Digital Terrain Models created from existing 10 m and 20 m contours sourced from the NSW Topographic Map Archive. The Data Base contains raster height data in 25 m pixels for the Eastern and Central Divisions of NSW. The Sydney Basin is supplemented by the integration of 2 m contour data.
	NSW Digital Topographic Database DTDB *(ANZLIC Identifier: ANZNS0404001262)*	Themes include a cultural layer incorporating transportation, facilities and utilities; drainage/hydrography; contours, buildings, built up areas, distinctive land surfaces and a names layer. Data generally correspond to 1:25 000, 1:50 000 and 1:100 000 mapping areas represented on the Australian National Map Sheet Breakdown System.

Appendix D: Dataset Attribute Table Information and Colour Schemes

Attribute Table Header

The attribute table attached to the HGL geodatabase contains the information used to describe Hydrogeological Landscapes. The following table summarises the attributes used and the ranges used for each attribute.

	No	HGL	Salt_land	Xport_Strm	EC_stream	Sodicity	Salt_store	Salt_avail	Haz_impact	Haz_likeli	Haz_ovrall	Data_Sourc	Function	Strategy
Attribute Description (Volumes 2 & 4)	HGL number	HGL name	Impact of land salinity in HGL (pie chart)	Impact of Salt export in HGL (pie chart)	Impact of water quality in HGL (pie chart)	Sodicity hazard in HGL (only recorded if high)	Salt store in HGL (salt mobility table)	Salt availability in HGL (salt mobility table)	Potential impact of salinity in HGL (hazard table)	Likelihood of salinity occurring in HGL (hazard table)	Overall salinity hazard in HGL (hazard table)	Reliability / integrity of boundary definition data sources	Landscape functions of HGL (management options)	Management strategy objectives for HGL (management options)
Attribute Range			High Moderate Low	High Moderate Low	High Moderate Low	High	High, Moderate Low	High, Moderate Low	Severe Significant Limited	High, Moderate Low	Very high High Moderate Low Very low	High, Medium Low	A to I	1 to11

Colour Ranges

On HGL derivative maps, colours have been used to define attribute ranges for each HGL. These are summarised in the table below.

Attribute	Range	Colour	RGB Colour Scheme
Overall Salinity Hazard	Very High High Moderate Low Very Low	Red Orange Yellow Green Blue	255, 50, 0 255, 150, 0 255, 255, 150 200, 255, 150 200, 255, 255
Land Salinity Salt Export Water Quality Impact Salt Availability Salt Store Likelihood of Salinity Occurrence	High Moderate Low	Red Yellow Blue	255, 0, 0 255, 255, 0 0, 204, 255
Potential Impact of Salinity	Severe Significant Limited	Red Yellow Blue	255, 0, 0 255, 255, 0 0, 204, 255
Sodicity Hazard	High	Red	255, 0, 0

It should be noted that where hill-shading is used on the maps, the attribute colours may appear slightly paler than specified in the table if a transparency factor has been applied.