Burra Landscape Management Plan

25th March 2018

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Contributions and Acknowledgements

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We would like to gratefully acknowledge the NSW Environmental Trust for providing funding to develop this plan, South East Local Land Services for their assistance, and Burra Landcare Group for their input.

Cover: Active erosion in the Burra area (Photo: L Gould).

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Molonglo Catchment Group / South East Local Land Services

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Introduction and Purpose of the Plan

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The Land Management Framework (LMF) describes the nature and consequences of soil degradation in the Burra catchment and identifies management issues relevant to specific parts of the landscape (management areas). The framework has been applied to the two Burra catchment HGL units:

- Michelago
- Chakola

This Management Plan also builds on historical learnings and past investments in the Burra landscape. It also builds on recent project work by Molonglo Catchment Group assisting 85 landholders to manage their land to capability and remediating erosion through a series of land management workshops and site visits (funded through the NSW South East Local Lands Services).

The work revealed a series of highly vulnerable, priority sites for remediation throughout the Burra sub-catchment and recommended the importance of educating and assisting the many hobby farmers managing these fragile lands. The HGL report provided tailored recommendations for land management actions to prevent sediment loss and dryland salinity and was presented to the Burra community during a series of workshops on erosion in 2017. Through these workshops, it was clear that the application of the HGL method would be extremely useful for property planning.

This Management Plan synthesises the HGL reports into one document for easy access to guide property planning, future investment in Burra and best practice remediation practices. The intended users of this Plan are extension staff and trained landholders who understand the HGL method including the Burra Landcare Group.

The Plan is structured as follows:

- Overview of the Burra Catchment
- Burra Landscape Framework (split into two landscapes)
  - Michelago Landscape Framework (soils)
  - Michaelago HGL (salinity)
  - Chakola Landscape Framework (soils)
  - Chakola HGL (salinity)

Once a property location is found within the management area map (**Figure 9**) relevant management units, risks and recommendations can be looked up using the charts to guide remediation and management.

For more information on using this Plan, or for extension advice, please contact Molonglo Catchment Group on 02 6299 2119.

Burra Creek Catchment

1. OVERVIEW

The Burra Creek Catchment, shown in Figure 1, occurs wholly within NSW and is a sub catchment of the Molonglo River. Burra Creek Catchment drains to the Queanbeyan River, which drains to the Molonglo River and then into the Murrumbidgee River.

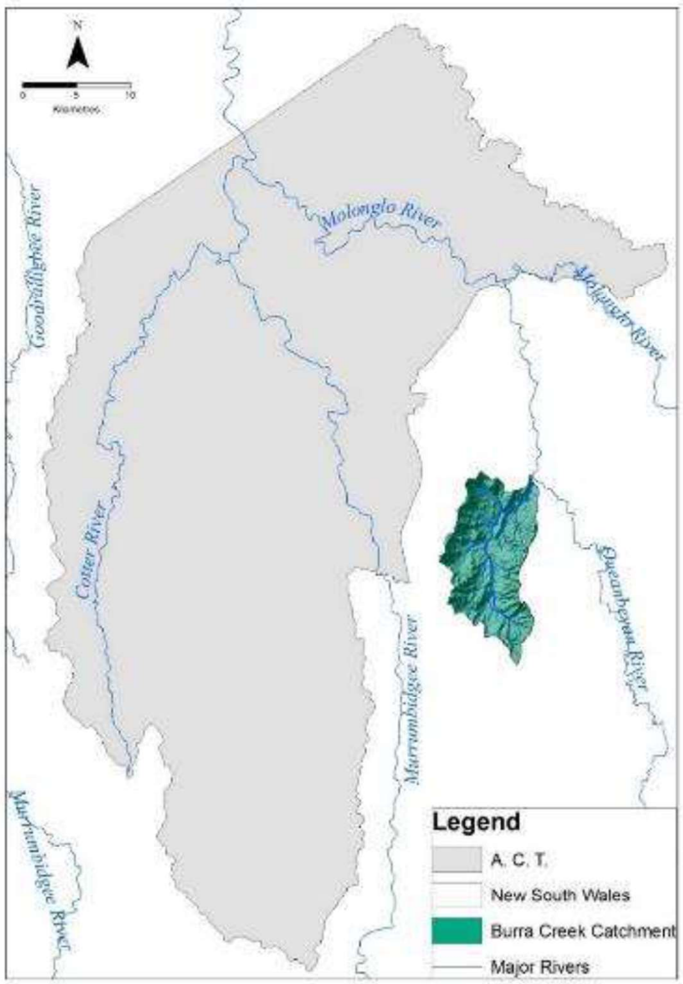


Figure 1: Location Map of the Burra Creek Catchment Relative to the ACT

Burra's landscape has vastly changed over the past 200 years. Prior to European settlement, the landscape was mostly timbered on the hills and slopes, with areas of woodland and grassland on the floodplains. Much of the drainage system was once a chain-of-ponds, a series of deep ponds set within broad floodplains, which spread high flows passively across the tussock dominated valley floor (Figure 2). Burra is in a landscape of ranges and valley corridors that form a cross-road of significant Aboriginal pathways and river crossings for the Ngunawal, Ngambri and Ngarigo peoples, leading from Lake George and the Molonglo Plains to the Murrumbidgee River and the Monaro. Prior to European settlement Aboriginal people managed those pathways using fire to maintain access for camping and hunting, and to sustain their food and water resources (pers. comm. Williams, K. 2018, Gammage, B. 2011).

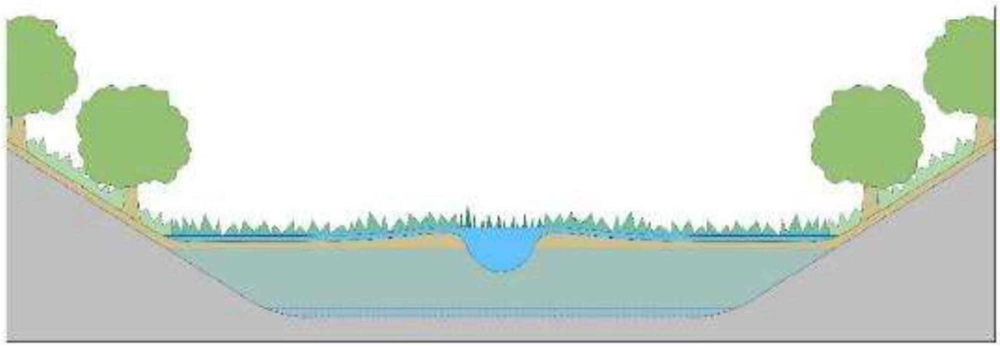


Figure 2: Intact chain-of-ponds system, comprising a near surface water table and flows spread passively across the tussock dominated valley floor (Cam Wilson, 2017)

2. <u>EUROPEAN SETTLEMENT</u>

In 1823, Captain Currie, being led by Aboriginal people following local pathways, passed through the Burra valley on his journey from Lake George, noting on his map that the area was a "fine forest country intersected by stony ranges" (Eyles, 1977). Burra catchment was initially held under leasehold by the Campbell family from Duntroon, a part of several thousand acres centred on what appears to have been a treeless area in the valley centre known as "the plain" which was purchased in 1837 to form Burra Station. Over time (1861-1864), other large properties in the valley opened much of Burra's alluvial flats and lower colluvial slopes as selections, cropping the land and grazing sheep and cattle with relatively high stocking rates (as was common in this time). The sons of the original selectors then gradually cleared blocks in the dry sclerophyll forest of the eastern portion of the catchment. Their attempts at grazing the cleared land surrounding the selections (1869-1895) failed, and the eastern half of the catchment reverted to a forested condition (Eyles, 1977).

3. <u>IMPACTS OF LAND USE CHANGE</u>

During European settlement, large changes in vegetation cover and hydrogeology occurred in Burra, essentially reducing the roughness of the complex vegetated landscape to form a 'smoother' surface of grasses and bare-ground, resulting in increased water run-off during rainfall events. Increased water velocity created more erosive force on exposed patches of bare ground; and after a period of prolonged drought, major rainfall events between 1851-1870, caused major erosion scars across many parts of the landscape (Figure 3). In 1851, the Rev W B Clarke witnessed the formation of a gully leading into the *'Berudba'* (Bredbo) River during a storm. He wrote, *"…the masses of rock and earth had been washed away down to the Berudba, were perfectly astonishing"* (Starr et al, 1999). Similar journal accounts of major erosion incidents in Upper Murrumbidgee are further explored in a historical account of *Soil Erosion, Phosphorous and Dryland Salinity in the Upper Murrumbidgee* (Starr et al, 1999), including accounts of active erosion from road formation and high stocking rates of grazing. A.G Hamilton (1892) wrote of the damage created by the hooves of sheep and cattle in the Upper

Murrumbidgee, "*The tracks made by these animals carry off the rainwater, when there is a slight incline, these tracks deepen into gullies…"* (Starr et al, 1999, p.74).

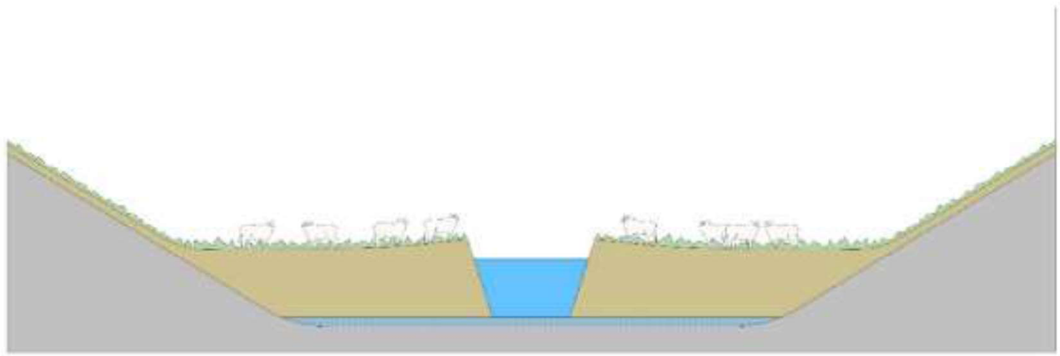


Figure 3 Incised gully with high energy flows contained within channel and a drained alluvial aquifer (Wilson, 2017)

Hamilton's accounts of minor stock movements (1892) are also enlightening when considering gully formation in this landscape, "*where the cattle of the settler cross a well grassed slope, immediate changes are affected. The surface waters begin their work at some small hole made by the hoof, and gradually enlarge to deepen it, until a dry channel several feet deep is excavated. In this way thousands of cubic feet of soil are carried into the low-lying valleys and streams"* (Starr et al, 1999, p.74).

3.1. WHY IS BURRA SO SUSCEPTIBLE TO EROSION?

(a) Parent materials drive soil type

- Ordovician Sediments (Timbered Hills) = Thin soils: very shallow and prone to rain splash erosion if left unprotected.
- Silurian Volcanics (most cleared areas) = Thicker soils: nutrient poor, highly erodible, especially in drainage lines, hard to repair, unless dispersive nature is understood.

(b) Sodic soils

- Inherent (naturally formed) from Silurian Volcanic parent materials
- High exchangeable sodium (Na) in the cations attached to clay particles
- Hardpan crusts (when dry) on surface layers
- Excessive swelling, dispersion (clay particles separate) and tunnelling (when wet)
- Chemistry weakens aggregates in the soil, causing structural collapse and closing off pores to plant roots.

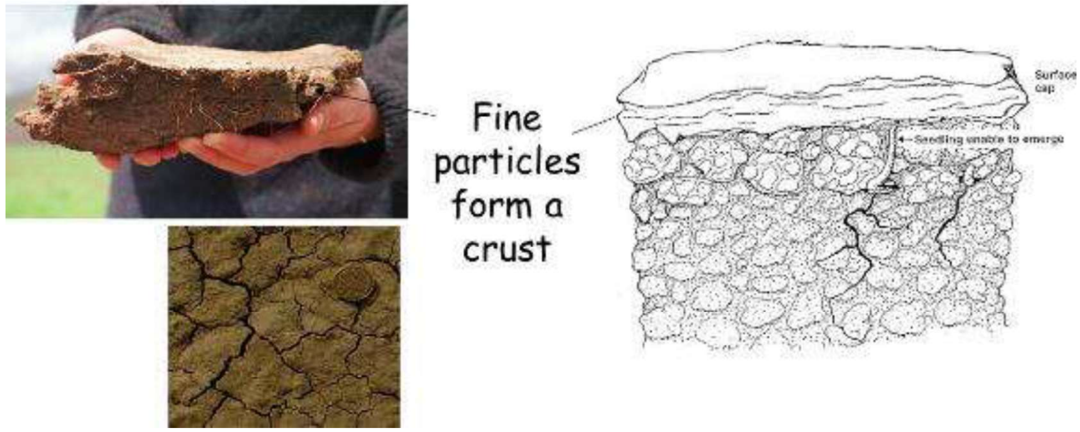
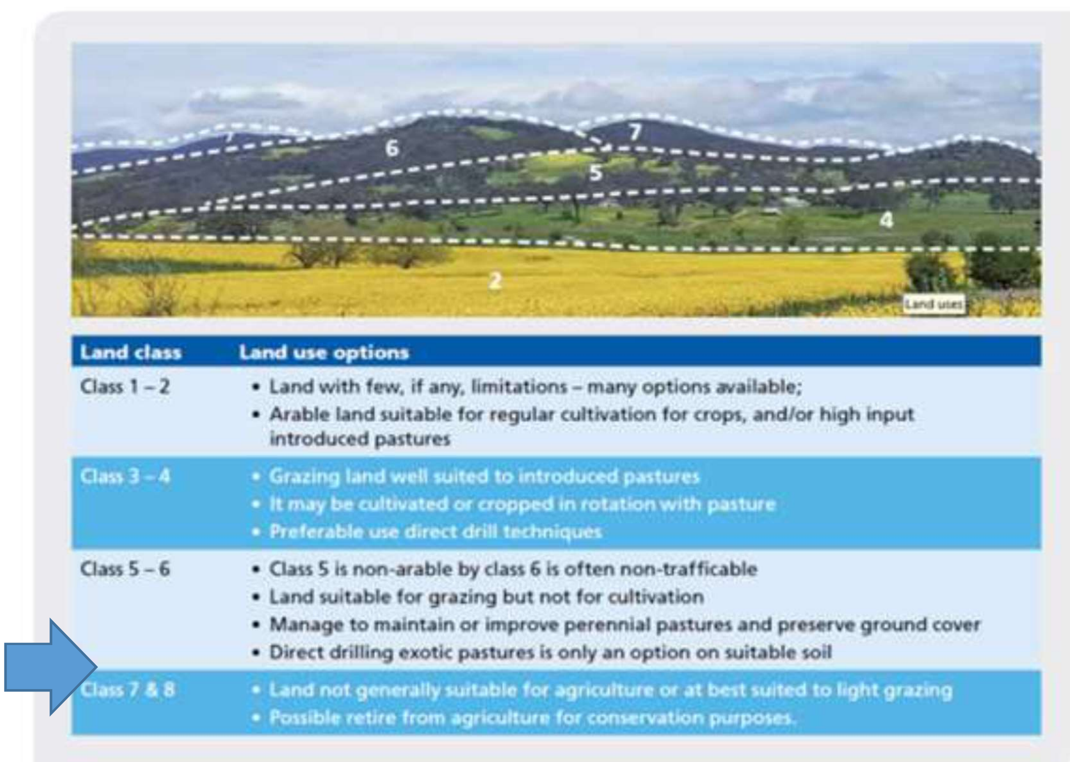


Figure 4: Impact of sodic soils on seedling emergence – Source: Soil Types and Structures Module DEPI, Victoria

(c) Higher land capability ratings

- There are 8 land classes that outline the capability of the land to undertake activities, as pictured in Diagram 4.
- Land capability is more complex than topography, it must take in inherent vulnerabilities and risks like soil type.
- Burra lands are classed as **5-7 due to soil vulnerabilities, best suited to light grazing, perennial grasses and trees.**
- If land is managed outside of its limits, it can create erosion.



Land class	Land use options
Class 1 – 2	• Land with few, if any, limitations – many options available; • Arable land suitable for regular cultivation for crops, and/or high input introduced pastures
Class 3 – 4	• Grazing land well suited to introduced pastures • It may be cultivated or cropped in rotation with pasture • Preferable use direct drill techniques
Class 5 – 6	• Class 5 is non-arable by class 6 is often non-trafficable • Land suitable for grazing but not for cultivation • Manage to maintain or improve perennial pastures and preserve ground cover • Direct drilling exotic pastures is only an option on suitable soil
Class 7 & 8	• Land not generally suitable for agriculture or at best suited to light grazing • Possible retire from agriculture for conservation purposes.

Figure 5 Land Capability Rating with Arrow showing Burra's Land Capability due to Inherent Soil Vulnerabilities (South East LLS Rural Living Guide 2016)

4. “HOBBY FARMING” AND CONSERVATION EFFORTS

In the 1960’s, considerable subdivision occurred in Burra, allowing lifestyle or “hobby” farmers to live out in the country. This land-use change lessened the stocking rates and pressure of hooved animals on the fragile soils and created interest in building dams and planting trees for aesthetic and conservation purposes (Starr et al, 1999). In Starr et al (1999), it is concluded that for the Burra area at least, the net impact of the rural residential change is, at worst, benign. And fortunately, the Landcare movement in Burra gave rise to considerable revegetation efforts which is ongoing today thanks to the dedication of its members. The reinstating of native perennial grasses, trees and shrubs into the landscape is gradually increasing the surface roughness, which slows and protects soil from erosive forces.

Due to its erosive parent materials and its past land-uses, Burra has long been known as a sediment source problem area in the region. As such, large scale investment in Burra occurred in the 1970-90’s to ensure that Lake Burley Griffin and Googong Dam were not blocked with silt from the upper catchment. To address this, the Soil Conservation Service worked out at Burra for many years, constructing formal erosion control structures in the landscape to slow, buffer and minimise the sediment loss. The highly dispersive nature of these soils was not fully understood during these works, and as a result many structures have aged or failed now due to the undercutting of sodic sub-soils (Starr et al, 1999).

5. MURRUMBIDGEE TO GOOGONG WATER TRANSFER

The ACTEW (now Icon Water) Murrumbidgee to Googong Water Transfer was opened in 2012 and allows for the transfer water from the Murrumbidgee River to Burra Creek where it runs to storage in Googong Dam (GHD, 2013). This was undertaken to secure Canberra’s water supply during drought and involved the construction of two pumping stations from the Murrumbidgee River and underground placement of a 12-kilometre pipeline through to Burra Creek. When in use, the water directly discharges into Burra Creek, allowing for the flow of water into Googong Dam. This event in Burra’s history is of interest due to the potential for large changes in the hydrology at times when the transfer is in use and the subsequent additional pressure on bank and bed stability in higher flows (Skinner, 2009).

6. VEGETATION COMMUNITIES

Vegetation in the Burra area is dominated by Dry Schlerophyll forests on the upper slopes which are well-adapted to the shallow soils found in these areas; Box-Gum Woodlands on the lower slopes associated with deeper soils, and treeless swampy meadows on the flat valleys. Vegetation across the valley floors and lower slopes tends to have been significantly modified from the once native grass and sedge dominated landscapes, in association with incision of the original chain-of-ponds landscapes into channels, and the planting (and colonisation) of exotic trees and shrubs such as willows as well as pastures such as *Phalaris*. However, good vegetation still remains. Large areas of Dry Schlerophyll forests on the upper slopes tend to be in reasonable condition (for the most part) with a high diversity of native species in all structures. There are moderate to good Box-Gum remnants and swampy meadows remaining in small patches. Refer to Appendix 1 for a Burra Region species list. The high diversity of vegetation not only protects soils and contributes to biodiversity but provides important habitat for a range of wildlife including a number of threatened species.

Burra Landscape Management Plan

The Burra Landscape Management Plan builds on historical learnings and past investments in the Burra landscape. It also builds on recent project work by Molonglo Catchment Group assisting 85 landholders to manage their land to capability and remediating erosion through a series of land management workshops and site visits (funded through the NSW South East Local Lands Services).

This report is also informed by recent detailed Hydrogeological Landscapes mapping by Department of Primary Industries (commissioned by MCG and South East LLS) which used a mixture of geology, salinity and soil vulnerability science to create detailed maps and management recommendations. It revealed a series of highly vulnerable, priority sites for remediation throughout the Burra sub-catchment and noted the importance of educating and assisting the many new hobby farmers managing these fragile lands. The HGL report provided tailored recommendations for land management actions to prevent sediment loss and dryland salinity and was presented to the Burra community during a series of workshops on erosion in 2017. Through these workshops, it was clear that the application of the HGL method would be extremely useful for property planning.

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Land Management Framework for the Burra Creek Catchment

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The LMF provides information on the landscape, the soils, types of erosion and importantly the soils management action required to address erosion. The Framework draws on both Soil Landscapes and Hydrogeological Landscapes, which can be accessed via eSPADE. http://www.environment.nsw.gov.au/eSpade2WebApp

Enabling systems including various classifications, ratings and metrics were taken from the soil landscapes and HGLs or generated from their data. Each system provides specific information to form the LMF.

Enabling System	**Service**
Landscape Function	How the landscape works
Management Areas	Readily understood landform elements (eg crests, Rises)
Land and Soil Capability	Land capability to sustain a range of land uses
Soil Regolith Stability	Sediment delivery to streams due to soil disturbance
Soil Conservation Earthwork (SoilWorks)	Engineering properties of soils
Soil Classification	Soil properties

1. SOIL LANDSCAPES

Soil landscapes of the Michelago 1:100 00 map sheet area (Jenkins, 1993) have been used as a primary data source for soil regolith stability classification, soil types and the SoilWorks classification. Soil Landscapes for the Burra Creek Catchment are mapped below in figure 6.

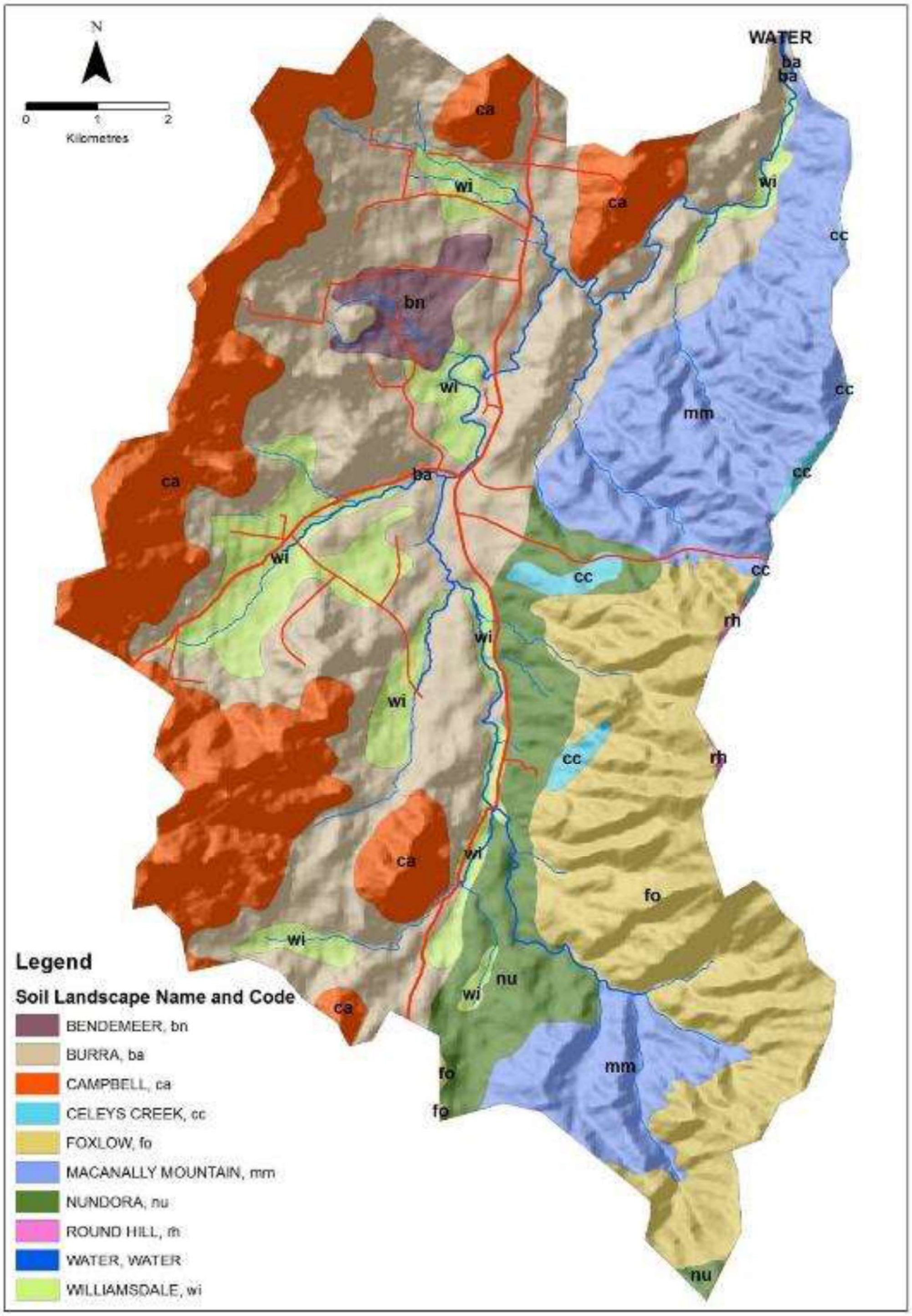


Figure 6: Soil Landscapes in the Burra Creek Catchment.

2. HYDROGEOLOGICAL LANDSCAPES

The Hydrogeological Landscapes (HGLs) of Burra catchment (DPI/OEH 2017) have been used as a primary data source in the development of the Burra Catchment Landscape Management Framework. The HGL descriptions provide the management area units used in this report, detailed landscape function information and comprehensive salinity management recommendations. Figure 7 illustrates the distribution of HGLs within the Burra Creek Catchment.

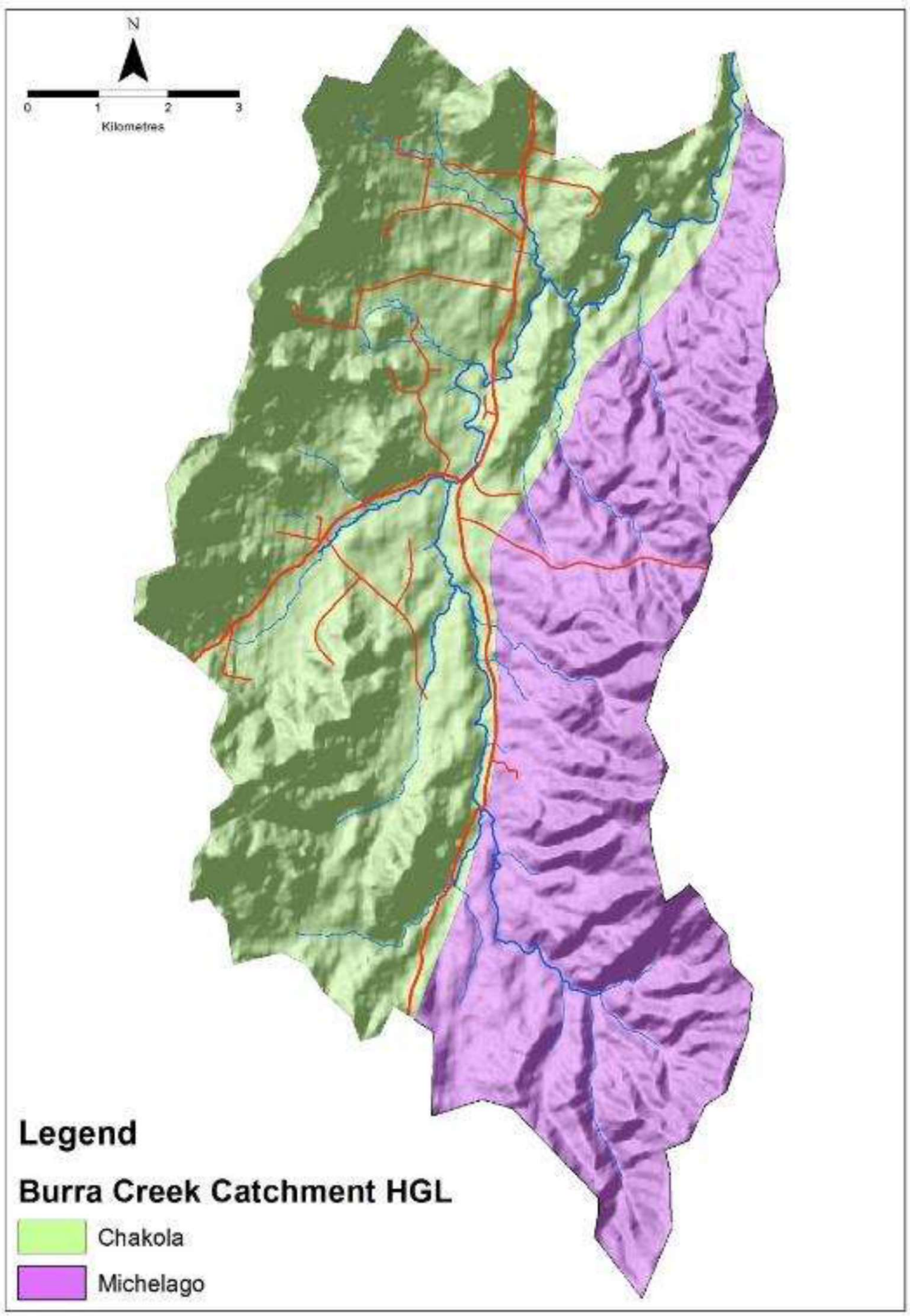


Figure 7: HGL distribution Map for the Burra Creek Catchment

2.1. LANDSCAPE FUNCTION

The different functions that a landscape can provide, from a soil conservation viewpoint, are listed below and described in the Land Management Framework descriptions for Michelago and Chakola. Landscape functions that can be ascribed to a landscape are listed below:

- **SC_A** The landscape provides fresh water (sediment free)
- **SC_B** The landscape generates sediment from surface water runoff and processes (sheet and rill erosion)
- **SC_C** The landscape generates sediment from gully erosion, head cuts and sidewall expansion (gully erosion)
- **SC_D** The landscape generates sediment from instream processes and streambank erosion
- **SC_E** The landscape contains high hazard for acid sulfate processes
- **SC_F** The landscape contains high hazard for sodicity, and for generating sodic sediments.
- **SC_G** The landscape contains high hazard for mass movement
- **SC_H** The landscape contains high hazard for acidification
- **SC_I** The landscape contains high hazard for wind erosion
- **SC_J** The landscape contains high hazard for structural decline
- **SC_K** The landscape contains high hazard for decline in soil fertility
- **SC_L** The landscape contains high hazard for infrastructure stability
- **SC_M** The landscape is inherently acid
- **SC_N** The landscape lacks organic matter and/or biological activity
- **SC_O** The landscape is inherently infertile

There may be multiple functions for each landscape, as landscapes are often highly variable.

2.2 HYDROGEOLOGICAL LANDSCAPE (HGL) 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 1).

Table 1: Standardised HGL 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	Rise
MA 7	Saline site
MA 8	Structurally controlled saline site
MA 9	Alluvial plain
MA 10	Alluvial channel

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 as conceptual cross-section for the individual HGL as shown in Figure 8, or spatially on a map as shown in Figure 9. The management areas are based in part on the terminology used in the Australian Soil and Land Survey Field Handbook (NCST 2009).

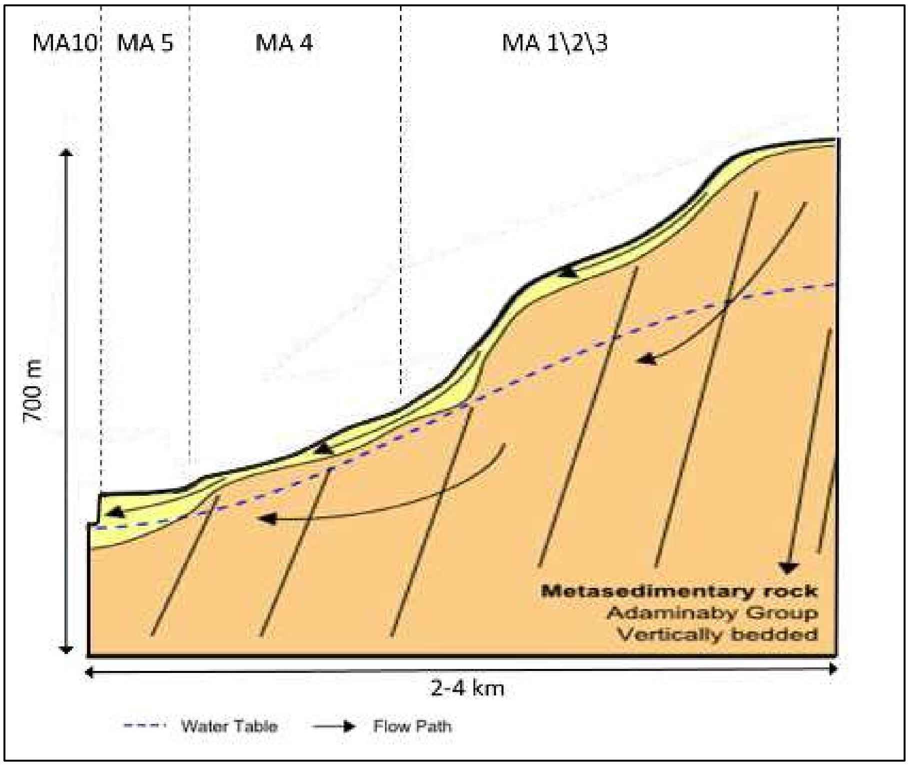


Figure 8: Conceptual Cross-section for Michelago HGL showing Management Areas

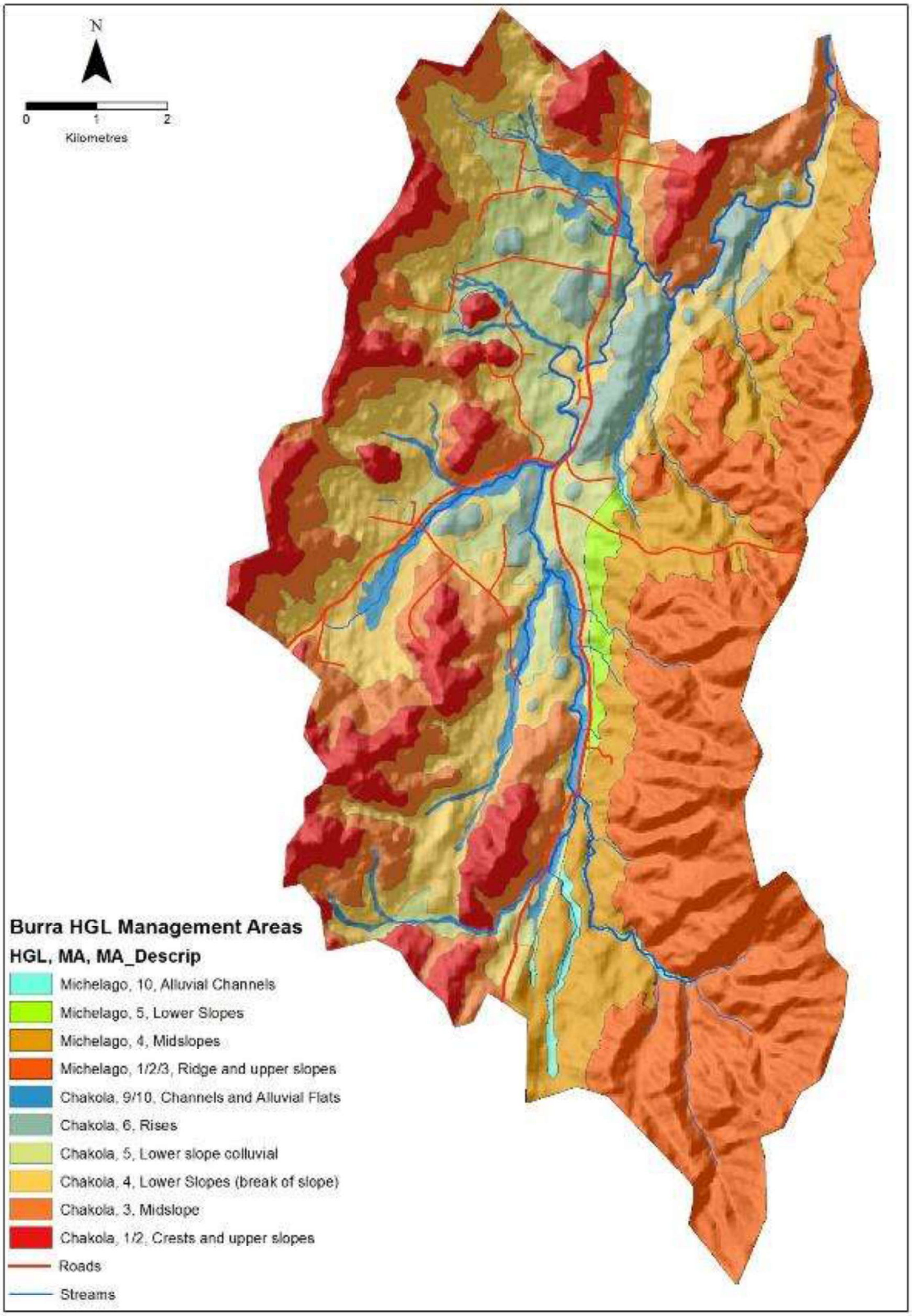


Figure 9: Map showing Hydrogeological Landscapes and Management Areas of the Burra Creek Catchment

3. 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 (Dent & Young 1981). Failure to manage land in accordance with its capability risks results in 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 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 2.

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.

LSC provides a mechanism to consider land and soils in a resilience framework. It may be defined as: "the ability of the land and soil to absorb disturbance and still retain its basic function and structure.

The current 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.

Table 2: Land and Soil 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 of 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 impact 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.

For the Burra Catchment, both HGL units contain several LSC classes. Dominant classes are derived for each HGL management area. However, it is likely that both higher and lower classes will be present in localised areas of each management area.

An example of how overall LSC is developed and reported in the Land Management Framework descriptions for each Management Area is shown in table 3. Overall land and soil capability can then be mapped. LSC for the Burra Catchment is shown in figure 10.

Table 3: Land and Soil Capability (LSC) Classification for each Management Area (MA) in the Michelago HGL

LAND DEGRADATION HAZARD	MA 1\2\3	MA 4	MA 5	MA 10
WATER EROSION	**6**	**4**	**4**	**8**
WIND EROSION	3	3	3	3
STRUCTURAL DECLINE	3	3	3	3
SHALLOW SOILS AND ROCKINESS	7	4	4	1
MASS MOVEMENT	1	1	1	1
SALINITY	3	3	3	6
WATERLOGGING	2	3	3	6
ACIDITY	5	5	5	5
OVERALL LAND AND SOIL CAPABILITY	**7**	**5**	**5**	**8**

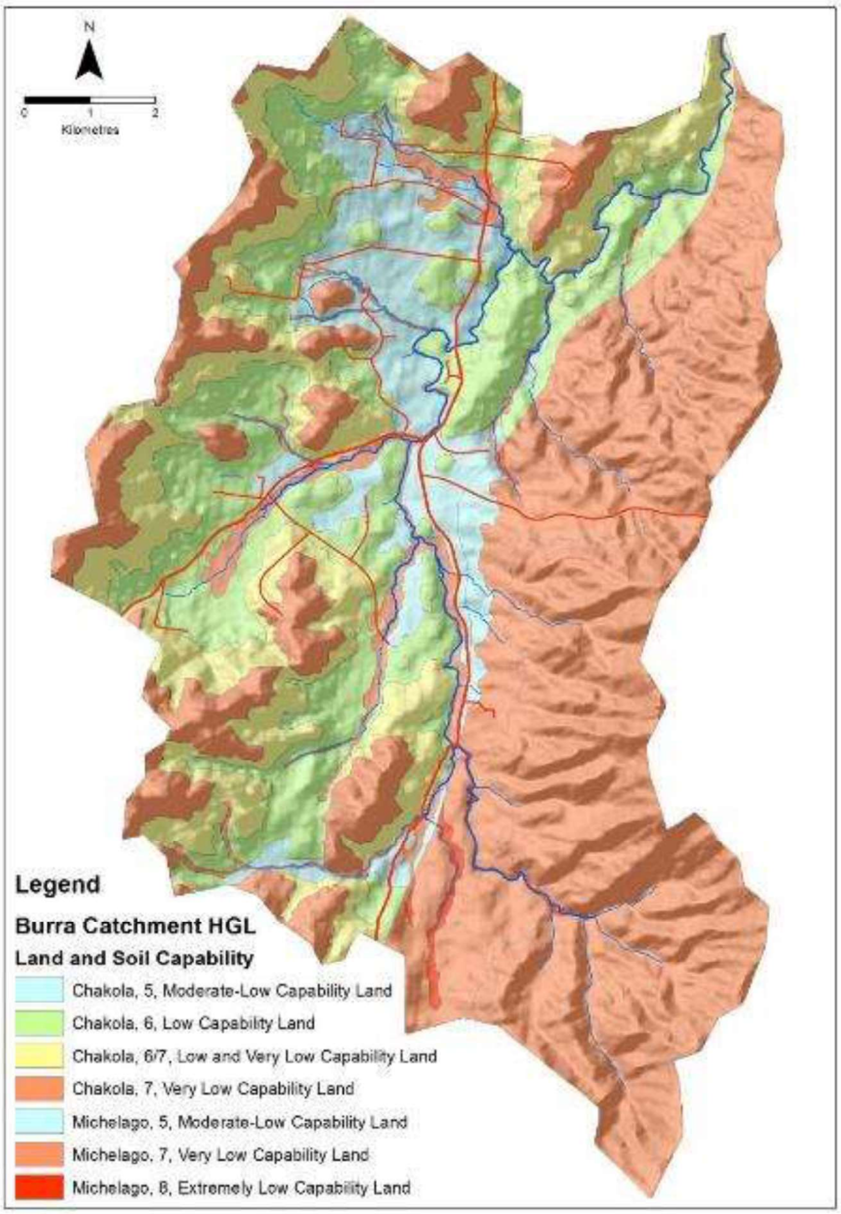


Figure 10: Land and Soil Capability Map for each HGL in the Burra Creek catchment.

4. SOIL REGOLITH STABILITY

Each Management Area has been classified into Soil Regolith Stability Classes (Murphy *et al.* 1998). Soil regolith stability is an expression of combined soil and substrate erodibility and sediment delivery potential.

The soil regolith stability class is a useful predictor of how likely a soil is to cause turbidity in surface waters and long-distance sedimentation down the catchment, if the soil is disturbed. It is a logical two by two matrix giving four regolith classes (R1 to R4) as shown in Table 4.

Table 4: Soil Regolith Stability Classification Matrix

		Potential for sediment to move long distance	
		LOW (sediment is coarse)	HIGH (fine clay particles)
Potential for soil to release sediment	HIGH (low soil stability)	**R2**	**R4**
	LOW (high soil stability)	**R1**	**R3**

It has been possible to allocate a regolith classification to all management areas based on dominant soil types.

The Soil Regolith Classification system is summarised in Table 5.

Table 5: Soil Regolith Stability Classification Guide

Soil Regolith Stability Class	Soil field behaviour	Soil regolith criteria	Soil types[1]
Class R1 *High coherence soils with low sediment delivery potential*	Stable soils with no appreciable erosion. Generally well-drained, permeable soils. Earth batters stable. Little or no general evidence of coarse or fine sediment movement.	Extensive rock outcrop.	Lithosols (Tenosols, Rudosols).
		Very stony or very gravelly well-armoured soils, well-drained, often occurring on ridgelines and steep slopes. Variety of soils including fine-grained sediments and metasediments, fine grained volcanic soils.	Stony soils (> 20 % stone throughout) includes Lithosols (Tenosols, Rudosols), and stony and gravelly Podzolic Soils (Kurosols), stony Red Brown Earths (e.g. Chromosols, Stony Non Calcic Brown soils)

Soil Regolith Stability Class	Soil field behaviour	Soil regolith criteria	Soil types[1]
		Strongly structured, freely draining soils, generally non-slaking and non-dispersible. Generally reddish or dark brown coloured subsoils without an A2 horizon. Includes iron-rich soils from sedimentary and mafic volcanic rocks and highly weathered granodiorites and microgranites in high rainfall areas.	Krasnozems (Red Ferrosols), Xanthozems (Dermosols), Euchrozems (Ferrosols,Dermosols) Chocolate Soils (Brown Ferrosols), Terra Rossa Soils (Dermosols) Structured Red Earths, Structured Loams (Dermosols). Prairie Soils (Dermosols)
		Highly organic soils, very resistant to erosion and generally associated with swamps.	Peats and Alpine Humus Soils (Organosols)
Class R2 *Low coherence soils (when wet) with low sediment delivery potential*	Sandy soils which, when exposed, commonly exhibit sheet wash and evidence of coarse sediment movement such as sediment fans at drain outlets and in gutters. Little sediment transport into drainage network.	Coarse sandy soils often derived from coarse-grained and quartz-rich sandstone, conglomerate, granite, adamellite and volcanic materials. High sand content and little clay and silt content throughout profile. Sandy or earthy fabric.	Coarse grained: colon? Siliceous Sands and Calcareous Sands (Rudosols, Tenosols), Podzols (Podosols), Earthy Sands (Tenosols), some sandy Yellow Earths (Kandosols) and Yellow Podzolic Soils with deep (> 50 cm coarse sandy topsoils) and stable clay subsoils (Kurosols). Desert Loams (Rudosols)
		Unconsolidated coastal and aeolian sands and sandy colluvium.	As above.

Soil Regolith Stability Class	Soil field behaviour	Soil regolith criteria	Soil types[1]
Class R3 *High coherence soils with high sediment delivery potential*	Clayey and silty soils which are liable to sheet erosion. Typically slowly permeable and drainage generally impeded. Earth batters and exposed surfaces subject to minor to moderately extensive rill erosion and minor slumping. Minor gully erosion may develop in drainage lines and incision may occur along road drains. Localised films of fine sediment at drain outlets and in drainage lines.	Soils formed on fine grained acid volcanic, metasedimentary and sedimentary rocks. Duplex soils with clay or silty B horizon, slowly permeable, weakly to moderately structured, often with a pronounced A2 horizon. B horizons usually yellow or grey to light brown colours, commonly mottled. Tendency to slake to small stable aggregates (not individual particles) and not highly dispersible.	Red, Brown, Yellow and Grey Podzolic Soils and non-dispersible Soloths (Kurosols). Black Earths (Vertosols), Red, Brown and Grey Clays (Vertosols), Humic Gleys (Hydrosols), Red Brown Earths and Non-Calcic Brown Soils (Chromosols), Rendzina (Dermosols)
Class R3 *cont.* *High coherence soils with high sediment delivery potential*		Weakly to moderately structured soils, with silty to clay textures and gradational to uniform texture profiles. Tendency to slake but not highly dispersible. Hard-setting when dry but often boggy when wet. Developed on colluvial/alluvial surfaces, range of fine-grained highly- weathered siliceous rocks and some basic and intermediate volcanic lithologies such as trachyte.	Some fine grained Red Earths and Yellow Earths (Kandosols).

Soil Regolith Stability Class	Soil field behaviour	Soil regolith criteria	Soil types[1]
Class R4 *Low coherence soils (when wet), with very high fine sediment delivery potential.*	Unstable, dispersible soils which are prone to severe sheet and rill erosion and to gully erosion. Rill erosion and/or slumping common on batters and gully erosion common in drainage lines and along road drains. Snig tracks display frequent rill erosion. Drainage lines show extensive fine sediment films.	Clay or silt textured soils, which slake to very fine particles and/or are highly dispersible. Massive to coarsely structured, frequently sodic. Often have bleached surface horizon. May include duplex soils with sandy non-coherent surface over unstable clay subsoil. Generally found on lower slopes and low undulating terrain associated with weathered colluvium and alluvium or siliceous rocks.	Soloths, Solodic and Solodized Solonetzic (Sodosols, natric Kurosols).
1. Great Soil Groups (Stace *et al*. 1968) with Australian Soil Classification (Isbell 2002) in brackets			

5. SOIL CONSERVATION SERVICE EARTHWORK (SOILWORKS) CLASSIFICATION

Soil conservation earthworks are earthen structures designed and constructed to minimise soil erosion by intercepting and/or diverting runoff. The main earthworks are dams for water retention, gully control structures for restricting erosion in gullies and banks for diverting water flow.

Limitations for earthworks for each management area are assessed from the local knowledge of experienced soil conservationists, soil test result and interpretations and recommendations for small dams from soil test data (Crouch *et al*. 2000). The classification ranges from 'A' – Suitable for normal [earthwork] use to 'K' – Not recommended [for earthworks]. Table 6 provides details of this classification.

Table 6: SoilWorks Classes for Earthworks

SoilWorks Class	General definition
A	Suitable for normal use. Take care to achieve good compaction, preferably with moist soil. If the soil is dry (cannot be moulded without breaking), reduce layer thickness to <15 cm. Minimum batter grades 1:2.5 upstream, 1:2 downstream, except for CH and MH classifications when they should be decreased to 1:3 and 1:2.5, respectively.
B	This material is stable and impervious when well compacted--to at least 85 per cent of Proctor maximum dry density. To achieve this, the soil should be close to the optimum moisture content for compaction plant, be placed in layers <15 cm thick and compacted with four complete passes of a crawler tractor or roller. For crawler tractors, the soils should be sufficiently moist to be made into a thread 10 mm thick, but not moist enough to be rolled thinner than 3 mm without breaking. Minimum batter grades 1:3 upstream, 1:2.5 downstream.
C	Aggregated material which may not hold water. Compact with at least four passes of a sheeps-foot roller when the soil is slightly wet of optimum (can be rolled into a 3 mm diameter thread). Use a vibrating roller for dry soils An ameliorant--STPP or sodium carbonate--is probably required. If EAT is Class 6 or dispersion percentage is less than 10, then the dam is likely to leak unless sealed with better clay or treated with an ameliorant to induce dispersion.

SoilWorks Class	General definition
D	This soil is highly susceptible to tunnelling or piping failure. It must be well compacted throughout to reduce permeability and saturation settlement. If drier than optimum, gypsum or hydrated lime should be used at 1 t/750 m3 of wall to reduce dispersion. The soil should be compacted to at least 85 per cent of Proctor maximum dry density by ensuring the correct moisture content (see Recommendation B), placing in layers <15 cm thick and rolling with at least four complete passes of the plant. For additional stability, the structure should be designed to hold no more than 1 m of water against the wall and batter grades should be decreased to 1:3.5 upstream and 1:3 downstream.
E	This soil is very susceptible to tunnelling or piping failure. In addition to Recommendation D, the structure must hold no more than 1 m depth above the original ground surface at the upstream side of the wall and not be subject to more than 0.3 m/day drawdown (trickle pipes must not be more than 0.3 m below top water level). Gypsum or hydrated lime at 1 t/750 m3 of wall should be incorporated in the upstream side of the wall. The upstream batter grades should be decreased to 1:4.
F	This soil is very susceptible to tunnelling or piping failure. Due to the high shrink-swell potential, batter grades must be decreased. In addition to Recommendation D, freeboard must be increased to at least 1 m above surcharge level and hydrated lime or gypsum should be applied at rates determined in the laboratory. Batter grades should be decreased to 1:4 upstream and 1:3 downstream.
G	The high shrink-swell potential of this soil can result in cracks extending through the wall below top water level. To reduce this possibility, a compact central core (at least 85 percent Proctor maximum compaction) must be obtained by constructing when the soil is sufficiently moist to be rolled into a 10 mm diameter thread, but not moist enough to roll to 3 mm without breaking. The freeboard must be increased to at least 1 m above surcharge to prevent surface cracks extending below the waterline. Recommended batter grades are 1:35 upstream and 1:3 downstream. The structure must be designed to retain sufficient water to keep the wall moist and minimise crack development.
H	Not recommended unless the following precautions can be implemented. The central core must be well compacted, preferably with a vibrating sheeps-foot roller, to obtain a density of at least 85 per cent Proctor maximum as determined in the laboratory. The settled freeboard must be increased to 1 m above surcharge level and batter grades should be to at least 1:4 upstream and 1:3 downstream.
I	Pervious. Not recommended for general use but may be used in a zoned embankment or sealed with bentonite or a plastic line. Recommended batter grades are 1:3 upstream and 1:3 downstream.
J	Not recommended.
K	Not recommended.

6. SOIL LANDSCAPES AND SOIL CLASSIFICATION FOR EACH MANAGEMENT AREA

Soil Landscapes are areas of land with unique landform features and characteristic soil types. Because landscapes and their soils are formed by the same natural processes soils can generally be mapped on a landscape basis. OEH has undertaken Soil Landscape mapping of the Burra Catchment as part of the Soil landscapes of the Michelago 1:100 00 map sheet area (Jenkins, 1993)

Soil classification groups soils by their properties, behaviour or development, The Australian Soil Classification (Isbell 2002) is the classification system currently used to classify and describe soils in Australia. It supersedes the Great Soil Groups (Stace et al. 1968) and the Factual Key (1979).

For each management area the dominant Soil Landscape and dominant soil types are listed as shown in the example for Michelago HGL in Table 7.

For ease of comparison all three soil classifications are provided.

Table 7: Soil Landscapes and Dominant Soil Types for each Management Area in the Michelago HGL.

	MA 1/2/3	MA 4	MA 5	MA 10
Dominant Soil Landscape	Foxlow Macanally Mt.	Macanally Mt. Foxlow Nundora	Nundora	Nundora Foxlow Macanally Mt
Great Soil Group	Lithosols	Lithosols Red Podzolic Soils Red and Yellow Earths	Yellow Podzolic Soils Red Podzolic Soils Non Calcic Brown Soils	Solodic Soils Siliceous Sands
Australian Soil Classification	Rudosols	Rudosols Red and Brown Kurosols	Brown Kurosols Brown Chromosols Magnesic Brown Kurosols	Magnesic Sodosols Rudosols
Factual Key	Um1.41 Um1.42 Um 1.43	Uc1.44 Um1.44 Dr3.11 Dr2.21	Dy3.41 Dr3.42	Dy3.43 Uc1.23

7. SOIL AND LAND DEGRADATION MANAGEMENT ACTIONS

Soil and land degradation are driven by interactions between land management, environmental limitations and climatic events. The influence of both continual and episodic climatic events on land degradation can be severe. The impacts of extreme weather events need to be considered when deciding on appropriate management actions. It is also important to identify the optimal management strategies and actions relevant to any given parcel of land to maintain soil health and minimise land degradation.

Management actions deliver management outcomes. Detailed specific management actions are assigned to appropriate management areas, ensuring that the management options are applicable to all parts of the landscape. Recommended management actions are specified for each management area in each Burra Land Management Framework description.

If a management action in Table 8 is considered hazardous, it is included in the High Hazard Land Use section of each Burra *Land Management* Framework description.

An expanded list of vegetation for ecosystem service **(VE)** and vegetation for production **(VP)** actions aimed at salinity management can be found in Wooldridge *et al.* (2015).

Table 8: Groups of Management Actions for Soil and Land Degradation

Management Action Group	Code	Management Action
Animal management	AM1	Control total grazing pressure - kangaroos
	AM2	Exclusion fencing
	AM3	Feral animal control
Acid sulfate hazards	AS1	Improve or maintain the hydrological regime to keep acid sulfate soil saturated

Management Action Group	Code	Management Action
	AS2	Isolate and improve acid sulfate soil sites
Biological and vegetative soil remediation	BV1	Green manuring
	BV2	Compost application (e.g. biosolids and organics)
	BV3	Mulching
	BV4	Revegetation with native/exotic species
	BV5	Filter strips
	BV6	Strip cropping
	BV7	Biological additives – compost tea
Chemical soil remediation	CR1	Sodicity – lime and gypsum application
	CR2	Fertiliser application
	CR3	Lime application
Gully stabilisation	GS1	Gully control structures
	GS2	Gully control structures with pipe to handle trickle flow
	GS3	Rock groins and gabions – control structures constructed to account for sodic soils. Refer to SCS training manuals for conservation earthworks
	GS4	Flumes (masonry/rock/chute)
	GS5	Gully fill
	GS6	Gully shaping
	GS7	Gully edge ripping
	GS8	Manage gullies (and headcuts) using construction methods appropriate for region
Sediment control	SC1	Sediment and erosion control (design, implementation)
	SC2	Implementation of stormwater and sediment management measures
Stream stabilisation	SS1	Weirs (loose rock, concrete)
	SS2	Gabion structures and rock revetment
	SS3	Loose rock channels
	SS4	Concrete lined channels

Management Action Group	Code	Management Action
	SS5	Batter rehabilitations – jute mesh/spray seed – long term stability
	SS6	Fishways
	SS7	Stream crossings
Stormwater	SW1	Flood detention basins and stormwater management
	SW2	Water sensitive urban design (WSUD) measures
	SW3	Constructed wetlands
	SW4	Sediment traps and sediment control works
	SW5	Stream bank stabilisation measures
Tracks and access	TA1	Track location and design
	TA2	Track drainage
	TA3	Track maintenance and monitoring
	TA4	Track surfacing
Vegetation for ecosystem service	VE1a	Establish and manage blocks of trees and shrubs to control land degradation
	VE3a	Maintain and improve existing native woody vegetation to control land degradation
Vegetation for production	VP1a	Improve grazing management of existing perennial pastures to manage land degradation

7.1. HIGH HAZARD MANAGEMENT ACTIONS

Inappropriate management actions will impact on land and soil affecting agricultural production and the environmental amenity. Eighteen high hazard management actions are presented. These have the potential to make salinity and soil and land degradation problems worse and may override positive management actions. If a land use action is identified as high hazard it should be actively discouraged.

Specific high hazard management actions are identified for each management area in the High Hazard Land Use section of each Burra Land Management Framework description. The list of high hazard land uses in table 8 is not exhaustive and new management actions or land management techniques can be added after salinity and soil and land degradation impacts have been assessed.

Michelago HGL Land Management Framework

1. OVERVIEW

This Land Management Framework (LMF) description is for the Michelago HGL in the Burra Creek catchment. It utilises information derived from the soil landscapes of the area. The description deals with issues (Table 9) and actions for management of land degradation and soil health. Specific management actions are recommended for different elements of the landscape.

The Michelago Hydrogeological Landscape (HGL) in the Burra Creek Catchment, is located East of the Burra Road. From to the confluence of the Burra Creek and Queanbeyan river in the north to the headwaters of Burra Creek in the south (Figure 11). The Michelago HGL covers an area within of the Burra Creek Catchment of 40 km^2 and receives 550 - 750mm of rain per annum.

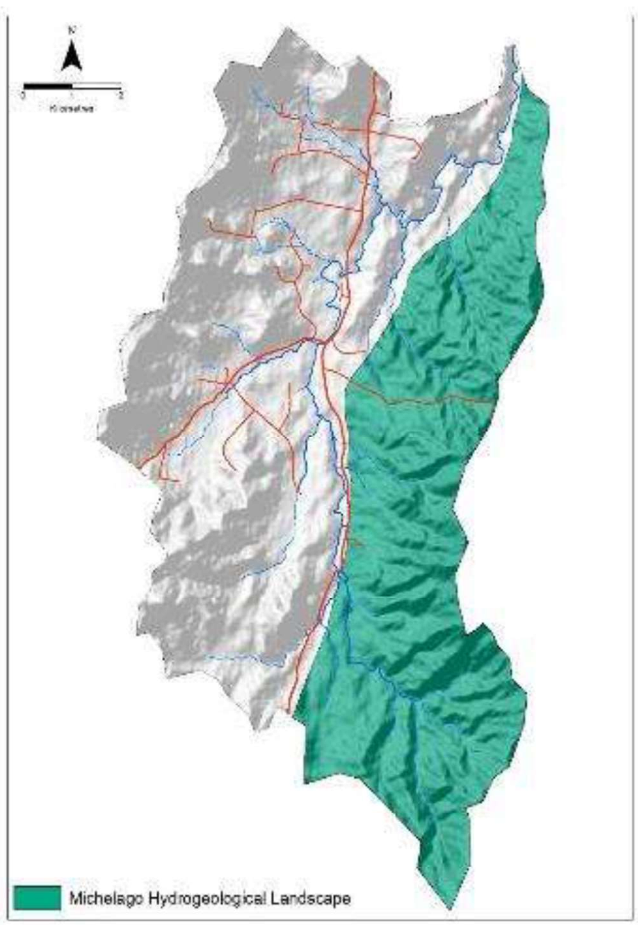


Figure 11: Michelago HGL Distribution Map.

Table 9: General Management Issues for Soils in this HGL.

Functions	• **SC_B:** The landscape generates sediment from surface water runoff and processes (sheet and rill erosion) • **SC_C:** The landscape generates sediment from gully erosion, head cuts and side wall expansion (gully erosion).
General management issues	• Sheet erosion • Shallow Soils • Overgrazing • Stream bank erosion
General management comments	Preservation and enhancement of existing vegetation is the dominant management issue.

2. LANDSCAPE CHARACTERISTICS

The Michelago HGL is a steep catchment-based unit defined by Ordovician metasediments (Figure 12).

The HGL has thin acidic soils. The HGL is dominated by native timber. The land use of the area is conservation and minor grazing.

Figure 12: Google Earth image of typical Michelago HGL Terrain (Image © 2015 Digital Globe; Image © 2015 Aerometrex; Image Landsat; © 2015 Google).

Photo 1: Michelago HGL (Photo: DPI / A Nicholson).

Photo 2: Michelago HGL (Photo: DPI / A Nicholson).

3. MANAGEMENT AREAS

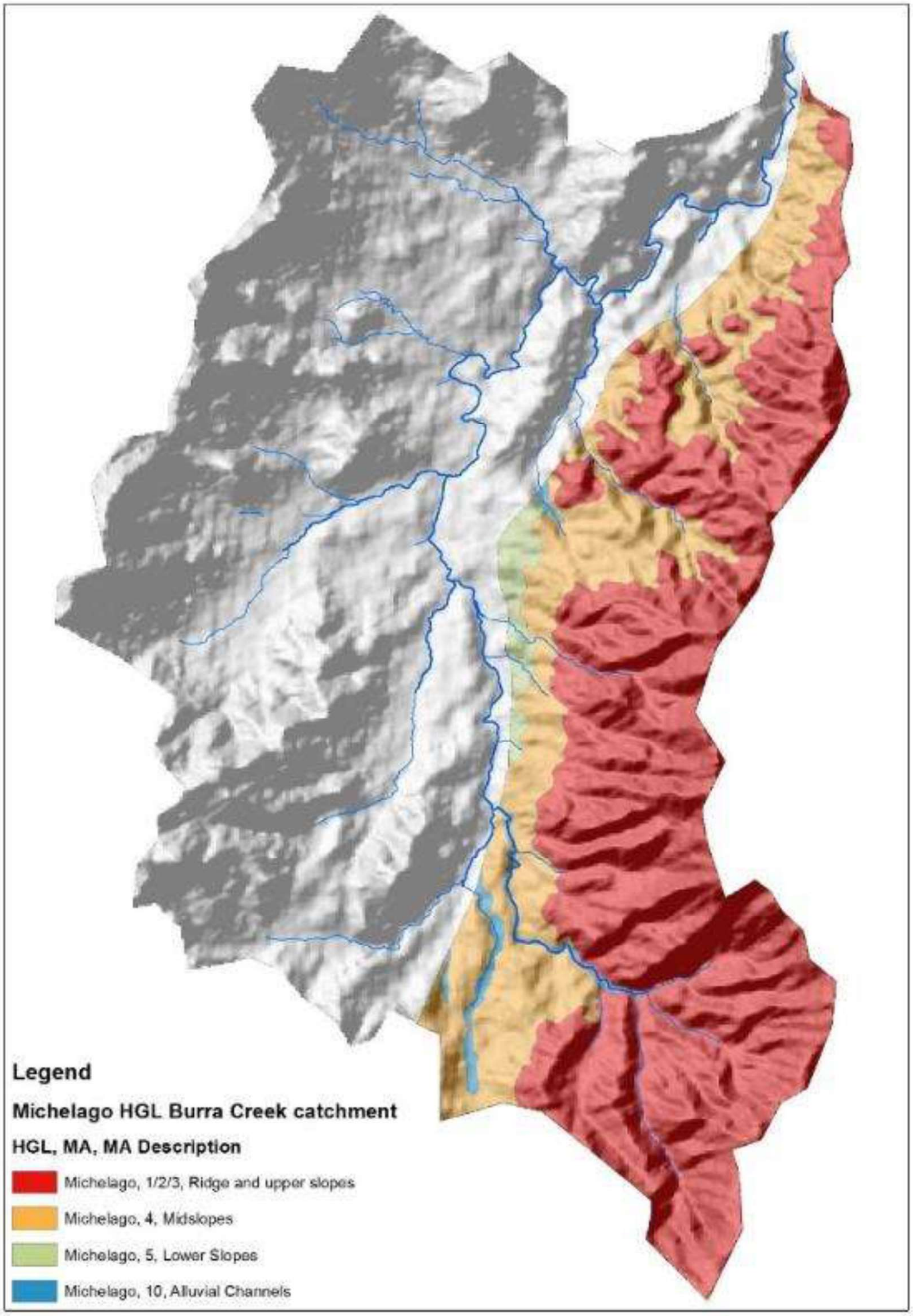


Figure 13: Spatial Distribution of Management Areas for Michelago HGL.

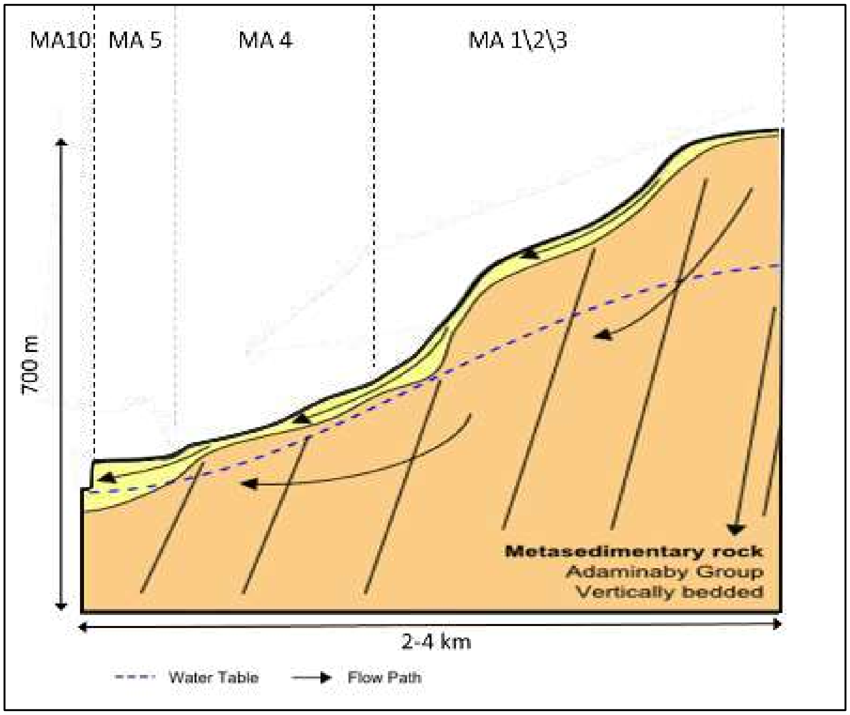


Figure 14: Conceptual Cross-section for Michelago HGL showing Management Areas.

4. LAND AND SOIL CAPABILITY

The LSC classification uses biophysical features of the land including landform position, slope gradient, drainage and climate together with 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. Land and soil capability is discussed fully in OEH (2012). LSC classes for this HGL are given in Table 10.

Table 10: Land and Soil Capability (LSC) Classification for each management area (MA) within the Michelago HGL.

Land degradation hazard	MA 1\2\3	MA 4	MA 5	MA 10
Water Erosion	6	4	4	8
Wind Erosion	3	3	3	3
Structural Decline	3	3	3	3
Shallow Soils and Rockiness	7	4	4	1
Mass Movement	1	1	1	1
Salinity	3	3	3	6
Waterlogging	2	3	3	6
Acidity	5	5	5	5
Overall	**7**	**5**	**5**	**8**

5. SOIL REGOLITH STABILITY

Soil regolith stability classification is a useful predictor of how likely a soil is to cause turbidity in surface waters and long-distance sedimentation down the catchment if the soil is disturbed. It is derived from a logical two by two matrix giving four regolith classes (R1 to R4). Soil regolith stability is described fully in Murphy *et al.* (1998). Soil regolith stability classes for this HGL are given in Table 11 along with key soil properties.

5. SOILWORKS CLASSIFICATION

This classification indicates suitability for soil conservation earthworks. It was developed by the NSW Soil Conservation Service (SCS). Soil conservation earthworks are earthen structures designed and constructed to minimize soil erosion by intercepting and/or diverting runoff. The main earthworks are dams for water retention, gully control structures for restricting erosion in gullies and banks for diverting water flow. The classification ranges from 'A' (suitable for normal earthworks) to 'K' (not recommended for earthworks). Training manuals for conservation earthworks can be obtained from SCS – http://www.scs.nsw.gov.au/education-and-training. SoilWorks classes for this HGL are given in Table 11.

Table 11: Key Soil Properties relevant to Land Management for each Management Area (MA) of the Michelago HGL. Regolith Stability Class in brackets.

	Soil Properties	SoilWorks Classification
MA 1/2/3	Shallow soils **(R1)** Shallow soils **(R3)**	**J:** Earthworks not recommended
MA 4	Shallow and acid texture contrast soils with red coloured B horizon **(R3)**	**J:** Earthworks not recommended
MA 5	Moderately deep, acidic, texture contrast soils with a bleached hard setting A2 horizon and red subsoils. (R3)	**H:** Not recommended unless the following precautions can be implemented. The central core must be well compacted, preferably with a vibrating sheeps-foot roller, to obtain a density of at least 85 per cent Proctor maximum as determined in the laboratory. The settled freeboard must be increased to 1 m above surcharge level and batter grades should be to at least 1:4 upstream and 1:3 downstream.
MA /10	Texture contrast soils with a bleached hardsetting A2 horizon and mottled dispersible subsoil. These soils are highly erodible and prone to gully erosion **(R4)** Shallow soils **(R3)**	**J:** Earthworks not recommended

7. SOIL LANDSCAPES AND SOIL CLASSIFICATIONS FOR EACH MANAGEMENT AREA

Soil variation within and across a landscape depends on many environmental variables. The delineation of management areas (MA) reflects these differences. Soil types and behaviors can be extrapolated from known soil properties and landscape position within an area. The likely soil types expected to be found in each management area in this HGL are detailed in Table 12.

Table 12: Dominant Soil Types for each Management Area (MA) within the Michelago HGL.

	MA 1/2/3	MA 4	MA 5	MA 10
Dominant Soil Landscape	Foxlow Macanally Mt.	Macanally Mt. Foxlow Nundora	Nundora	Nundora Foxlow Macanally Mt
Great Soil Group	Lithosols	Lithosols Red Podzolic Soils Red and Yellow Earths	Yellow Podzolic Soils Red Podzolic Soils Non Calcic Brown Soils	Solodic Soils Siliceous Sands
Australian Soil Classification	Rudosols	Rudosols Red and Brown Kurosols	Brown Kurosols Brown Chromosols Magnesic Brown Kurosols	Magnesic Sodosols Rudosols
Factual Key	Um1.41 Um1.42 Um 1.43	Uc1.44 Um1.44 Dr3.11 Dr2.21	Dy3.41 Dr3.42	Dy3.43 Uc1.23

8. LAND AND SOIL MANAGEMENT OPTIONS

Land and soil degradation is driven by interactions between land management, environmental limitations and climatic events. Inappropriate management actions will impact on land and soil affecting agricultural production and the environmental amenity. It is important to identify the optimal management strategies and actions relevant to any given parcel of land to maintain soil health and minimise land degradation.

The influence of both continual and episodic climatic events on land degradation can be severe. The impacts of extreme weather events need to be considered when deciding on appropriate management actions.

8.1. Specific Targeted Actions

Management areas for this HGL description are illustrated in Figure 13. The specific management actions for these areas are described in Table 13.

Table 13: Specific Land and Soil Management Actions for Management Areas within the Michelago HGL.

Management Area (MA)	Action
MA 1 (RIDGES)	**Animal management** Control total grazing pressure - kangaroos/ rabbits **(AM1)** **Biological and vegetative soil remediation** Mulching **(BV3)** Revegetation with native/exotic species **(BV4)** **Vegetation and ecosystem service** Maintain and improve existing native woody vegetation to control land degradation **(VE3a)**
MA 4 (MID SLOPE – COLLUVIAL)	**Animal management** Control total grazing pressure - kangaroos/ rabbits **(AM1)** **Biological and vegetative soil remediation** Mulching **(BV3)** Revegetation with native/exotic species **(BV4)** **Gully stabilisation** Gully control structures with pipe to handle trickle flow **(GS2)** Rock groins and gabions – control structures constructed to account for sodic soils. Refer to SCS training manuals for conservation earthworks **(GS3)** Flumes (masonry/rock/chute) **(GS4)** Manage gullies (and headcuts) using construction methods appropriate for region **(GS8)** **Sediment control** Sediment and erosion control (design, implementation) **(SC1)** Implementation of stormwater and sediment management measures **(SC2)**
MA 5 (LOWER SLOPE – COLLUVIAL)	**Biological and vegetative soil remediation** Mulching **(BV3)** Revegetation with native/exotic species **(BV4)** **Gully stabilisation** Gully control structures with pipe to handle trickle flow **(GS2)** Rock groins and gabions – control structures constructed to account for sodic soils. Refer to SCS training manuals for conservation earthworks **(GS3)** Flumes (masonry/rock/chute) **(GS4)** Manage gullies (and headcuts) using construction methods appropriate for region **(GS8)** **Sediment control** Sediment and erosion control (design, implementation) **(SC1)** Implementation of stormwater and sediment management measures **(SC2)**

Management Area (MA)	Action
MA 10 (CHANNEL – ALLUVIAL)	**Animal management** Exclusion fencing **(AM2)** **Biological and vegetative soil remediation** Revegetation with native/exotic species **(BV4)** **Gully stabilisation** Rock groins and gabions – control structures constructed to account for sodic soils. Refer to SCS training manuals for conservation earthworks **(GS3)** Manage gullies (and headcuts) using construction methods appropriate for region **(GS8)** **Sediment control** Sediment and erosion control (design, implementation) **(SC1)** Implementation of stormwater and sediment management measures **(SC2)** **Stream stabilisation** Weirs (loose rock, concrete) **(SS1)** Gabion structures and rock revetment **(SS2)** Loose rock channels **(SS3)** Concrete lined channels **(SS4)** Batter rehabilitations – jute mesh/spray seed – long term stability **(SS5)** **Stormwater** Sediment traps and sediment control works **(SW4)** **Vegetation and ecosystem service** Maintain and improve existing native woody vegetation to control land degradation **(VE3a)**

8.2. High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative land and soil impacts as shown in Table 14.

Table 14: Management Actions having Negative Land and Soil Impacts in the Michelago HGL.

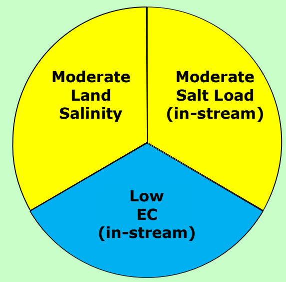
At Risk Management Areas	Action
MA 1	Poor management of grazing pastures **(DLU2)** Clearing and poor management of native vegetation **(DLU4)** Deep ripping of soils to maximise infiltration of water to subsoil **(DLU11)**

At Risk Management Areas	Action
MA 4	Gully shaping **(GS6)** Poor management of grazing pastures **(DLU2)** Annual cropping with annual plants **(DLU3)** Locating infrastructure on discharge areas **(DLU7)** Deep ripping of soils to maximise infiltration of water to subsoil **(DLU11)**
MA 5	Gully shaping **(GS6)** Poor management of grazing pastures **(DLU2)** Poor soil management – tillage causing poor structure **(DLU8)**
MA 10	Gully shaping **(GS6)** Poor management of grazing pastures **(DLU2)** Annual cropping with annual plants **(DLU3)** Clearing and poor management of native vegetation **(DLU4)** Locating infrastructure on discharge areas **(DLU7)**

Michelago Hydrogeological Landscape

Burra Creek Catchment

LOCALITIES	**Michelago Forest, Michelago Settlement**
MAP SHEET	**Canberra 1:100 000**
CONFIDENCE LEVEL	**Moderate**



1. OVERVIEW

The Michelago Hydrogeological Landscape (HGL) in the Burra Creek Catchment, is located East of the Burra Road from to the confluence of Burra Creek and Queanbeyan river in the north to the headwaters of Burra Creek in the south as seen in Figure 15. The Michelago HGL covers an area within of the Burra Creek Catchment of 40 km2 and receives 550 to 750 mm of rain per annum.

Michelago HGL is a steep, catchment-based landscape defined by Ordovician Adaminaby Group Geology as seen in Figure 16. Creek lines are generally stable. Burra Creek appears to be actively eroding above its confluence with Cassidys Creek in the Tinderry Nature Reserve.

The area is dominantly steep forested land with a small area of undulating lower slope that has been cleared. The cleared area includes the Concoeur, Coorumbene and Maniffera Hill properties, extending south to the Stoney Ridge property.

Land use includes a small area of grazing in the lower landform unit. A significant proportion of the Michelago HGL in the Burra Creek catchment (approximately 1/3) is Nature Reserve managed by NPWS.

There are a small number of properties within the uncleared area of this HGL, mostly located along Urila Road.

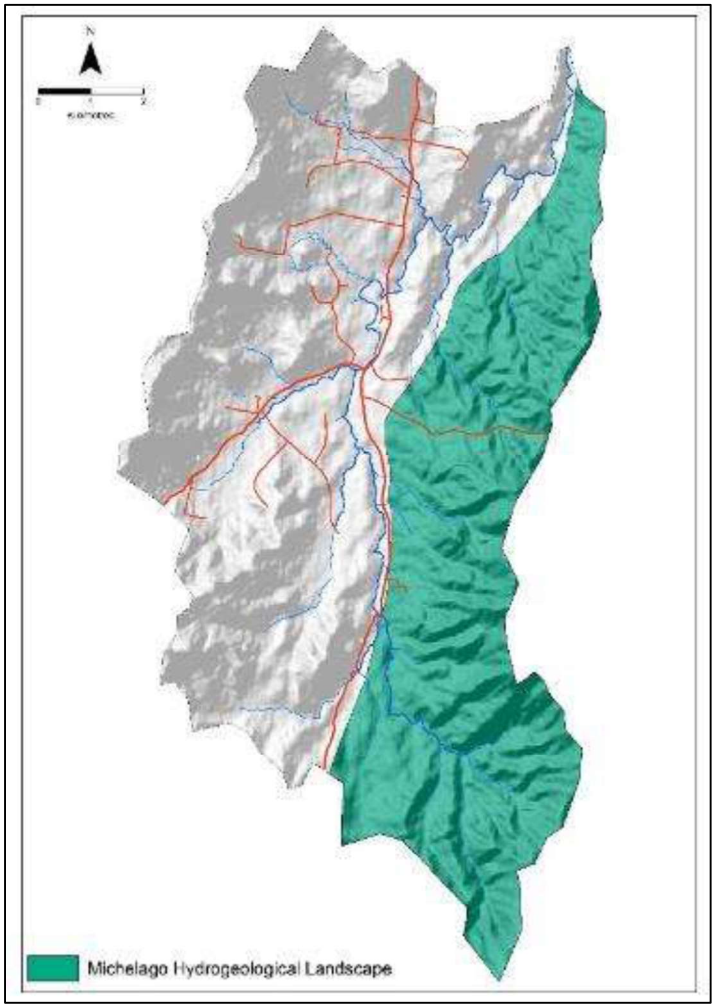


Figure 15: Michelago HGL distribution map.

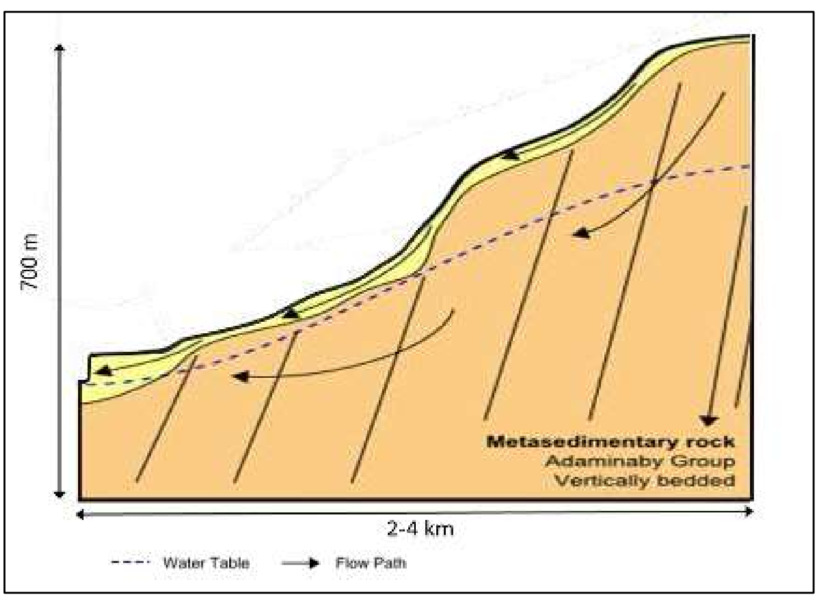


Figure 16: Conceptual cross-section for Michelago HGL showing the Distribution of Regolith and Landforms, Salt Sites present, and Flow Paths of Water Infiltrating the System.

Table 15: Michelago HGL Salinity Expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	Moderate - No land salinity has been observed in the Michelago HGL within the Burra Creek catchment. However outside of the Burra Creek Catchment this landscape has moderate to high land salinity
Salt Load (Export)	Low - Moderate – Intermittent flow in creek. Salt is derived from fractured rock aquifer in the metasediments
EC (Water Quality)	Low-Moderate – EC spikes within Burra Creek have been observed.

Salt store refers to the amount of salt stored in soil and geology materials. Salt availability refers to how easily this salt can be moved by water. Salt is stored in the Michelago HGL in fractures and within pore spaces of weathered rocks. Salt stored in this HGL has moderate mobility. Salt store and availability are moderate as seen in Table 16.

Table 16: Michelago HGL Salt Store and Availability.

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

Overall salinity hazard is based on the likelihood of salinity occurring and how much impact it would have. The overall salinity hazard in Michelago HGL within the Burra catchment is low Table 17.

Table 17: Likelihood of Salinity Occurrence, Potential Impact and Overall Hazard of Salinity for Michelago HGL.

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

Very Low	Low	Moderate	High	Very High

The current salinity hazard is low, however changes in land management could increase the salinity hazard. Due to the significant potential impact of salinity in the Michelago HGL combined with the moderate likelihood of occurrence if any changes were to occur, the Michelago HGL has a Moderate Overall Salinity Hazard.

2. LANDSCAPE FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 18.

Photo 3 Forested Hills of Michelago HGL in the Distance with Chakola HGL in the Foreground (Photo: W Cook)

Photo 4: Typical Soil Vegetation of the Michelago HGL from Urila Rd. (Photo; W Cook).

Photo 5: Ordovician Metasediments of the Michelago HGL. (Photo: W Cook).

Table 18: Summary of Information Used to Define Michelago HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2015)*	The dominant Geology is: Ordovician Metasediments • Adaminaby Group ○ Sandstone, Siltstone and Mudstone. Deposited in a deep marine environment 460 to 480 Ma.
Annual Rainfall	550–750 mm
Regolith and Landforms	Soil generally <0.2 m deep higher in the landscape and <1 m on lower slopes and in drainage lines. Shallow soils provide low potential for salt store. Slopes generally 32-56% (Steep); 3–10% (Moderately inclined) in valley bottoms Elevation range is 680–1320 m
Soil Landscapes *(Jenkins 1993; Jenkins 2000; Cook & Jenkins in prep)*	Soil landscapes include: • Foxlow • Macanally Mountain • Nundora Shallow well drained Rudosols (Lithosols) on crests and upper slopes. Moderately deep Red Kurosols (Red Podzolic Soils) on sideslopes. Deep imperfectly drained Magnesic Brown Kurosols (Yellow Podzolic Soils) and Mottled Magnesic Sodosols (Solodic Soils) on some lower slopes and in drainage depressions.
Land and Soil Capability	Class 7, minor class 5 on lower slopes
Land Use	• Nature Reserve • Grazing • Rural Residential
Key Land Degradation Issues	• Water erosion (sheet and streambank) • Soil acidity • Shallow soils
Native Vegetation *(Keith 2004; Gellie 2005; Dept. of Environment 2012)*	This HGL is situated within the IBRA7 South Eastern Highlands (Murrumbateman subregion) The HGL has limited clearing with remaining vegetation formations of Dry Sclerophyll Forest Local vegetation is described by Gellie (2005)

3. HYDROGEOLOGY

Typical values for the hydrogeological parameters of this HGL are summarised in Table 19.

Table 19: Summary of values for typical hydrogeological parameters of Michelago HGL.

Aquifer Type	Unconfined to semi-confined in fractured rock and saprolite Lateral flow through unconsolidated colluvial and alluvial sediments on 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	Moderate Range: 5 - 15%%
Hydraulic Gradient	Gentle to moderate Range: <10–30%
Groundwater Salinity	Fresh Range: <800 µS/cm
Depth to Watertable	Shallow to intermediate Range: <2–8 m
Typical Sub-Catchment Size	Small (100 - 1000 ha)
Scale (Flow Length)	Local Flow length: <5 km (short)
Recharge Estimate	Moderate
Residence Time	Medium (years)
Responsiveness to Change	Fast (months to years)

4. 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.

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

4.1. Landscape Functions

Landscape function is the highest order within the hierarchical HGL structure. Functions are inherent biophysical characteristics of a landscape which impact upon catchments. 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

Functions that the Michelago HGL 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.

4.2. Landscape Management Strategies

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.

4.3. Key Management Focus

The key management focus is to maintain and improve current vegetation levels. This landscape has the potential for salinity but this potential is minimised by the widespread native forest and nature conservation.

The area is highly erodible when cleared and would be susceptible to major erosion after fire.

4.4. Specific Land Management Opportunities

Specific opportunities for this HGL:

- Good native vegetation base
- Nature conservation
- Limited rural residential development

4.5. Specific Land Management Constraints

Constraints on land management in this HGL include:

- Fragile, infertile and shallow soils.
- Streambank and gullying will remain a long-term risk in the landscape.
- Lack of understorey vegetation.

4.6. Specific Targeted Actions

Management areas for this HGL are illustrated in Figures 17 and 18. The specific management actions for these areas are described in Table 20. Further explanation of land management actions can be found in Wooldridge *et al.* (2015).

http://www.environment.nsw.gov.au/research-and-publications/publications-search/guidelines-for-managing-salinity-in-rural-areas

Actions and codes used in Table 20 are derived from the above document and were assessed as being relevant to the Burra Creek catchment.

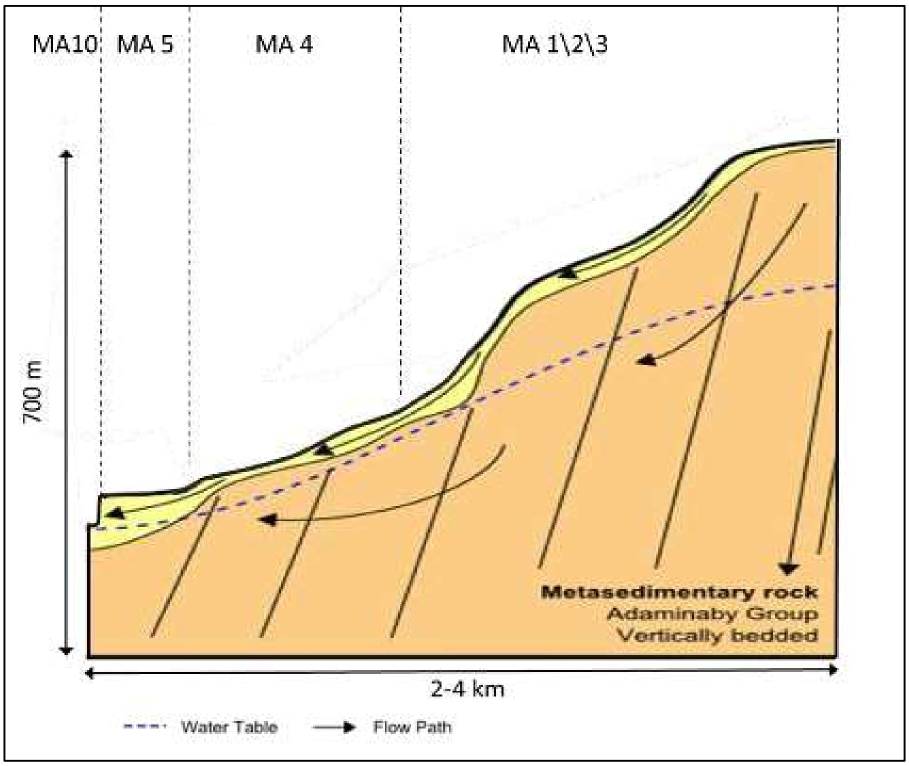


Figure 17: Management Cross-section for Michelago HGL showing Defined Management Areas.

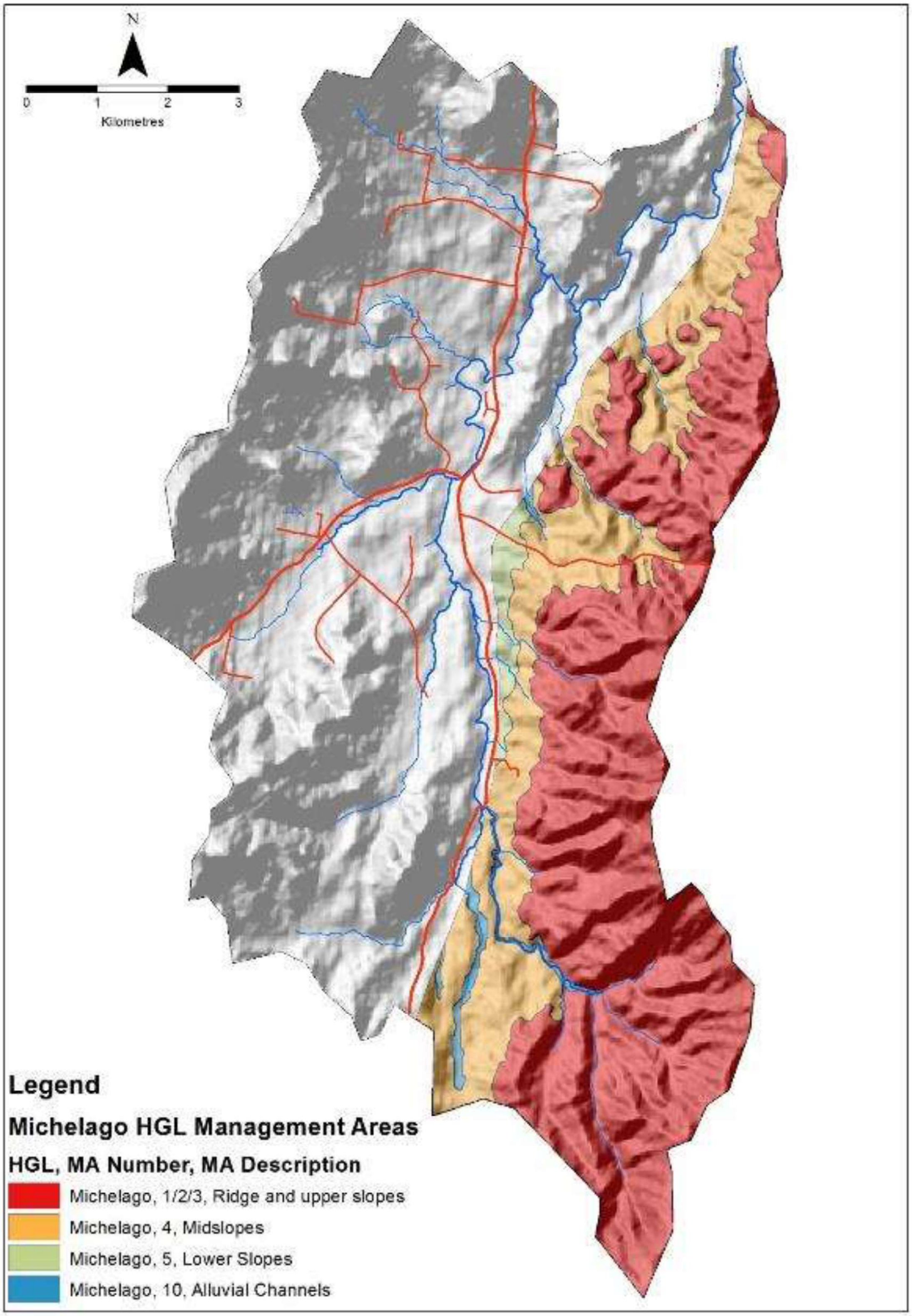


Figure 18: Spatial Distribution of Management Areas for Michelago HGL.

Table 20: Specific Management Actions for Management Areas within Michelago HGL.

Management Area (MA)	Action
MA 1/2/3 (RIDGES & UPPER SLOPES – EROSIONAL)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3)** Manage total grazing pressure to maintain and improve native vegetation for hydrology outcomes **(VE9)** Revegetate non-agricultural land with native species to manage recharge **(VE6)**
MA 4 (MID SLOPES)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3)** Manage total grazing pressure to maintain and improve native vegetation for hydrology outcomes **(VE9)** Revegetate non-agricultural land with native species to manage recharge **(VE6)**
MA 5 (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)** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5)** Revegetate non-agricultural land with native species to manage recharge **(VE6)**
MA 10 (FLOWLINES)	**Vegetation for ecosystem function** Maintain and improve riparian native vegetation to reduce discharge to streams **(VE4)**

4.7. High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative impacts on salinity as seen in Table 21.

Table 21: Management Actions resulting in Negative Salinity Impacts in Michelago HGL

At Risk Management Areas	Action
MA 1/2/3	Poor management of grazing pastures **(DLU2)** Clearing and poor management of native vegetation **(DLU4)** Deep ripping of soils to maximise water infiltration to subsoil **(DLU11)**
MA 4	Poor management of grazing pastures **(DLU2)** Annual cropping with annual plants **(DLU3)** Clearing and poor management of native vegetation **(DLU4)**
MA 5	Poor soil management **–** tillage causing poor structure **(DLU8)** Poor management of grazing pastures **(DLU2)** Annual cropping with annual plants **(DLU3)**
MA 10	Clearing and poor management of native vegetation **(DLU4)**

Chakola Land Management Framework

1. OVERVIEW

The Chakola Hydrogeological Landscape (HGL) within the Bura Creek catchment is located mainly to the West of Burra Road. (Figure 19). The HGL covers an area of 60km^2 and receives 550 to 750 mm of rain per annum.

The Chakola HGL is defined by geological units of Silurian volcanic rocks with small intrusions of Silurian granitic rocks included (Figure 20). The area is mostly cleared grazing land with a strong rural residential character. Several small unnamed creeks drain to Burra Creek.

The HGL has sodic material in alluvial/colluvial fill material expressed in some drainage lines. These drainage lines were significantly eroded in the past. Gully and stream bank erosion are currently active in some drainage lines. The HGL has waterlogged discharge areas and salinity indicators in drainage lines and lower slope areas. Streams have some salt load and elevated EC occurs during spike events. Salt land is evident as areas of poor vegetation cover, discharge sites and soil erosion.

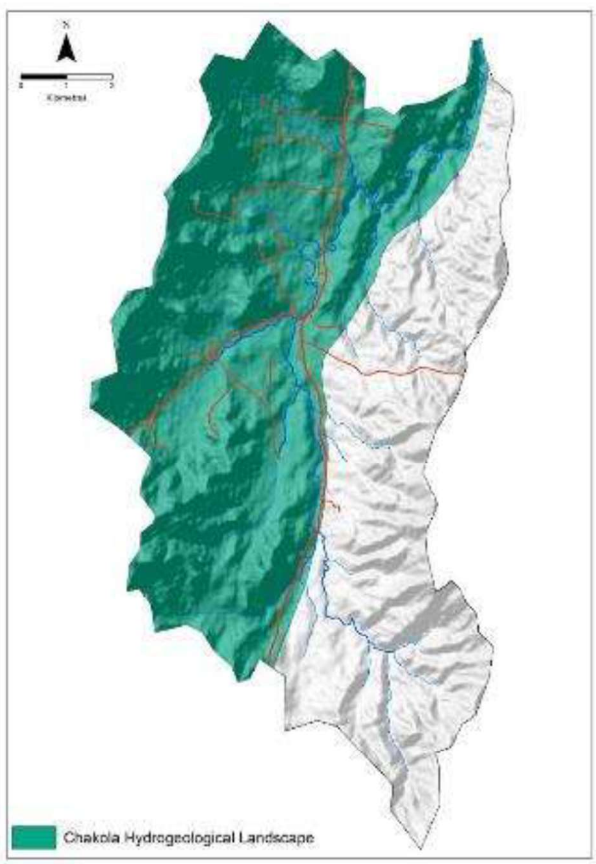


Figure 19: Chakola HGL Distribution Map.

Table 22: Management issues for soils in this HGL.

Functions	• **SC_A:** The landscape provides fresh water (sediment free) • **SC_B:** The landscape generates sediment from surface water runoff and processes (sheet and rill erosion) • **SC_C:** The landscape generates sediment from gully erosion, head cuts and side wall expansion (gully erosion) • **SC_F:** The landscape contains high hazard for sodicity, and for generating sodic sediments • **SC_D:** The landscape generates salt loads which enter the streams and are redistributed in the catchment
General management issues	• Gullying • Shallow acid soils • Sodicity – sensitive soils • Wide scale erosion and scalds • Overgrazing • Salinity
General management comments	• Overgrazing. • Rural residential • Gully erosion • Effluent

2. LANDSCAPE CHARACTERISTICS

The Chakola HGL boundary is derived from the geological boundaries of the Silurian volcanics as shown in Figure 20. The Murrumbidgee Gorge runs through the unit and has rolling grazing land to the east and steeper grazing country to the west. Land use is principally grazing, and the area also includes a solar farm. The area is sodic and is subject to significant erosion.

Figure 20: Google Earth image of typical Chakola HGL terrain with Management Areas shown as black lines. (Image © 2015 DigitalGlobe; © 2015 Google; Image © 2015 Aerometrex).

Photo 6: Typical Landscape in Chakola HGL (Photo: W Cook).

3. MANAGEMENT AREAS

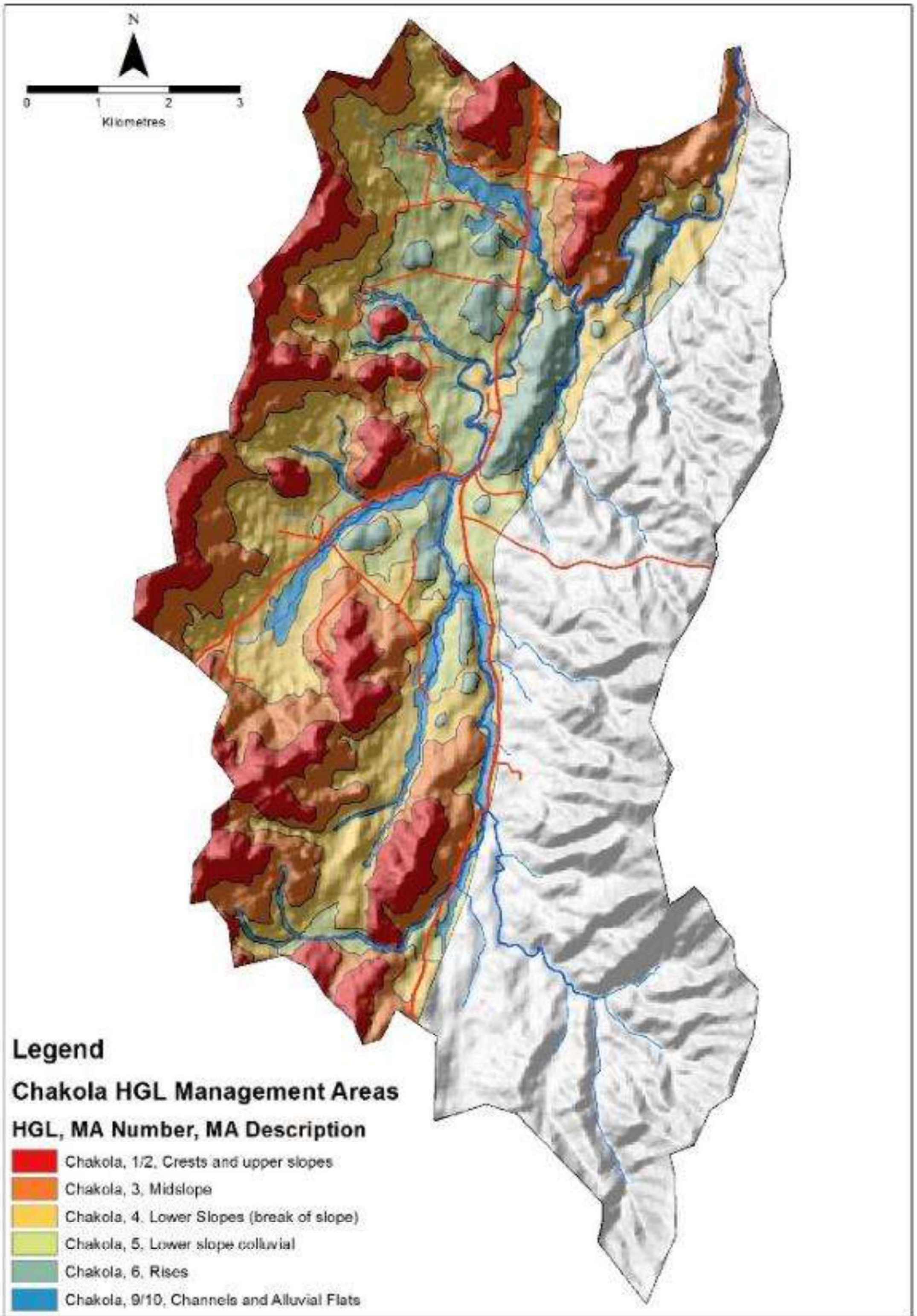


Figure 21: Spatial Distribution of Management Areas for Chakola HGL

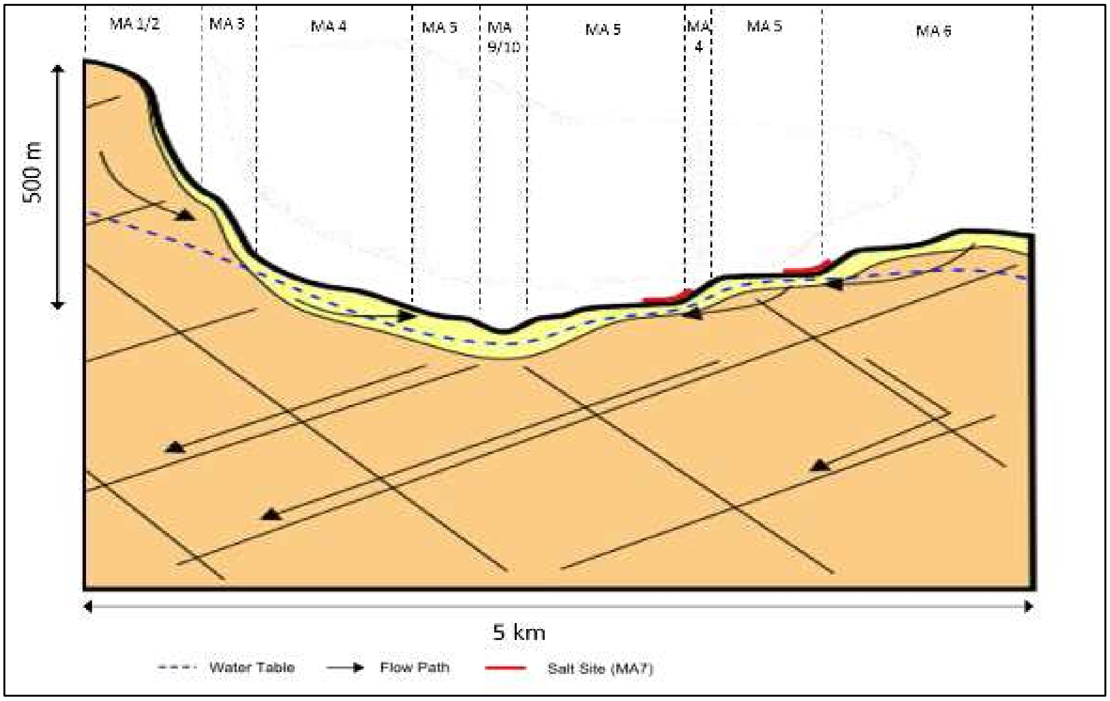


Figure 22: Conceptual cross-section for Chakola HGL showing Management Areas

4. LAND AND SOIL CAPABILITY (LSC)

The LSC classification uses biophysical features of the land including landform position, slope gradient, drainage and climate together with 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. Land and soil capability is discussed fully in OEH (2012). LSC classes for this HGL are given in Table 23.

Table 23: Land and Soil Capability Classification (LSC) for each Management Area (MA) in the Chakola HGL.

Land degradation hazard	MA 1/2	MA 3	MA 4	MA5	MA 6	MA 9/10
Water Erosion	3	6-7	6	4	6	7
Wind Erosion	3	3	3	3	3	3
Structural Decline	3	3	3	3	3	3
Shallow Soils and Rockiness	7	6	4	3	4	3
Mass Movement	1	1	1	1	1	1
Salinity	3	3	3	4	3	4
Waterlogging	2	2	2	2	2	6
Acidity	5	4	4	5	4	5
Overall	**7**	**6/7**	**6**	**5**	**6**	**7**

5. SOIL REGOLITH STABILITY

Soil regolith stability classification is a useful predictor of how likely a soil is to cause turbidity in surface waters and long-distance sedimentation down the catchment if the soil is disturbed. It is derived from a logical two by two matrix giving four regolith classes (R1 to R4). Soil regolith stability is described fully in Murphy *et al.* (1998). Soil regolith stability classes for this HGL are given in Table 3 along with key soil properties.

6. SOILWORKS CLASSIFICATION

This classification indicates suitability for soil conservation earthworks. It was developed by the NSW Soil Conservation Service (SCS). Soil conservation earthworks are earthen structures designed and constructed to minimise soil erosion by intercepting and/or diverting runoff. The main earthworks are dams for water retention, gully control structures for restricting erosion in gullies and banks for diverting water flow. The classification ranges from 'A' (suitable for normal earthworks) to 'K' (not recommended for earthworks). Training manuals for conservation earthworks can be obtained from SCS – http://www.scs.nsw.gov.au/education-and-training. SoilWorks classes for this HGL are given in Table 24.

Table 24: Key Soil Properties relevant to Land Management for each Management Area (MA) of the Chakola HGL. Regolith Stability Class in brackets.

	Soil Properties	SoilWorks Classification
MA 1/2	Shallow soils **(R1)**	**J:** Earthworks not recommended
MA 3	Shallow and acid texture contrast soils with red coloured B horizon **(R3)**	**J:** Earthworks not recommended
MA 4	Moderately deep texture contrast soils with shallow topsoils and yellow coloured subsoils **(R3)**	**D:** This soil is highly susceptible to tunnelling or piping failure. It must be well compacted *throughout* to reduce permeability and saturation settlement. If drier than optimum, gypsum or hydrated lime should be used at 1 t/750 m3 of wall to reduce dispersion. The soil should be compacted to at least 85 per cent of Proctor maximum dry density by ensuring the correct moisture content (see Recommendation B), placing in layers <15 cm thick and rolling with at least four complete passes of the plant. For additional stability, the structure should be designed to hold no more than 1 m of water against the wall and batter grades should be decreased to 1:3.5 upstream and 1:3 downstream.

MA 5	Moderately deep texture contrast soils with shallow topsoils and yellow coloured subsoils **(R3)**	**D:** This soil is highly susceptible to tunnelling or piping failure. It must be well compacted *throughout* to reduce permeability and saturation settlement. If drier than optimum, gypsum or hydrated lime should be used at 1 t/750 m3 of wall to reduce dispersion. The soil should be compacted to at least 85 per cent of Proctor maximum dry density by ensuring the correct moisture content (see Recommendation B), placing in layers <15 cm thick and rolling with at least four complete passes of the plant. For additional stability, the structure should be designed to hold no more than 1 m of water against the wall and batter grades should be decreased to 1:3.5 upstream and 1:3 downstream.
MA 6	Moderately deep texture contrast soils with shallow topsoils and yellow coloured subsoils **(R3)**	**D:** This soil is highly susceptible to tunnelling or piping failure. It must be well compacted *throughout* to reduce permeability and saturation settlement. If drier than optimum, gypsum or hydrated lime should be used at 1 t/750 m3 of wall to reduce dispersion. The soil should be compacted to at least 85 per cent of Proctor maximum dry density by ensuring the correct moisture content (see Recommendation B), placing in layers <15 cm thick and rolling with at least four complete passes of the plant. For additional stability, the structure should be designed to hold no more than 1 m of water against the wall and batter grades should be decreased to 1:3.5 upstream and 1:3 downstream.
MA 9/10	Sodic yellow to gleyed coloured B horizons (subsoils) that are often water logged and highly erodible. **(R4)**	**E:** This soil is very susceptible to tunnelling or piping failure. In addition to Recommendation D, the structure must hold no more than 1 m depth above the original ground surface at the upstream side of the wall and not be subject to more than 0.3 m/day drawdown (trickle pipes must not be more than 0.3 m below top water level). Gypsum or hydrated lime at 1 t/750 m3 of wall should be incorporated in the upstream side of the wall. The upstream batter grades should be decreased to 1:4.

7. SOIL LANDSCAPES AND SOIL CLASSIFICATIONS

Soil variation within and across a landscape depends on a number of environmental variables. The delineation of management areas (MA) reflects some of these differences. Soil types and behaviours can be extrapolated from known soil properties and landscape position within an area. The likely soil types expected to be found in each management area in this HGL are detailed in Table 25.

Table 25: Dominant Soil Types for each Management Area (MA) within the Chakola HGL.

	MA 1/2	MA 3	MA 4	MA 5	MA 6	MA 9/10
Dominant Soil Landscape	Campbell	Campbell Burra	Campbell Burra	Burra Williamsdale	Burra	Burra Williamsdale
Great Soil Group	Lithosols	Lithosols Red Podzolic Soils	Red Podzolic Soils Yellow Podzolic soils	Yellow Podzolic Soils Solodic Soils Solodized Solonetz	Yellow Podzolic Soils Red Podzolic Soils	Solodic Soils Solodized Solonetz Gleyed Podzolic Soils
Australian Soil Classification	Clastic Rudosols Leptic Tenosols	Red Chromosols	Red/Brown Chromosols	Yellow Chromosols Sodosols	Red/Brown Chromosols	Sodosols Gleyed Chromosols Hydrosols
Factual Key	Um1.24 Um1.22 Um4.12 Um4.13	Um1.24 Um1.22 Dr3.11 Dr2.21	Um1.24 Um1.22 Dr3.11 Dr2.21	Dy2.21 Dy2.22 Dy2.42	Um1.24 Um1.22 Dr3.11 Dr2.21	Dy3.43 Dg2.12 Dg2.13 Dg2.22

8. LAND AND SOIL MANAGEMENT OPTIONS

Land and soil degradation is driven by interactions between land management, environmental limitations and climatic events. Inappropriate management actions will impact on land and soil affecting agricultural production and the environmental amenity. It is important to identify the optimal management strategies and actions relevant to any given parcel of land to maintain soil health and minimise land degradation.

The influence of both continual and episodic climatic events on land degradation can be severe. The impacts of extreme weather events need to be considered when deciding on appropriate management actions.

8.1. Specific Targeted Actions

Management areas for this HGL description are illustrated in Figure 3. The specific management actions for these areas are described in Table 26.

Table 26: Specific Land and Soil Management Actions for Management Areas within the Chakola HGL.

Management Area (MA)	Action
MA 1/2 (RIDGESAND UPPER SLOPES)	**Vegetation and ecosystem service** Maintain and improve existing native woody vegetation to control land degradation **(VE3a)**
MA 3 (UPPER SLOPE)	**Biological and vegetative soil remediation** Compost application (e.g. biosolids and organics) **(BV2)** Mulching **(BV3)** **Gully stabilisation** Manage gullies (and headcuts) using construction methods appropriate for region **(GS8)** **Vegetation and ecosystem service** Maintain and improve existing native woody vegetation to control land degradation **(VE3a)**
MA 4 (MID SLOPE – COLLUVIAL)	**Biological and vegetative soil remediation** Compost application (e.g. biosolids and organics) **(BV2)** Mulching **(BV3)** **Gully stabilisation** Gully control structures with pipe to handle trickle flow **(GS2)** Rock groins and gabions – control structures constructed to account for sodic soils. Refer to SCS training manuals for conservation earthworks **(GS3)** Flumes (masonry/rock/chute) **(GS4)** Manage gullies (and headcuts) using construction methods appropriate for region **(GS8)** **Vegetation and ecosystem service** Maintain and improve existing native woody vegetation to control land degradation **(VE3a)**
MA 5 (LOWER SLOPE – COLLUVIAL)	**Biological and vegetative soil remediation** Compost application (e.g. biosolids and organics) **(BV2)** Mulching **(BV3)** **Gully stabilisation** Gully control structures with pipe to handle trickle flow **(GS2)** Rock groins and gabions – control structures constructed to account for sodic soils. Refer to SCS training manuals for conservation earthworks **(GS3)** Flumes (masonry/rock/chute) **(GS4)** Manage gullies (and headcuts) using construction methods appropriate for region **(GS8)** **Vegetation and ecosystem service** Maintain and improve existing native woody vegetation to control land degradation **(VE3a)**

MA 6 (RISES)	**Biological and vegetative soil remediation** Compost application (e.g. biosolids and organics) **(BV2)** Mulching **(BV3)** **Gully stabilisation** Gully control structures with pipe to handle trickle flow **(GS2)** Rock groynes and gabions – control structures constructed to account for sodic soils. Refer to SCS training manuals for conservation earthworks **(GS3)** Flumes (masonry/rock/chute) **(GS4)** Manage gullies (and headcuts) using construction methods appropriate for region **(GS8)** **Vegetation and ecosystem service** Maintain and improve existing native woody vegetation to control land degradation **(VE3a)**
MA 9/10 (PLAIN AND CHANNEL – ALLUVIAL)	**Stream stabilisation** Weirs (loose rock, concrete) **(SS1)** Gabion structures and rock revetment **(SS2)** Batter rehabilitations – jute mesh/spray seed – long term stability **(SS5)** Fishways **(SS6)** Stream crossings **(SS7)** **Track and access** Track location and design **(TA1)**

8.2. High Hazard Land Use

There are some management actions that should be discouraged in this HGL as they will have negative land and soil impacts as shown in Table 26.

Table 27: Management Actions having Negative Land and Soil impacts in the Chakola HGL.

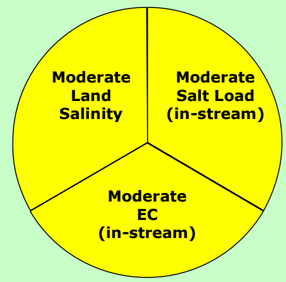
At Risk Management Areas	Action
MA 1/2	Poor management of grazing pastures **(DLU2)** Clearing and poor management of native vegetation **(DLU4)**
MA 3	Gully shaping **(GS6)** Poor management of grazing pastures **(DLU2)** Annual cropping with annual plants **(DLU3)** Clearing and poor management of native vegetation **(DLU4)**
MA 4	Gully shaping **(GS6)** Poor management of grazing pastures **(DLU2)** Annual cropping with annual plants **(DLU3)** Clearing and poor management of native vegetation **(DLU4)**

MA 5	Gully shaping **(GS6)** Poor management of grazing pastures **(DLU2)** Annual cropping with annual plants **(DLU3)** Clearing and poor management of native vegetation **(DLU4)**
MA 6	Gully shaping **(GS6)** Poor management of grazing pastures **(DLU2)** 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)**
MA 9/10	Clearing and poor management of native vegetation **(DLU4)**

Chakola Hydrogeological Landscape

Burra Creek Catchment

LOCALITIES	**Michelago Forest, Michelago Settlement**
MAP SHEET	**Canberra 1:100 000**
CONFIDENCE LEVEL	**Moderate**



1. OVERVIEW

The Chakola Hydrogeological Landscape (HGL) within the Bura Creek catchment is located mainly to the West of Burra Road as shown in Figure 23. The HGL covers an area of 60km^2 and receives 550 to 750 mm of rain per annum.

The Chakola HGL is defined by geological units of Silurian volcanic rocks with small intrusions of Silurian granitic rocks included as shown in Figure 24. The area is mostly cleared grazing land with a strong rural residential character. Holdens Creek and several small unnamed creeks drain to Burra Creek.

The HGL has sodic material in alluvial/colluvial fill material expressed in some drainage lines. These drainage lines were significantly eroded in the past. Gully and stream bank erosion are currently active in some drainage lines. The HGL has waterlogged discharge areas and salinity indicators in drainage lines and lower slope areas. Streams have some salt load and elevated EC occurs during spike events. Salt land is evident as areas of poor vegetation cover, discharge sites and soil erosion.

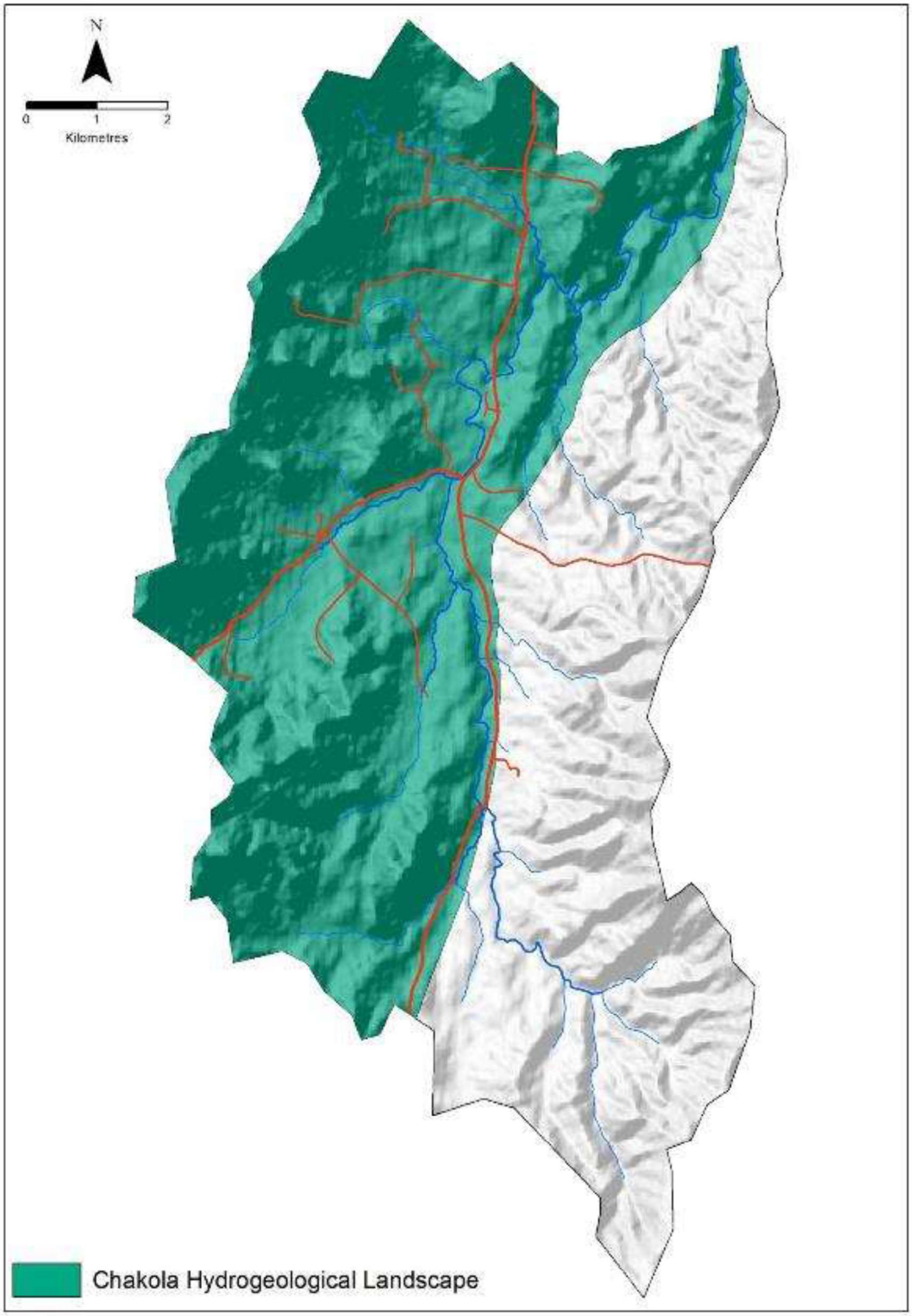


Figure 23: Chakola HGL Distribution Map.

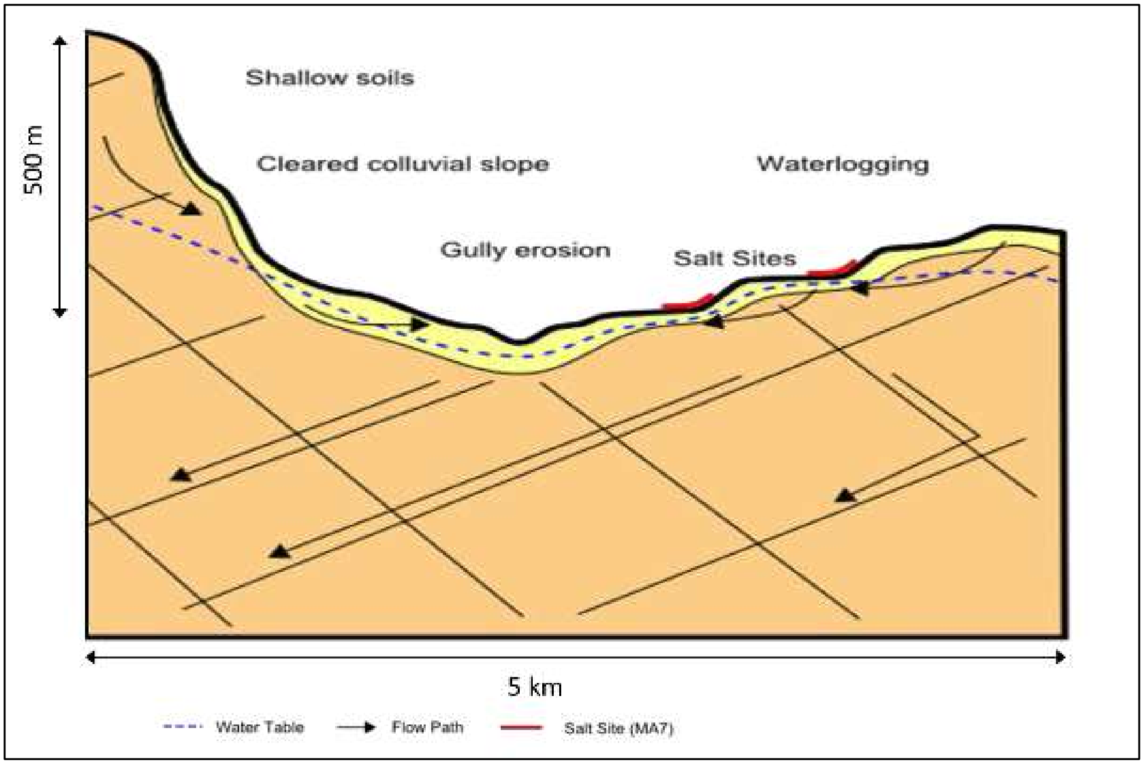


Figure 24: Conceptual cross-section for Chakola HGL showing the Distribution of Regolith and Landforms, Salt Sites if present, and Flow Paths of Water infiltrating the System.

Salinity expression in this HGL is in the form of salt land and stream salt load and EC as shown in Table 28.

Table 28: Chakola HGL Salinity Expression.

SALINITY EXPRESSION	
Land Salinity (Occurrence)	Moderate **–** Saline sites in some lower slope elements and drainage lines.
Salt Load (Export)	Moderate **–** There is a moderate salt store and salt export via soil and regolith throughflow to the eroded drainage lines. Seasonal.
EC (Water Quality)	Moderate **–** Stream EC values are moderate with occasional high spikes.

Salt store refers to the amount of salt stored in soil and geology materials. Salt availability refers to how easily this salt can be moved by water. Salt stored within Chakola HGL has moderate mobility. There is a moderate salt store that has moderate availability as shown in Table 29.

Table 29: Chakola HGL Salt Store and Availability.

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

Overall salinity hazard is based on the likelihood of salinity occurring and how much impact it will have. The overall salinity hazard in Chakola HGL is moderate. This is due to the moderate likelihood that salinity issues will occur that would have potentially significant impacts as shown in Table 30.

Table 30: Likelihood of Salinity Occurrence, Potential Impact and Overall Hazard of Salinity for Chakola HGL.

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

Very Low	Low	Moderate	High	Very High

2. LANDSCAPE FEATURES

The following photographs illustrate landscapes and specific features observed in this HGL. Information used to define the HGL is summarised in Table 31.

Photo 7: Chakola HGL showing typical Landscape Variation and Land Use (Photo: W Cook).

Photo 8: View looking South from Moore Road, Lower Slope Elements of Chakola HGL (Photo: W Cook).

Photo 9: Typical semi-stable Erosion Gully on Lower Slope. Large tree in gully shows the gully formed a long time ago. (Photo: W Cook).

Photo 10: Soil Erosion (Mass movement) on Upper Slope Elements. (Photo: W Cook).

Table 31: Summary of Information Used to Define Chakola HGL.

Lithology *(Raymond et al. 2007; Geoscience Australia 2015)*	This HGL comprises Silurian volcanic rocks. Key lithologies include:
	• Silurian Volcanics
	  • Colinton Volcanics
	  • Williamsdale Dacite
	    Pyroclastic rocks ejected from volcanoes into a shallow marine environment.
	• Unnamed Silurian Igneous units
	    Igneous rocks chemically similar to the volcanic rocks.

Annual Rainfall	550–750 mm
Regolith and Landforms	Soil generally <0.3 m deep higher in the landscape and >1 m on lower slopes and in drainage lines. Deeper soil and imperfect drainage in the lower landscape provide moderate potential for salt store. Slopes generally 10–32%; 0–10% in valley bottoms. Elevation Range is 680–1140 m.
Soil Landscapes *(Jenkins 1993; Jenkins 2000; Cook et al. 2016)*	The following soil landscapes are dominant in this HGL: • Campbell • Burra • Williamsdale Clastic Rudosols or Leptic Tenosols (Lithosols) on crests and associated with outcrops and subcrops. Well drained Red and Yellow Chromosols (Red and Yellow Podzolic Soils) occur in many mid to lower slope positions. A number of areas of impeded drainage are found in the lower slope-rolling terrain to the east of the Murrumbidgee Gorge. Typically these areas will have poorly drained Sodosols (Solodized Solonetz and Solodic Soils) or Gleyed Chromosols and Hydrosols (Gleyed Podzolic Soils). The Sodosols are sodic and have a high erosion hazard. They readily gully and are often associated with dryland salinity.
Land and Soil Capability	Class 5 - 7
Land Use	• Grazing • Native forest (scrub) • Rural residential
Key Land Degradation Issues	• Water erosion • Mass movement • Shallow rock • Soil acidity • Soil Sodicity

Native Vegetation *(Keith 2004; Gellie 2005; Dept. of Environment 2012)*	This HGL is situated within the IBRA7 South Eastern Highlands (Murrumbateman subregion). The HGL is extensively cleared with remaining vegetation formations comprising Grassy Woodland, with areas of Wet and Dry Sclerophyll Forest, Grasslands and Forested Wetlands. Local vegetation is described by Gellie (2005).

3. HYDROGEOLOGY

Typical values for the hydrogeological parameters of this HGL are summarised in Table 32.

Table 32: Summary of Values for Typical Hydrogeological Parameters of Chakola 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	Low Range: <2 m^2/day
Specific Yield	Moderate Range: 5–15%
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: <2–8 m
Typical Sub-Catchment Size	medium (100-1000 ha)
Scale (Flow Length)	Local Flow length: <5 km (short)
Recharge Estimate	Moderate
Residence Time	Medium (years)
Responsiveness to Change	Medium (years)

4. 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, actions and relevant codes can be found in Wooldridge *et al.* (2015), by following the link below.

http://www.environment.nsw.gov.au/research-and-publications/publications-search/guidelines-for-managing-salinity-in-rural-areas

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

4.1. Landscape Functions

Landscape function is the highest order within the hierarchical HGL structure. Functions are inherent biophysical characteristics of a landscape which impact upon catchments. 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.

Functions that the Chakola HGL provides within a catchment scale salinity context:

- **A.** The landscape provides fresh water runoff as an **important water source**.
- **D.** The landscape generates salt loads which enter streams and are redistributed in the catchment.
- **H.** The landscape contains high hazard for generating sodic and saline sediments.

4.2. Landscape Management Strategies

Management strategies are aimed at maintaining or improving landscape functions. One or more strategies may be applicable to any landscape.

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 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.
- **Discharge rehabilitation and management (4)**: Discharge sites appear in the landscape during 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 to use excess soil moisture and shallow groundwater. Healthy, actively growing vegetation will also buffer groundwater accessions in wet seasonal conditions.
- **Intercept the lateral flow and shallow groundwater (2):** Target shallow water tables that exist at the colluvial slope change. Rows of trees (8 - 30 rows) can be effective in interception of lateral flow. Rooting depth will intercept this shallow groundwater.

4.3. Key Management Focus

The landscape has the potential to become saline and eroded if land is used outside its capability. Groundcover plays an important role in erosion control and salinity control. Mid slope areas have potential for salinity issues to develop.

- Gully erosion – Significant Gully erosion exists in this HGL.
- Overgrazing- Total grazing pressure is a factor in this HGL.
- Effluent discharge- There is an effluent discharge hazard in this HGL.
- Farm dams – Farm dams can have an impact on catchment hydrology.

4.4. Specific Land Management Opportunities

Specific opportunities for this HGL:

- Grazing land has good native pasture base.
- Gully stabilisation via natural processes and on ground works.

4.5. Specific Land Management Constraints

Constraints on land management in this HGL include:

- Soil limitations – acid, low fertility sodicity, salinity
- Erosion and gullying
- Total grazing pressure

4.6. Specific Targeted Actions

Management areas for this HGL are illustrated in Figures 3 and 4. The specific management actions for these areas are described in Table 33. Further explanation of land management actions can be found in Wooldridge *et al.* (2015).

http://www.environment.nsw.gov.au/research-and-publications/publications-search/guidelines-for-managing-salinity-in-rural-areas

Actions and codes used in Table 33 are derived from the above document and were assessed as being relevant to the Burra Creek catchment.

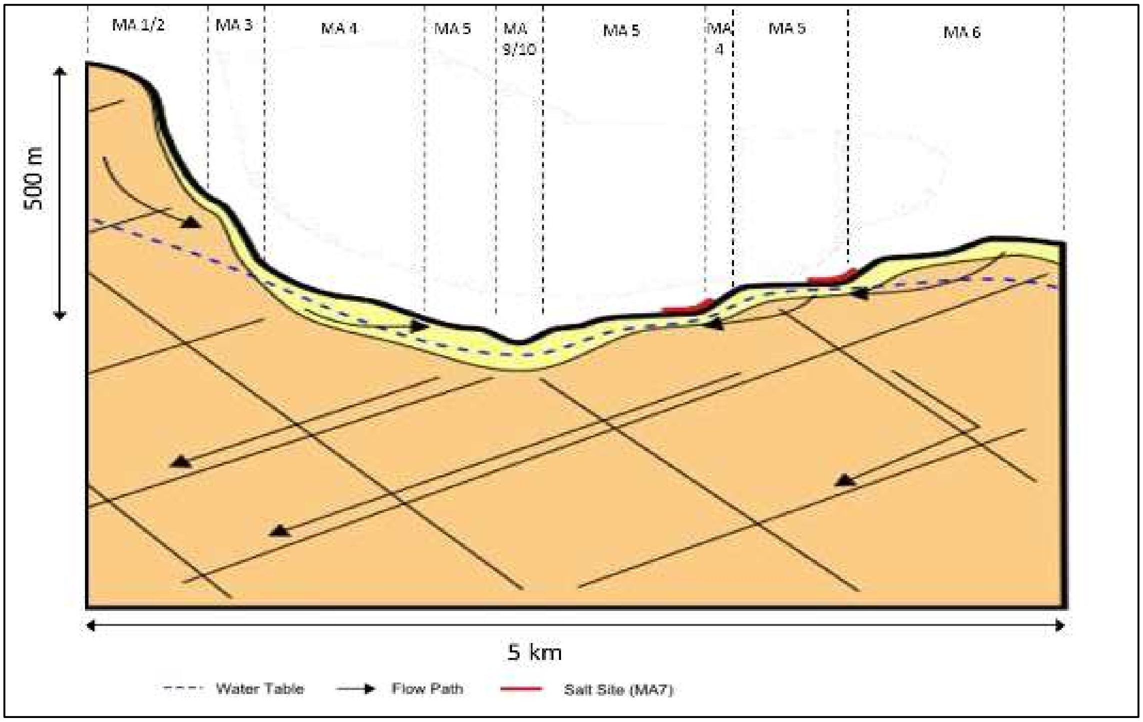


Figure 25: Management Cross-section for Chakola HGL showing Defined Management Areas.

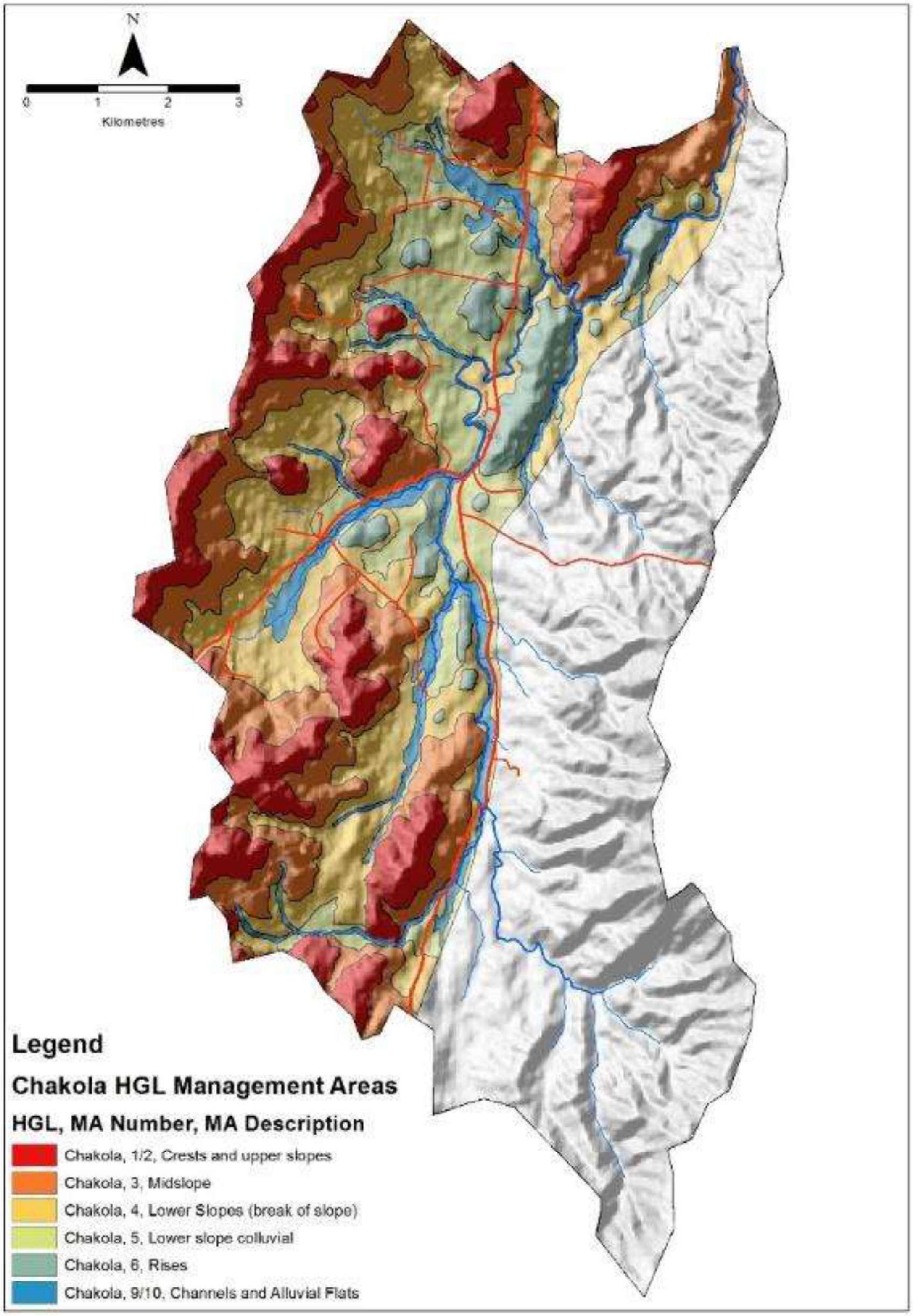


Figure 26: Spatial Distribution of Management Areas for Chakola HGL.

Table 33: Specific Management Actions for Management Areas within Chakola HGL.

Management Area (MA)	Action
MA1/2 (RIDGES & UPPER SLOPE)	**Vegetation for ecosystem function** Maintain and improve existing native woody vegetation to reduce discharge **(VE3)** Maintain and improve existing native woody vegetation to protect current landscape hydrology **(VE8)** **Vegetation for production** Improve grazing management to improve or maintain native pastures to manage recharge **(VP5)**
MA 3 (UPPER SLOPE – COLLUVIAL EROSIONAL)	**Vegetation for ecosystem function** Interception planting of native woody species to target shallow groundwater **(VE2)** Maintain and improve existing native woody vegetation to reduce discharge **(VE3)** Manage total grazing pressure to maintain and improve native vegetation for hydrology outcomes **(VE9)** **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)**
MA 4 (MID SLOPES – COLLUVIAL-BREAK OF SLOPE)	**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** Rotational cropping with perennial pasture component **(FS3)** Pasture cropping **(FS1)** **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 salt sites to reduce evaporation and promote pasture growth **(SR8)**
	Vegetation for production

MA5 (MID SLOPES & LOWER SLOPES – COLLUVIAL) NB: INCLUDES MA7 – SALTLAND	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** Rotational cropping with perennial pasture component **(FS3)** Pasture cropping **(FS1)** **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 salt sites to reduce evaporation and promote pasture growth **(SR8)**
MA 6 (RISES)	**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** Rotational cropping with perennial pasture component **(FS3)** Pasture cropping **(FS1)** **Farming Systems** Rotational cropping with perennial pasture component **(FS3)** Pasture cropping **(FS1) Delete if rise is steep** **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 salt sites to reduce evaporation and promote pasture growth **(SR8)**
MA 9/10	**Vegetation for ecosystem function**

	Maintain and improve riparian native vegetation to reduce discharge to streams **(VE4)** Mulch salt sites to reduce evaporation and promote pasture growth **(SR8)**

4.7. 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 34).

Table 34: Management Actions having Negative Salinity Impacts in Chakola HGL.

At Risk Management Areas	Action
MA 1/2	Annual cropping with annual plants **(DLU3)**
MA 1, 2, 3, 4 5 & 6	Poor management of grazing pastures **(DLU2)** Clearing and poor management of native vegetation **(DLU4)**
MA 7	Deep ripping of soils **(DLU11)** Poor management of grazing pastures **(DLU2)** Clearing and poor management of native vegetation **(DLU4)**
MA 9/10	Clearing and poor management of native vegetation **(DLU4)**

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Appendix A Burra Vegetation Species List for Revegetation

This list is to be used as a basic guide only. Professional site-specific advice is recommended due to the likelihood of high variability, particularly in modified areas.

Land Class	Vegetation Type	Recommended Species
1 & 2	Swampy meadows grasslands, riparian flood plains. [Note that these areas are often dominated by willows, poplars and other European plants]	*Poa labillardieri* (River Tussock), *Carex appressa* (Sedge), *Lomandra longifolia* (Mat Rush), *Eucalyptus viminalis* (Ribbon Gum), *Eucalyptus stellulata,*(Black Sallee) *Leptospermum sp* (Tea Tree)
3 & 4	Box-Gum Woodland	*Euclayptus melliodora* (Yellow Box), *E.polyanthemos* (Red Box), *E.bridgesiana* (Apple Box), *E.blakelyi* (Blakely's Red Gum), *Acacia dealbata* (Silver Wattle), *Acacia implexa* (Lightwood)
5 & 6	Often transition zone between Box-Gum Woodlands and Dry Schlerophyll forest	Combination of above and below depending on topography and aspect. *Euclayptus.pauciflora* (Snow Gum) in colder pockets. *Eucalyptus goniocalyx* (Bundy), *Eucalyptus nortonii, E.rubida* (Candlebark) (Mealy Bundy)
7 & 8	Dry Schlerophyll Forest	*E.macrorhyncha* (Red Stringybark) *E.mannifera* (Brittle Gum), *E.rossii,* (Scribbly Gum) *E.dives* (Narrow-leaf Peppemint), *Casuarina verticillata* (Drooping She-oak) *Acacia dealbata* (Silver Wattle) *Acacia implexa* (Lightwood), *Hardenbergia violaceae* (Purple Coral Pea), *Indigofera australis* (Austral indigo). There is a very high diversity of heaths and groundcover plants in Dry Schlerophyll forests in the Burra area which are available from some nurseries.