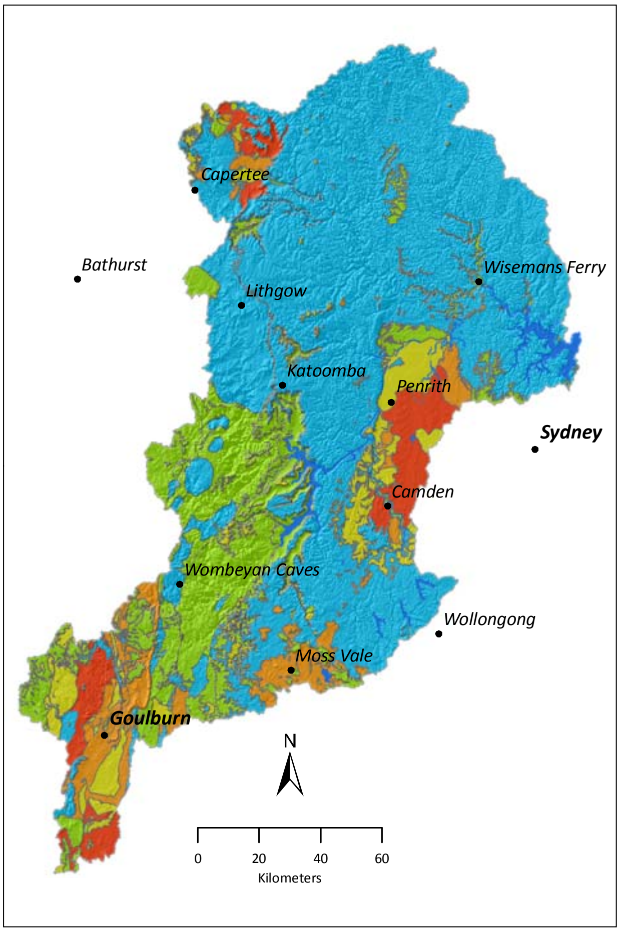
Salinity hazard report for Catchment Action Plan upgrade - Hawkesbury-Nepean CMA



Publisher: NSW Department of Primary Industries

Salinity hazard report for Catchment Action Plan upgrade - Hawkesbury-Nepean CMA

First published February 2013.

Print ISBN: 978 1 74256 449 4

Web ISBN: 978 1 74256 450 0

This document should be cited as: Winkler, M.A., Nicholson, A., Jenkins, B.R., Muller, R., Cook, M., Moore, C.L. and Wooldridge, A. 2012, *Salinity hazard report for Catchment Action Plan upgrade - Hawkesbury-Nepean CMA*, NSW Department of Primary Industries, Sydney.

More information

Prepared by Landscape Management Technical Group – a cross agency group involving Catchments Unit / Department of Primary Industries and Office of Environment and Heritage.

Allan Nicholson (team leader) / Wellington, Marion Winkler / Parramatta, Wayne Cook / Queanbeyan, Andrew Wooldridge / Cowra (DPI); Rob Muller / Wagga Wagga / Brian Jenkins / Queanbeyan (OEH); Leah Moore / University of Canberra.

www.dpi.nsw.gov.au

Acknowledgments

We gratefully acknowledge funding provided by Catchment Action NSW to enable the project to be completed. A number of people have provided technical and critical support for the project. Special thanks to Neville Pavan, Aaron Smith, Di Shanks and Lauren Wilson. Thanks are also given to Jan Wightley of NSW Department of Primary Industries for assistance with editing and document control.

Cover image: Salinity hazard map of Hawkesbury-Nepean catchment management area

Trim No. BN13/1151

Contents

1 Introduction 1
1.1 Background 1
1.2 Resilience 1
2 Methodology 2
2.1 Overview of the descriptors 2
2.2 Overview of the salinity hazard for CAP update map 3
3 Descriptors 7
3.1 Very high hazard – Area 1 7
3.2 Very high hazard – Area 2 8
3.3 Very high hazard – Area 3 9
3.4 Very high hazard – Area 4 10
3.5 Very high hazard – Area 5 11
3.6 High Hazard – Area 1 13
3.7 High Hazard – Area 2 14
3.8 High hazard – Area 3 15
3.9 High hazard – Area 4 16
3.10 Moderate hazard – Area 1 17
3.11 Moderate hazard – Area 2 19
3.12 Moderate hazard – Area 3 20
3.13 Moderate hazard – Area 4 21
3.14 Low hazard – Area 1 22
3.15 Low hazard – Area 2 23
3.16 Low hazard – Area 3 24
3.17 Low hazard – Area 4 25
3.18 Low hazard – Area 5 26
3.19 Low hazard – Area 6 27
3.20 Very low hazard – Area 1 28
3.21 Very low hazard – Area 2 29
4 References 30
Appendix 1: Factors Influencing Resilience in Hawkesbury-Nepean CMA 34

1 Introduction

1.1 Background

The eleven NSW Catchment Management Authorities (CMAs) are required to update their Catchment Action Plans (CAPs) in a process to be completed by early 2013. The CAPs are required to be "Whole of Government" in order to provide greater coherence between policies and plans as they develop strategic direction at regional levels. CAPs must align with or take into account common elements of agency activity, and require a high level of co-ordination.

A cross-agency team was engaged in December 2011 to produce a salinity tool for the 2012-13 CAP update process. The Salinity Hazard for CAP Updates project is funded by Catchment Action NSW and delivers state-wide information.

The project work associated with this report was carried out prior to the formation of the new Local Land Services (LLS) areas. The boundaries used for hazard identification in this report relate to the CMA boundaries as they were prior to October 2012. The Hawkesbury-Nepean CMA area now incorporates the former Sydney Metropolitan CMA area.

The primary output of the Salinity Hazard for CAP Updates project is a broad scale salinity hazard spatial coverage and report for each CMA. This report is produced for the Hawkesbury-Nepean Catchment Management Authority (HNCMA) for use in upgrading its Catchment Action Plan. The Hawkesbury-Nepean CAP is a cabinet approved document which outlines the investment priorities and delivery targets for natural resource management (NRM) across the HNCMA area. The HNCMA is currently reviewing and upgrading the CAP which was developed in 2004-05.

Salinity information is required to guide the ten year strategic plan (CAP), to prioritise actions, and to target specific landscapes with spatially explicit management actions on ground. The CAPs must

- comply with the NRC Standards for Quality Natural Resource Management (the Standard)
- demonstrate "Adaptive Management"
- deal with emerging issues such as the MDBA Basin Plan / Strategic Landuse Plans etc
- consider the resilience of landscapes and systems

This project will utilise state-wide data sets and collect and integrate Hydrogeological Landscape (HGL) information where it exists. The project has the potential to be expanded to a detailed HGL project targeted at the areas identified in the state-wide approach.

This document describes the hazard posed by salinity for different parts of the HNCMA catchment. The associated Salinity Hazard for CAP Update map is a specific product for CAP planning. It is appropriate at the catchment scale. More detailed investigations are required for sub-regional works.

1.2 Resilience

The Natural Resource Commission (NRC) has released The Framework for Assessing and Recommending CAPs (2011). A key component of this document is a shift towards resilience thinking. This approach influences CAP targets, partnerships and the type of knowledge that the HNCMA should draw on to analyse, understand and communicate how the landscape functions.

"Resilience thinking aims to identify a small number of important variables that control the way a complex landscape system is functioning, and the thresholds within which the system can continue to function in a desired way" (NRC 2011).

Salinity is one of the 'small set of important variables' that control the function, thresholds and resilience of landscapes. The 5 salinity hazard classes (see Section 2.1 – Hazard Ranking) used as part of this Salinity Hazard for CAP Updates project provide a simple system for understanding how salinity influences landscape resilience.

The following is the Resilience definition of the Stockholm Resilience Centre (Walker et al., 2004; Folke et al. 2010). It is the definition adopted for the Salinity Hazard for CAP Updates project.

"The capacity of a system to absorb disturbance and reorganise while undergoing change so as to still retain essentially the same function and feedbacks and therefore identify, that is, the capacity to change in order to maintain the same identity."

Salinity is an important variable in landscape systems and is often a determining factor in the capacity of the landscape to absorb change. It has a three-pronged impact on landscapes namely land salinisation, in-stream salt load and in-stream salt concentration. Any of these can of themselves or in concert impact on landscape resilience.

"Management can then be designed to maintain a functioning system either by remaining within thresholds or transforming to a desirable (or least undesirable) alternative stable state." (NRC 2011)

Salinity as a major landscape degradation issue can determine the nature of thresholds and tipping points. If thresholds within landscapes are to be understood and managed then salinity must be understood and managed in a landscape context.

The drivers, variables, thresholds, priority actions and gap analysis for salinity in the HNCMA are provided in Appendix 1

2 Methodology

2.1 Overview of the descriptors

Each hazard area has a descriptor which includes a hazard ranking; a location diagram and description; a statement on the significance of the salinity hazard in that unit; a resilience statement; a confidence statement; and the decision rules used to derive the hazard ranking.

The reports on hydrogeological landscapes for the Hawkesbury-Nepean Catchment Management Authority in the Capertee and Lithgow Valleys, Goulburn Region and Western Sydney study area (Nicholson et al. 2010a, b, c, Grant et al. 2010, 2011a, b, Cook et al. 2011, Marchand et al. 2011, Wooldridge et al. 2011; Nicholson et al. 2011a, b and Winkler et al. 2011) and the Braidwood HGL report (Jenkins et al. 2010) were the primary data sources for the production of the salinity hazard descriptors.

Texts on specific aspects of the environment were extensively consulted and included geology maps and reports such as Geoscience Australia (2011), Bryan (1966), DPI (2009), Herbert (1983), Rasmus, Rose and Rose (1969), Felton and Huleatt (1975), Industry & Investment NSW, Geological mapping team (in prep), Stroud et al. (1985); land resource information (Emery, 1985); groundwater availability studies DLWC (2004); vegetation surveys DEC (2006), Keith (2004), Tozer et al. (2010); and soil landscape maps and reports Bannerman and Hazelton (1990), Clark and Jones (1991), Chapman and Murphy (1989), DECC (2008), King 1993, King 1994, Hazelton, and Tille (1990), Hird (1990) Jenkins, B.R. (1996), Kovac, Murphy and Lawrie, (1990) and Murphy and Lawrie (1990).

Hazard ranking

Areas are given a salinity hazard ranking – Very High, High, Moderate, Low or Very Low. Rankings are determined from a number of variables including salt stores, salinity outbreaks, water quality, salt loads, onsite and offsite impacts, presence of acid sulfate soils, presence of highly sodic soils, aquifer systems, ground water salinity and ground water depth.

Location diagram

A simple overview of where the hazard areas occur within the CMA catchment. Hazard areas are coloured using the following colour scheme.

Table 1 Salinity hazard colour scheme

Attribute	Range	Colour	RGB Colour Schemer
Salinity Hazard	Very High	Red	255, 50, 0
	High	Orange	255, 150, 0
	Moderate	Yellow	230, 230, 0
	Low	Green	150, 230, 0
	Very Low	Blue	0, 200, 255

This colour scheme is also used in the hazard descriptor headers and in the overall salinity hazard map (Figure 1).

Overview / location

General statements on the terrain and geological characteristics of the hazard area, and where it is located.

Significance

Salinity characterises such as salt stores, salinity outbreaks, water quality, onsite and offsite impacts, and other land degradation issues that may be relevant to salinity processes.

Resilience statement

Factors that drive salinity development and the salinity related variables which control, impact or influence the resilience of landscapes.

Confidence

High, moderate or poor. A qualifier is provided where relevant. E.g. poor due to lack of field investigation.

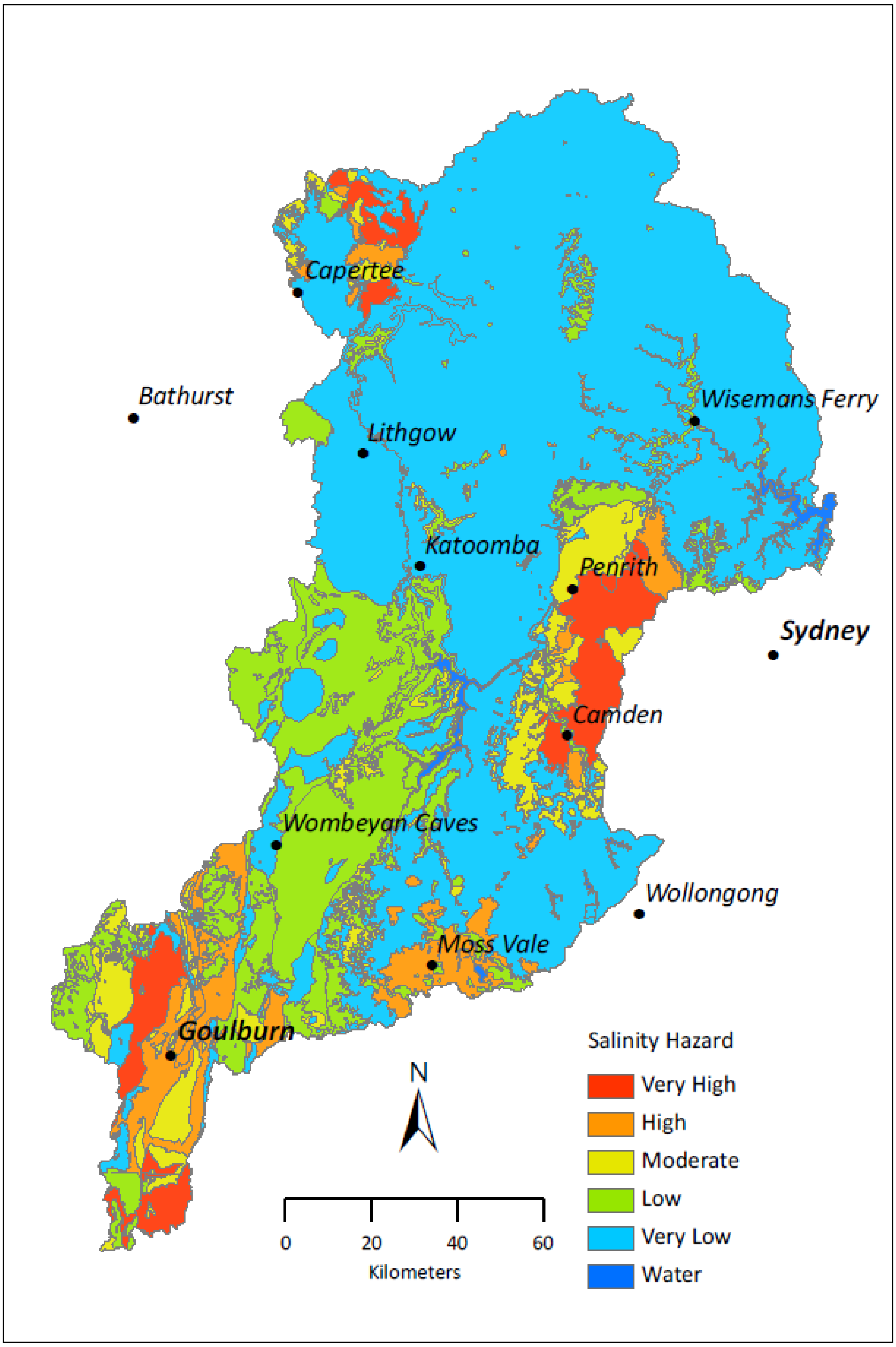
Decision rules

Decision rules for why a particular hazard rating was assigned. E.g. moderate hazard rating is based on HGL assessment which recognised significant areas of moderate levels of land salinity, moderate in-stream salt loads and moderate water EC.

2.2 Overview of the salinity hazard for CAP update map

The Salinity Hazard for CAP Update map (Figure 1) shows the broad salinity hazard distribution across the Hawkesbury-Nepean CMA. It is appropriate for planning at a CMA catchment scale. More detailed investigations are required to target sub-regional works.

Figure 1 Salinity Hazard for CAP Update map for the Hawkesbury-Nepean CMA area



The Hawkesbury-Nepean CMA Hydrogeological Landscape (HGL) maps (Figures 2, 3 and 4) and the Braidwood HGL map (Figure 5) were the primary data sources for the production of the Salinity Hazard for CAP Update map where available (Grant et al. 2010, 2011a, 2011b and Jenkins et al. 2010). Where HGL hazard data was not available, interpolation was made using geological information.

Figure 2 Hawkesbury-Nepean CMA map showing Capertee and Lithgow Valley HGLs

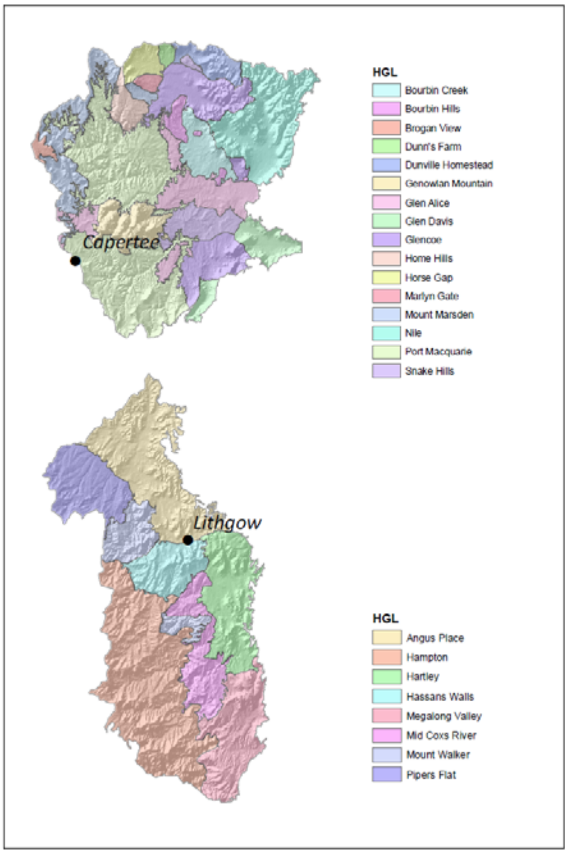


Figure 3 Hawkesbury-Nepean CMA map showing Goulburn Region HGLs

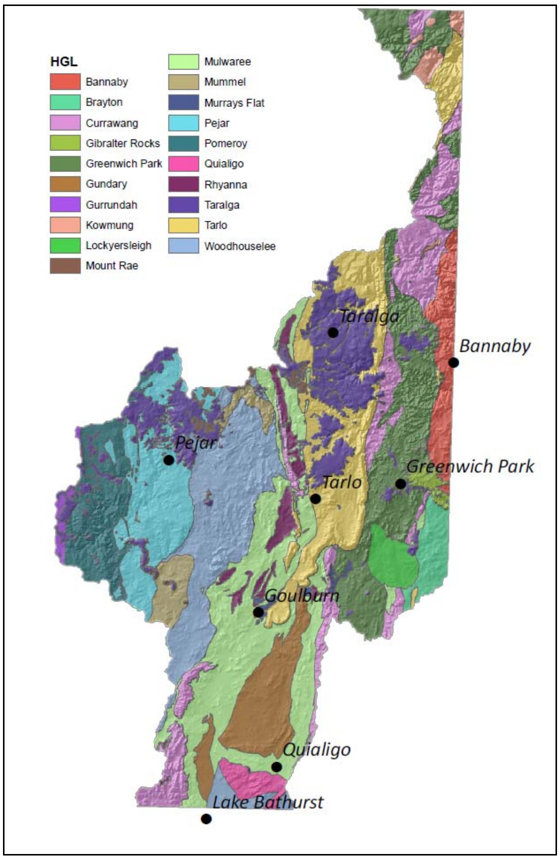


Figure 4 Hawkesbury-Nepean CMA map showing Western Sydney study area HGLs

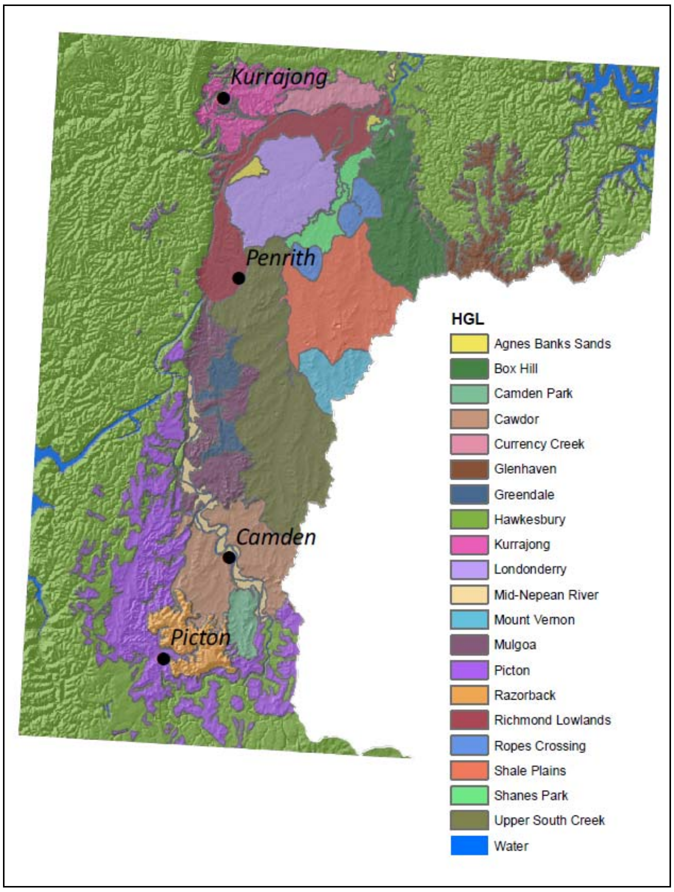
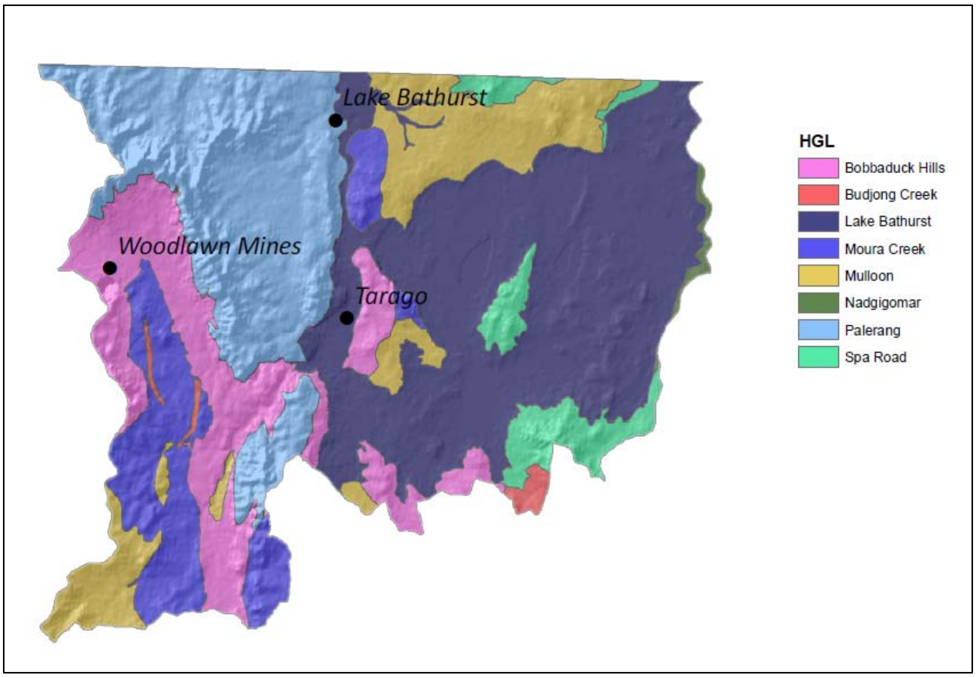


Figure 5 Southern Rivers CMA Braidwood 1:100 000 HGL map

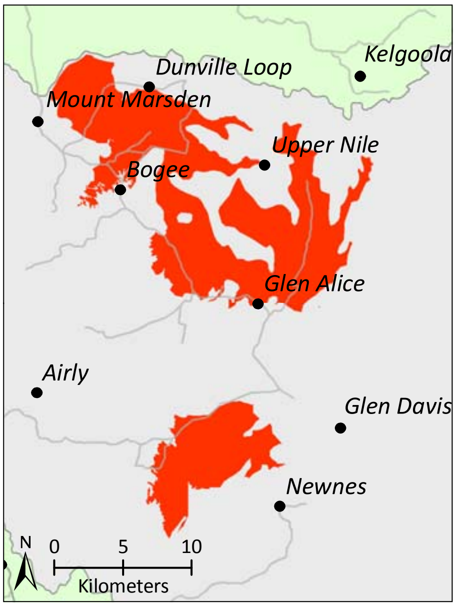


3 Descriptors

3.1 Very high hazard – Area 1

VH1	Capertee Sediments	Hazard:	Very High

Figure 6 Location diagram of very high hazard area 1



Overview / location

This category comprises colluvial slopes, valley constrictions and bowl shaped landforms on Permian aged sedimentary rocks of the Sydney Basin. These particular landforms and sediments are known to be found in the Capertee Valley.

This very high salinity hazard differs from other categories on Permian geology (H2 – Clay Rich Shoalhaven Group Sediments, M3 – Illawarra Coal Measures and L3 – Shoalhaven Group Sediments) due to the specific morphology of these landscapes involved in salinity development, and the stratigraphy of local geology.

Significance

These colluvial slopes, bowl formations and valley constrictions have formed on sediments that are horizontally bedded and contain highly saline layers. Sandstone cliffs sit above them providing a hydraulic head. Salt store in the Permian sediments is moderate to high and salt is moderately to highly available. The very high salinity hazard is related to this stratigraphic sequence: wherever water filters through saline strata before discharging on the surface, salinity is likely to express on the land surface or in streams. Groundwater salinity is brackish to saline (DLWC 2004) and salinity is concentrated due to the constricted nature of water flow.

On-site impacts include large seasonal saline sites, marginal to brackish stream flow, sheet and minor gully erosion with dispersive soils on colluvial slopes, and seasonal water-logging on colluvial slopes and alluvial plains. Off-site impacts include declining water quality along the Capertee River.

Detail on the location and processes of salinity development in this hazard category are described in HGLs of Nile HGL (minus sandstone geology), Glencoe HGL (minus sandstone geology), Bourbin Creek HGL, Horse Gap HGL and Marlyn Gate HGL (Nicholson et al. 2010b).

Resilience statement

Drivers of salinity development in these landscapes include poor grazing management on colluvial slopes and clearing of native vegetation. Salinity related variables impacting on the resilience of these landscapes include erosion, percentage of groundcover and extent of saline land.

Confidence

High. Salinity sites have been mapped and observed with a long history of salinity treatment and extension work. Stream EC tested.

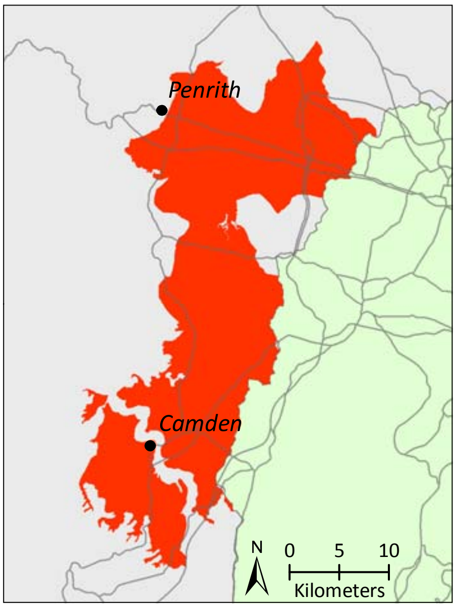
Decision rules

Very High hazard rating is based on HGL assessment which recognised high levels of land salinity, high in-stream salt load and highly saline water (Nicholson et al. 2010b).

3.2 Very high hazard – Area 2

VH2	Sydney Shales	Hazard:	Very High

Figure 7 Location diagram of very high hazard area 2



Overview / location

This category comprises Wianamatta Shale landscapes with low relief in the central Cumberland Plains area of Western Sydney.

Significance

Very high salinity hazard is due to flat lying shales (Ashfield Shale and Bringelly Shale) and the relative dominance of Ashfield Shale which contains high levels of salt, stored in both derived soils and regolith. Low relief contributes to saline land development at all points in the landscape, but particularly at discharge points on lower slopes and floodplains.

On-site impacts include locally severe salt scalding and associated gully erosion along drainage depressions, damage to buildings and infrastructure as a result of salinity, fluvial and sheet erosion, high in-stream salinity, saline groundwater (DLWC 2004) and localised water-logging and flood hazard. Off-site impacts include a decline in water quality.

Detail on the distribution and processes of salinity development in Sydney Shales are described in HGLs of Shale Plains HGL, Upper South Creek HGL, Cawdor HGL and Camden Park HGL, which all have similar hydrogeological processes and generation of high stream EC (Winkler et al. 2011).

Resilience statement

Drivers of salinity development in these landscapes include increased urbanisation (including urban and peri-urban development), over use of water, leakage of stormwater infrastructure and water delivery systems and inappropriate siting of infrastructure which will all have significant impact on hydrological pathways, and building and construction practices that are not sensitive to saline conditions. Salinity related variables controlling the resilience of these landscapes include planning, policy, siting of infrastructure, construction methods, water use patterns and volumes, localised volume of saline substrate and extent of saline land.

Confidence

High. Landscape salinity is mapped and observed and stream EC tested. Groundwater is marginal to saline (DLWC 2004).

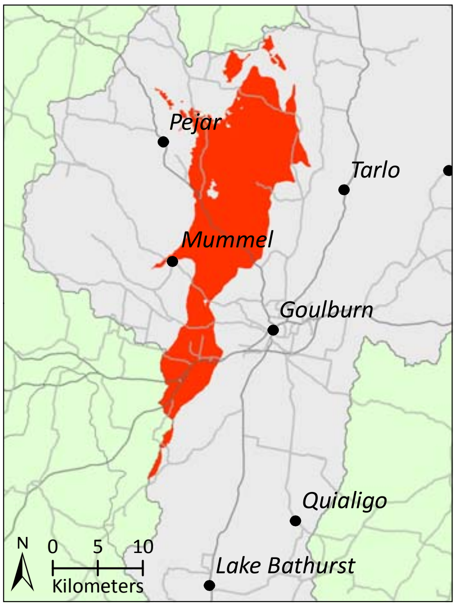
Decision rules

Very High hazard rating is based on HGL assessment which recognised high levels of land salinity, high in-stream salt load and highly saline water (Winkler et al. 2011).

3.3 Very high hazard – Area 3

VH3	**Undulating Landscapes on Vertically Bedded Ordovician Sediments**	**Hazard:**	**Very High**

Figure 8 Location diagram of very high hazard area 3



Overview / location

This category comprises Ordovician aged (predominantly Adaminaby Group) sediments that form low relief undulating landforms which are often cleared and farmed. Other occurrences of Ordovician aged sediments form higher relief landforms and they result in different salinity conditions (see VH5 – Spa Road and L5 – Steep Landforms on Vertically Bedded Sediments). This very high salinity hazard category occurs west of Goulburn around the Woodhouselee area.

Significance

The low relief undulating Ordovician (predominantly Adaminaby Group) sediments are highly fractured, faulted and have high salt store. Salt is also stored and cycled in shallow soils.

Outbreaks of salinity commonly occur across the area, particularly at mid-slope and footslope positions. Scalds are often up to 3 ha in size.

On-site impacts include scalding leading to erosion, soil sodicity leading to erosion, soil acidity and seasonal water-logging. Off-site impacts include decline of water quality. The landscape produces poor quality (saline) water and base flow in streams is commonly saline.

There is limited agricultural use of the upper slopes and ridges that are generally left under native timber because the land is poor, acidic and erodible.

The definition of this hazard area coincides with the distribution of Woodhouselee HGL (Marchand et al. 2011).

Resilience statement

Drivers of salinity development in these landscapes include poor grazing management, loss of groundcover and loss of soil health. Salinity related variables impacting on the resilience of these landscapes include groundcover percentage, perenniality and soil stability.

Confidence

High. Landscape salinity is mapped and there is a long history of salinity observation and trial work in this area.

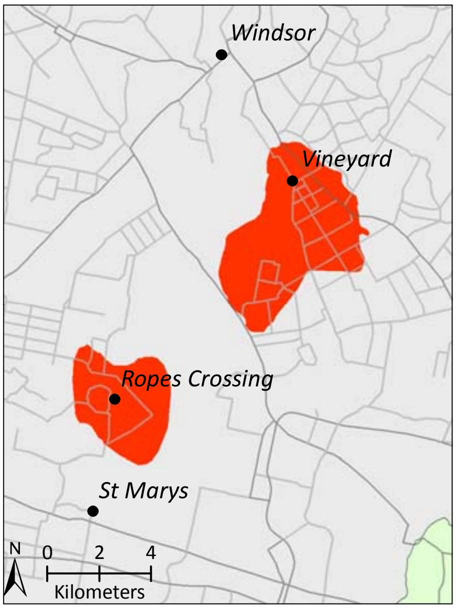
Decision rules

Very High hazard rating is based on HGL assessment which recognised high levels of land salinity, high in-stream salt load and highly saline water (Marchand et al. 2011).

3.4 Very high hazard – Area 4

VH4	St Marys Formation	Hazard:	Very High

Figure 9 Location diagram of very high hazard area 4



Overview / location

This category comprises localised and elevated pedi-plains (rises) with undulating surfaces of Quaternary aged St Marys Formation, plus associated colluvial slopes, in Western Sydney, close to St Marys and Ropes Crossing. These very high salinity hazard areas coincide with the occurrence of unique St Marys Formation geology.

Significance

The unique sedimentary layers of the St Marys Formation in the Sydney Basin contain highly saline horizontally bedded layers and impermeable layers. Water penetrating the surface tends to perch above the cemented layers. This perched water moves laterally creating areas of discharge on mid and upper slopes of the rises.

Pyrites are believed to be present in either the St Marys gravels or the weathered Wianamatta Group shale below them and as the water passes through the regolith the sulfates are mobilised and concentrate in areas of discharge. Discharge areas display strong evidence of saline affected land at specific topographic heights.

On-site impacts include salt seepage scalds and damaged infrastructure at mid to upper slope positions coinciding with location of impenetrable layers, hydrophobic topsoils on rises, localised seasonal water-logging, foundation hazard and sheet erosion. It is a strongly local system.

Much of this very high salinity hazard area is urbanised. On-site impacts also include highly saline water in streams and indicator species, such as Juncus acutus (spike rush) along drainage lines. Ground water is saline (DLWC 2004). Off-site impacts include decline of water quality.

Resilience statement

Drivers of salinity development in these landscapes include increased urbanisation (including urban and peri-urban development), over use of water, leakage of stormwater infrastructure and water delivery systems and inappropriate siting of infrastructure which will all have significant impact on hydrological pathways. Aggressiveness of sulfate salts which rapidly damage in situ infrastructure, and building and construction practices are a major issue. Salinity related variables controlling the resilience of these landscapes include planning, policy, siting of infrastructure, construction methods, water use patterns and volumes, and extent of saline land.

Confidence

High. Landscape salinity is mapped and observed. Urban infrastructure damage also observed in developing areas. Stream EC tested.

Decision rules

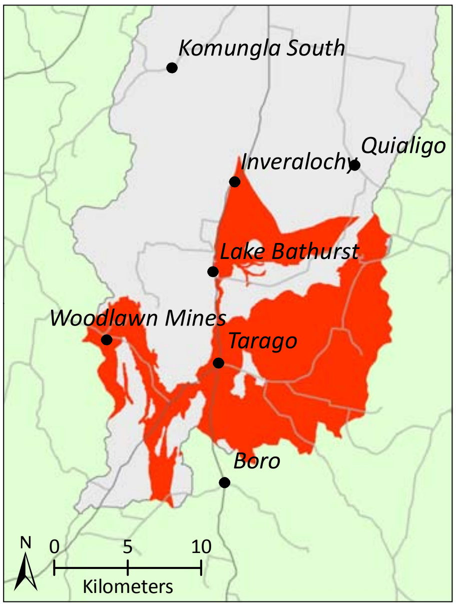
This hazard area is based on the Ropes Crossing HGL (Winkler et al. 2011).

Very high hazard rating is based on HGL assessment which recognised high levels of discrete land salinity, high in-stream salt load and highly saline water (Winkler et al. 2011).

3.5 Very high hazard – Area 5

VH5	**Spa Road**	**Hazard:**	**Very High**

Figure 10 Location diagram of very high hazard area 5



Overview / location

This category comprises duricrusts, undulating and rolling hills on deeply weathered, steeply dipping and intensely folded Ordovician aged sediments, felsic volcanics and volcanic sediments of the Silurian De Drack Formation, and undulating rises and plains on Neogene sand and gravel sediments in the far Southern Region of the catchment, including the recognised areas of Lake Bathurst and Spa Road.

Significance

Salt store in these landscapes is high. Soils tend to be sodic and acidic, with low fertility. The very high salinity hazard is due to a combination of layered sediments, duricrusts, highly complex geology, and terminal basins with structural controls around the Lake Bathurst area.

On-site impacts include salt outbreaks at breaks of slope in association with texture contrasts, in enclosed basin landscape depressions, on lower slopes, in drainage lines and in lake beds. Saline scalds are often present in the lower parts of the landscape. Salinity is most apparent during dry seasons and less evident when the landscape is wet. The landscapes also exhibit seasonal water-logging, wind erosion and salinity and potential for aluminium toxicity. Ground water quality is marginal (DLWC 2004). Off-site impacts include decline of water quality.

This hazard area incorporates HGLs of Budjong Creek, Bobbaduck Hills, Nadgigomar and Woodhouselee on the eastern boundary of the catchment area (Marchand et al. 2011 and Jenkins et al. 2010).

Resilience statement

Drivers of salinity development in these landscapes include clearing of native vegetation, poor grazing management and loss of soil health. Salinity related variables controlling resilience of these landscapes include seasonality of climate, percentage of groundcover, extent of saline land, erosion and salt load.

Confidence

High. Landscape salinity is mapped and observed and there has been a long history of salinity activity. Stream EC tested.

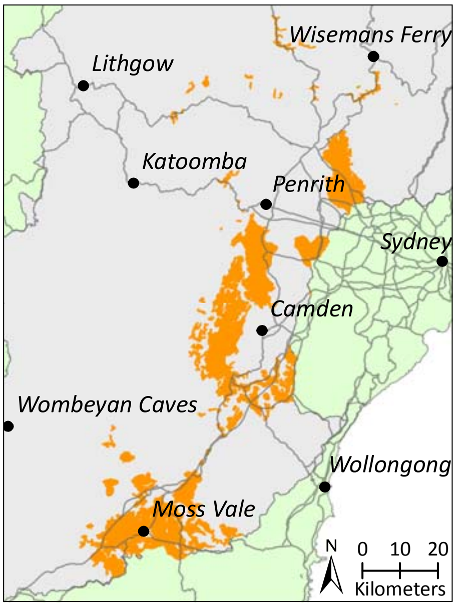
Decision rules

These landscapes have been grouped into this category based on location, common historical salinity activity and common Very High hazard rating (based on HGL assessment which recognised high levels of land salinity, high in-stream salt load and highly saline water across a variety of geologies) (Jenkins et al. 2010).

3.6 High hazard – Area 1

H1	Undulating Landforms on Wianamatta Shales	Hazard:	High

Figure 11 Location diagram of high hazard area 1



Overview / location

This category comprises Wianamatta Shale landscapes with moderate relief and relatively "high elevation" around the border of the Cumberland Plain, Western Sydney and Moss Vale. It generally occurs at the boundary between the shales and higher elevation sandstone circumference of the plains/tablelands.

Significance

These landscapes have a high salinity hazard due to flat lying shales (Ashfield Shale and Bringelly Shale) which contain high salt stores in soils and regolith.

Water percolates through the shale hills and laterally along clay rich layers within the soil material. Land salinity develops despite moderate relief and overland flow.

On-site impacts include changes in ground cover and damage to infrastructure and buildings. Frequent small salt sites occur at multiple landscape positions in the undulating landscapes including foot slopes, soil texture changes and upper slope drainage lines. Land salinity is also associated with sodic soils on upper slopes in the Picton area (Picton Soil Landscape). Small and shallow cyclic salt sites develop on ponded areas with seasonal drying.

Off-site impacts include decline of water quality. The landscapes generate high stream salinity (high EC) and groundwater salinity is notably high (DLWC 2004).

Details on distribution and processes of salinity in these undulating landforms are described in HGLs of Box Hill HGL, Picton HGL, Mulgoa HGL, Mt Vernon HGL and Greendale HGL, which all have similar hydrogeological processes, presence of land salinity and generation of marginal quality water (Western Sydney HGL Report Volume 2 ref.).

Resilience statement

Drivers of salinity include urbanisation, particularly peri-urban development and subdivision for hobby farming which may alter hydrological pathways. Impacts can be managed with urban and rural salinity management practices.

Variables that impact the resilience of this landscape include sodic soils and urban planning which should consider potential impacts of salinity on infrastructure and assets.

Confidence

High in Western Sydney (sites mapped and observed), low in Moss Vale (more investigation required).

Decision rules

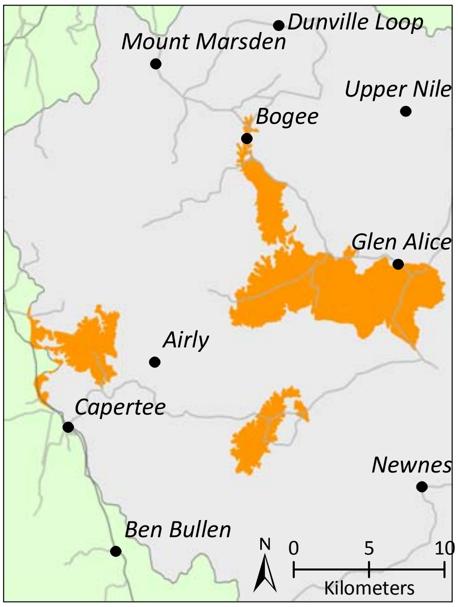
High hazard rating is based on HGL assessment of Western Sydney which recognised moderate to high levels of land salinity, moderately saline water and low to moderate in-stream salt loads (Winkler et al. 2011).

The shale landscapes of Moss Vale have been included to account for their high salinity hazard potential.

3.7 High hazard – Area 2

H2	Clay Rich Shoalhaven Group Sediments	Hazard:	High

Figure 12 Location diagram of high hazard area 2



Overview / location

This category comprises landscapes on flat lying Permian sandstone, siltstone and conglomerate sediments of the Shoalhaven Group situated centrally in the Capertee Valley near to Glen Alice. The sediments of the Shoalhaven Group in these landscapes are predominantly thin and clay rich. These sediments have weathered to create clay rich soils on rolling rises with gently inclined colluvial slopes and broad alluvial plains. They are generally cleared of native timber.

This high salinity hazard category differs from L3 –Shoalhaven Group Sediments because it occurs in a lower rainfall zone, the landscape is cleared and the thin clay rich layers are bounded below by less permeable geology layers, restricting flushing.

Significance

The geology in this category has weathered to form red soils, rich in clay, which impedes drainage in some locations. Resistant beds form structural hazards above which water ponding, and associated land salinity develops. These high salinity hazard landscapes feature soils that are occasionally strongly saline and generally sodic. Salt store is high in this clay rich environment.

On-site impacts include multiple small to medium salt sites associated with changes in slope, soil texture, and at drainage lines. The lower lying parts of the landscape are subject to water-logging and flooding, and salt sites in this part of the landscape reflect these seasonal changes. Water moves laterally through the unconsolidated colluvial and alluvial sediments and emerges at the land surface in wetter periods. On-site water quality is marginal to brackish.

Off-site impacts include decline in water quality.

Detail on the processes of salinity in clay rich Shoalhaven Group landforms are described in Glen Alice HGL (Nicholson et al. 2010b).

Resilience statement

Poor grazing management and poor cropping practices will drive salinity development. High cation exchange capacity (CEC) in these clay soils masks progress of salinity development until a threshold of salt store is reached and onsite impacts become evident.

Salinity related variables impacting on the resilience of this landscape include salt store and extent of land salinity.

Confidence

Moderate. Salt sites have been mapped in some locations and observed.

Decision rules

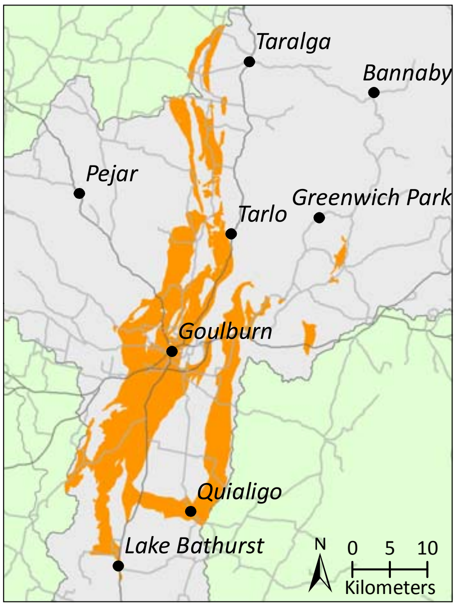
High hazard rating is based on HGL assessment which recognised moderate levels of land salinity, moderate in-stream salt loads and highly saline water (Nicholson et al. 2010b).

This high hazard salinity category differs to other occurrences of Shoalhaven Group Sediments due to the thickness of the clay-bearing geology in the Capertee Valley that weathers into clay rich soils.

3.8 High hazard – Area 3

H3	**Mulwaree Plains**	**Hazard:**	**High**

Figure 13 Location diagram of high hazard area 3



Overview / location

This category comprises undulating plains on Silurian aged sediments and related alluvial plains, to the north and south of Goulburn between Tarago and Quialigo.

Significance

The salt store is high and salt is highly available. Salt outbreaks occur at break of slope, in drainage lines, and on the alluvium where influenced by localised irrigation. Spike rush grows in some drainage lines. The Mulwaree Ponds are noted for their higher EC levels, particularly as systems dry out with change to seasonal patterns. Off-site impacts include decline of water quality. Groundwater quality is marginal (DLWC 2004).

Resilience statement

Irrigation can drive salinity development – use of salty groundwater or water recycled from salty streams will contribute salt to onsite salt store.

Reducing groundcover (resulting from overgrazing or cropping) drives increased recharge on lower colluvial slopes and can mobilise salt locally.

Self-regenerating riparian vegetation belts can buffer saline discharge into streams.

Major variables impacting the resilience of this landscape include salt store and availability and groundwater rise.

Confidence

Moderate. Salt sites mapped and observed.

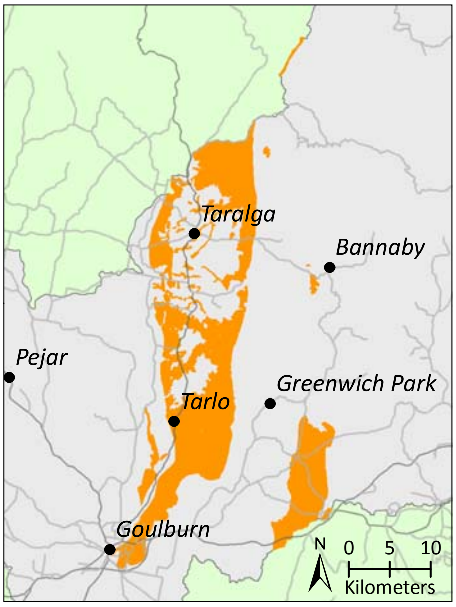
Decision rules

High hazard rating is based on HGL assessment which recognised associated areas with high levels of land salinity, moderate in-stream salt loads and highly saline water and/or common hydrogeological processes (Marchand et al. 2011). This hazard area incorporates HGLs of Mulwaree and Murrays Flat (Marchand et al. 2011).

3.9 High hazard – Area 4

H4	Cookbundoon	Hazard:	High

Figure 14 Location diagram of high hazard area 4



Overview / location

This category comprises variable landforms including steep hills, mountains and colluvial slopes on Devonian aged sediments, as well as pockets of basalt. It occurs along the Cookbundoon Range, westwards towards Tarlo and Strathaird, and also in the south-west of Brayton.

Significance

The landforms have moderate salt store. Land salinity is widespread and occurs in various locations including on mid- to lower slopes, in the drainage depressions, on the shales, and in association with basalt geology and faulting. This unit is highly complex and has multiple groundwater systems. On-site impacts include gullying and soil sodicity, which may be severe in localised areas. Off-site impacts include salt export and decline in water quality.

This hazard category incorporates HGLs of Tarlo and Brayton (Marchand et al. 2011).

Resilience statement

Reduced groundcover resulting from overgrazing (or cropping) drives increased recharge on lower colluvial slopes and can mobilise salt locally. Clearing of upper slopes drives recharge, contributing to hydraulic head which mobilises salt stores.

Barriers to water pathways (building of roads) can irreversibly alter the hydrology and salinity processes.

Salinity related variables that impact on resilience in this landscape include percentage of groundcover and soil stability.

Confidence

Moderate. Some salt sites are mapped and observed.

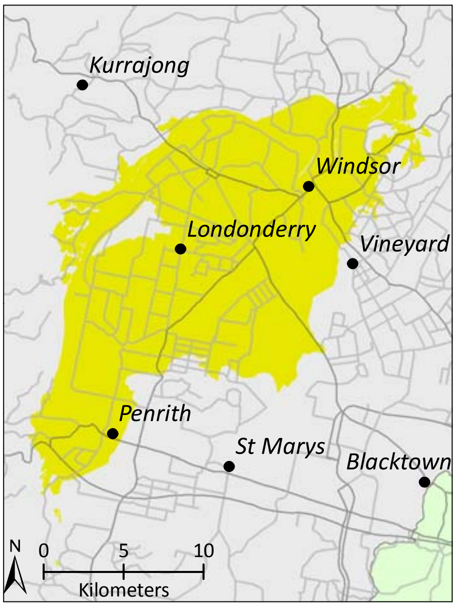
Decision rules

Defined by Brayton HGL (Marchand et al. 2011).

3.10 Moderate hazard – Area 1

M1	**Sydney Low-lying Plains**	**Hazard:**	**Moderate**

Figure 15 Location diagram of moderate hazard area 1



Overview / location

This category comprises unconsolidated alluvial deposits of gravels, sands, silts and clays from the Tertiary and Quaternary periods along the Hawkesbury and Nepean River floodplains. They form “low-lying plains” around Londonderry, Shanes Park and Richmond in Western Sydney.

The area roughly coincides with the Hawkesbury – Nepean Terrace Gravels Mitchell Landscape (Mitchell 2003).

Significance

The unconsolidated sediments are flat lying and store some salt. Land salinity develops along current drainage lines and where texture boundaries occur between Quaternary and Tertiary sedimentary layers.

Saline groundwater in the Wianamatta Group Shales underlies the unconsolidated sediments. Faulting at the Kooree Creek lineament may intersect the saline groundwater flows to produce upwelling of saline groundwater into the Sydney low-lying plains drainage lines and through its regolith.

On-site impacts include wet seep sites, with occasional salt expression at the base of alluvial terraces and changes in slope, salt sites along drainage lines, highly saline water in back swamps and moderately saline water in streams. Off-site impacts include decline in water quality and distribution of salt load.

This hazard area incorporates a number of HGLs including Londonderry, Shanes Park and Richmond Lowlands HGLs (Winkler et al. 2011).

Resilience statement

Minor irrigation and increased urbanisation will drive salinity development, particularly peri-urban development and golf courses which may alter hydrological pathways. Variables that influence resilience in these landscapes include flooding and groundwater rise.

Confidence

Moderate. Salt sites mapped and observed. Further investigation into spatial distribution and local salinity processes is needed.

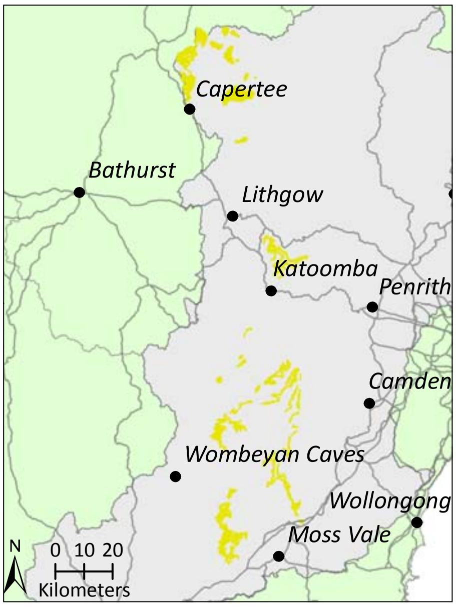
Decision rules

Defined by distribution of similar hydrogeological landscapes. Moderate salinity hazard rating is based on HGL assessment which recognised combinations of low to moderate levels of land salinity, low to moderate in-stream salt loads and moderately saline water (Winkler et al. 2011).

3.11 Moderate hazard – Area 2

M2	Illawarra Coal Measures	Hazard:	Moderate

Figure 16 Location diagram of moderate hazard area 2



Overview / location

This category comprises landscapes formed on Permian sediments of Illawarra Coal Measures. It combines known landscapes that are affected by highly saline layers of Illawarra Coal Measures in the Capertee Valley, plus landscapes throughout the Hawkesbury-Nepean Catchment where Illawarra Coal Measures occur.

Significance

The Illawarra Coal Measures contain layers that are highly saline. Salt stores are high. Salinity outbreaks are small, localised and numerous. On-site impacts include mass movement, highly dispersive, eroding sodic soils and water-logging. Severe rill, sheet and gully erosion are common. Water quality is low. Off-site impacts include decline in water quality and sediment source into streams.

Details on the processes of salinity development in Illawarra Coal Measures are described in HGLs of Snake Hills, Bourbin Hills, Mt Marsden and Dunns Farm (Nicholson et al. 2010b).

Resilience statement

Drivers of salinity development in these landscapes include mining, clearing of native vegetation, and urbanisation, particularly peri-urban development and subdivision for hobby farming which may alter hydrological pathways. Variables impacting on the resilience of these landscapes include percentage of groundcover, water-logging and water quality.

Confidence

Moderate. Salt sites and sodic slopes have been mapped and observed and have history of site treatment.

Decision rules

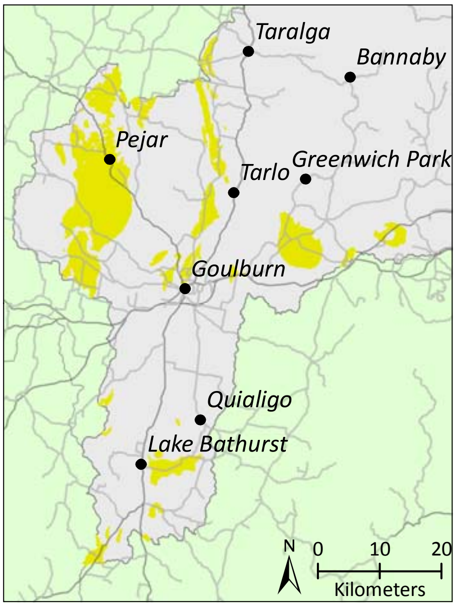
Moderate salinity hazard rating is based on knowledge of Illawarra Coal Measure salinity and HGL assessment which groups areas with similar hydrogeological processes.

The HGL assessment recognised combinations of low to moderate levels of land salinity, low to moderate in-stream salt loads and marginal to saline water (Nicholson et al. 2010b).

3.12 Moderate hazard – Area 3

M3	**Granites**	**Hazard:**	**Moderate**

Figure 17 Location diagram of moderate hazard area 3



Overview / location

This category comprises granite, monzonite, diorite and monzodiorite landscapes throughout the Hawkesbury-Nepean Catchment that have been cleared of native timber. They generally occur in the west of in the Southern Region.

Some granite batholiths have been included in the very low salinity hazard category VL2 – Mixed Geologies due to their low salinity potential under native forest/national park.

Significance

Salt store is moderate, potentially high. Salt is moderately available. Land salinity is localised, common and sites are small where high in the landscape, but frequent and large at colluvial slope changes, associated with water-logging.

Soils in this hazard category can be highly sodic. On-site impacts include water-logging in drainage lines, seasonal water table rise, extensive gully erosion in drainage lines, widespread sheet erosion, soil acidification and saline creek lines dominated by Juncus acutus (spike rush). Off-site impacts include decline in water quality and distribution of sediment load.

This hazard area incorporates HGLs of Pejar, Rhyanna, Mulloon and Lockyersleigh and other areas of igneous geology (Marchand et al. 2011 and Jenkins et al. 2010).

Resilience statement

Drivers of salinity development in these landscapes include poor grazing management, water-logging, loss of groundcover and loss of soil health. Variables that impact on the resilience of these landscapes include climatic variability, extent of saline land, soil stability, cropping frequency and percentage of groundcover.

Confidence

Moderate. Some sites mapped and observed and the areas have a history of trial sites for salinity management.

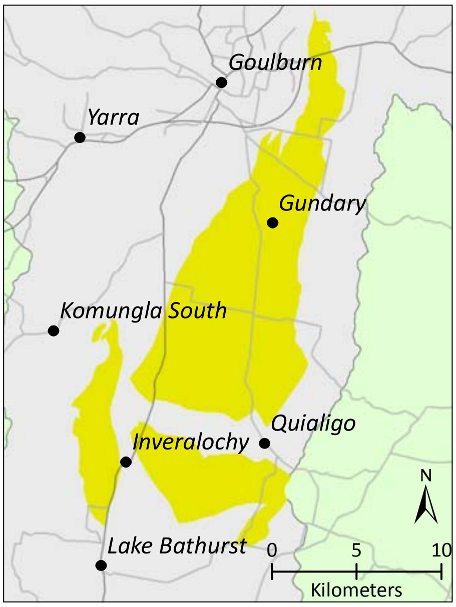
Decision rules

Defined by distribution of granite based and similar geologies that have been cleared of timber, and by HGL characteristics in granite based landscapes (Marchand et al. 2011).

3.13 Moderate hazard – Area 4

M4	Mixed Flat Landscapes (Silurian / Devonian)	Hazard:	Moderate

Figure 18 Location diagram of moderate hazard area 4



Overview / location

This category comprises flat landforms on Silurian and Devonian sedimentary geology. It is found in the far south-west corner of the Hawkesbury-Nepean Catchment south of Goulburn.

Significance

Salt store is moderate. Land salinity is moderate. Soil sodicity may be severe in localised areas. On-site impacts include scalding due to salinity in drainage depressions and at break of slope, localised high water tables in lower landscape, gully erosion, sedimentation and stream bank erosion. Groundwater quality is marginal (DLWC 2004).

This hazard area coincides with the distribution of Gundary and Quialigo HGLs (Marchand et al. 2011).

Resilience statement

Drivers of salinity in these landscapes include urbanisation, particularly subdivision for hobby farming which may result in altered hydrological pathways, poor grazing management and inappropriate cropping. Variables impacting on resilience in these landscapes include percentage of groundcover and soil health.

Confidence

Low. Sites mapped and observed however more investigation could be useful.

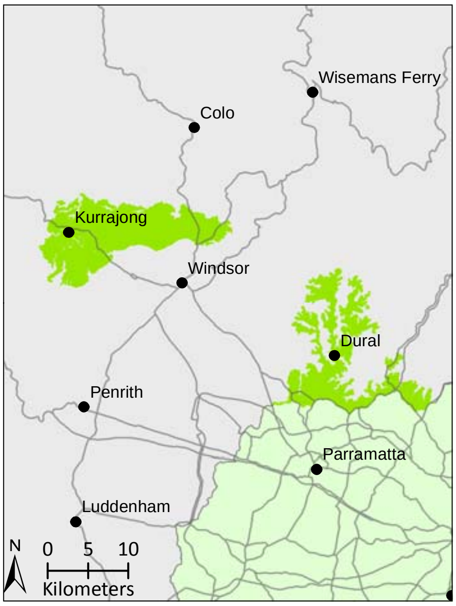
Decision rules

Defined by known salinity risk from HGLs and common sedimentary structure (Marchand et al. 2011).

3.14 Low hazard – Area 1

L1	Northern Sydney Shales	Hazard:	Low

Figure 19 Location diagram of low hazard area 1



Overview / location

This category comprises relatively shallow Wianamatta Shale landscapes on the northern boundary of the Cumberland Plain, Western Sydney adjacent to sandstone landscapes around Kurrajong, Currency Creek and Glenhaven.

It differs from the high salinity hazard category H1 – Undulating Landforms on Wianamatta Shales because this category has shallower depths of Wianamatta Shales and a greater influence of sandstone and flushing of fresh water through the landscape.

Significance

These landscapes have a low salinity hazard due to the influence from freshwater producing sandstone landscapes and the shallow depths of flat lying shales (Ashfield Shale and Bringelly Shale) which contain salt stores.

Water percolates through the Triassic sandstones and shale hills and laterally along clay rich layers within the soil material. Land salinity develops in association with wet seeps on shale derived soils and near drainage lines.

On-site impacts include salt sites in upper drainage depressions and at colluvial change in slope. Occasional sites also occur in shale drainage lines in lower parts of the landscape. Off-site impacts include decline of water quality.

The groundwater salinity is marginal (DLWC 2004).

Detail on the distribution and processes of salinity in these landforms are described in HGLs of Kurrajong HGL, Currency Creek HGL and Glenhaven HGL, which all have similar hydrogeological processes, presence of land salinity and stream EC (Winkler et al. 2011).

Resilience statement

Irrigation can drive salinity development – use of salty groundwater or water recycled from salty streams will contribute salt to onsite salt store, particularly on turf farms.

Increased urbanisation, particularly peri-urban development and subdivision for hobby farming will drive salinity development.

Variables that impact on resilience in these landscapes include drainage impedance and groundwater rise.

Confidence

Low to moderate. Some salt sites have been mapped and observed.

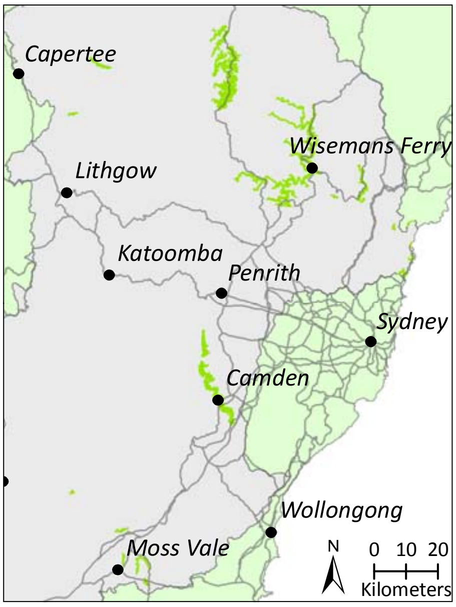
Decision rules

Low salinity hazard rating is based on HGL assessment which recognised a moderate likelihood of occurrence with limited impact across most locations in these landscapes (Winkler et al. 2011).

3.15 Low hazard – Area 2

L2	Quaternary Alluvium	Hazard:	Low

Figure 20 Location diagram of low hazard area 2



Overview / location

This category comprises landscapes formed on Quaternary aged alluvial deposits throughout the Hawkesbury-Nepean Catchment.

Significance

Salinity hazard in these landscapes relates to texture changes at the margin of Quaternary alluvium and surrounding geologies. Salt store is variable and dynamic (in association with flooding cycles) but generally low in Quaternary Alluvium. Occasional scalds develop at the base of terraces or where footslopes of adjoining landscapes meet the alluvial plain. On-site impacts also include water-logging, flooding, associated mass movement, foundation hazard and acidic topsoils.

Resilience statement

Irrigation can drive salinity development – use of salty groundwater or water recycled from salty streams will contribute salt to onsite salt store.

Barriers to water pathways (building of roads) can irreversibly alter the hydrology and salinity processes.

Confidence

Moderate. Salt sites observed and historical salt extension activities in these areas.

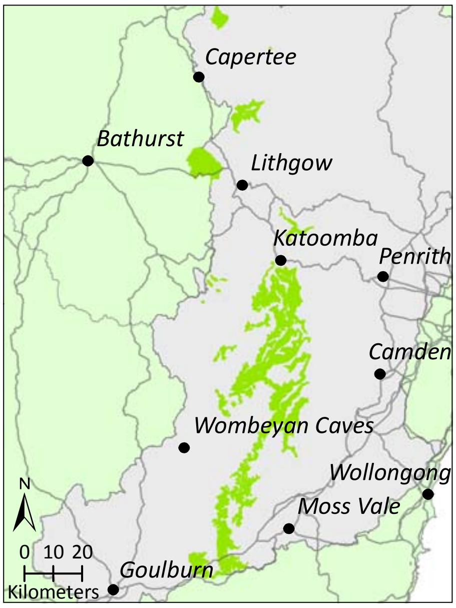
Decision rules

Low salinity hazard rating is based on knowledge of drainage patterns and salinity expression in studied areas of Quaternary Alluvium. All areas of Quaternary Alluvium are treated similarly.

3.16 Low hazard – Area 3

L3	Shoalhaven Group Sediments	Hazard:	Low

Figure 21 Location diagram of low hazard area 3



Overview / location

This category comprises landscapes formed on flat lying Permian sandstone, siltstone and conglomerate sediments of the Shoalhaven Group throughout the Hawkesbury-Nepean Catchment, apart from those defined otherwise in the Capertee Valley.

This low salinity hazard category differs from H2 – Clay Rich Shoalhaven Group Sediments because the sandstone and siltstone sediments in these locations are much thicker and highly permeable, allowing flushing.

Significance

Salt store is expected to be low to moderate. On-site impacts include small seasonal salt sites on cleared colluvial slopes, at the change of slope, and on the valley floor adjacent to drainage lines. Localised sheet and gully erosion also occur.

This category incorporates HGLs of Home Hills HGL and Pipers Flat HGL (Nicholson et al. 2010b).

Resilience statement

Clearing of vegetation on colluvial slopes may drive recharge which will mobilise salt stores.

Increased peri-urban development and subdivision for hobby farming may alter hydrological pathways which will drive salinity development.

Variables that influence resilience in these landscapes may include percentage of groundcover (tree cover) and soil stability.

Confidence

Low – some salt sites observed. Confidence is very low in areas outside the Capertee Valley and Lithgow areas – further investigation would be informative.

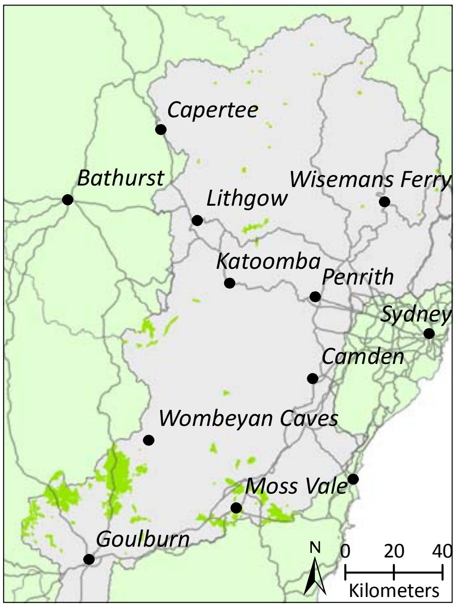
Decision rules

Low salinity hazard rating is based on HGL assessment which recognised similar geology features and salinity as having a low likelihood of occurrence in these areas. All other areas of Shoalhaven Group sediments in the catchment were given a similar hazard rating due to the potential salinity in the geology layers, although understanding of these areas is low.

3.17 Low hazard – Area 4

L4	**Basalt**	**Hazard:**	**Low**

Figure 22 Location diagram of low hazard area 4



Overview / location

This category comprises landscapes formed on basalt geology throughout the Hawkesbury-Nepean Catchment, particularly in the Crookwell and Taralga areas in the Southern Region of the CMA.

Significance

Salt store is generally moderate. Salt sites are relatively small and carbonate dominated. They usually occur at contact with underlying geology and where there are perched water tables, often with associated fresh springs. Water quality is generally fresh and salt export is moderate. Groundwater salinity is fresh (DLWC 2004).

These landscapes are generally fertile.

This hazard area incorporates Taralga HGL (Marchand et al. 2011).

Resilience statement

Drivers of salinity development in these landscapes include poor grazing management.

High cation exchange capacity (CEC) in clay rich basalt soils masks progress of salinity development until a threshold of salt store is reached and onsite impacts become evident.

Variables that influence resilience in these landscapes may include percentage of groundcover.

Confidence

Moderate. Sites mapped and observed with a history of trial sites for salinity management.

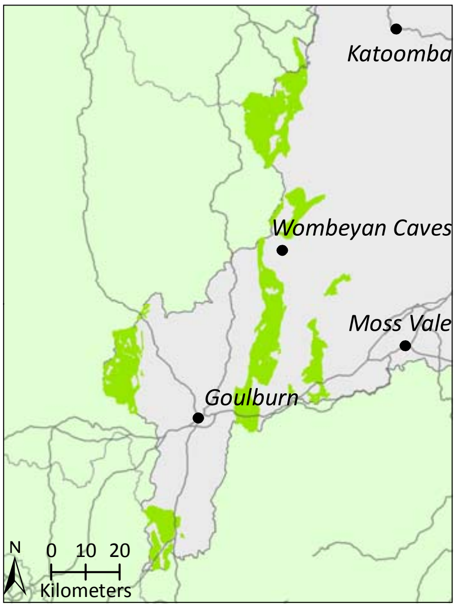
Decision rules

Occurrences of Tertiary or Jurassic basalt were incorporated into this category landscape.

3.18 Low hazard – Area 5

L5	Steep Landforms on Vertically Bedded Sediments	Hazard:	Low

Figure 23 Location diagram of low hazard area 5



Overview / location

This category comprises variably shaped but generally steep, rugged and vegetated landscapes on Ordovician and Silurian aged rocks throughout the Southern and Western Regions of the Hawkesbury-Nepean Catchment. The category is united by the common low salinity hazard and similar geologies.

Significance

These landscapes have limited salinity potential. Salt load is generally low. Some landscapes are under native forest and salinity development is unlikely where tree cover is maintained. They are all in relatively high rainfall areas. Rare salt sites may occur on lower slopes, sometimes associated with water-logging, including in association with basalt caps. Surface water is generally fresh however groundwater is brackish (DLWC 2004).

Deep recharge occurs to lower landscape areas. Potential total soil loss from sheet erosion may be associated with widespread clearing.

Resilience statement

Poor grazing management and clearing of native vegetation are drivers for salinity development. Variables influencing the resilience in this landscape are groundcover percentage and perenniality of species.

Confidence

Poor. Limited field investigation in this area.

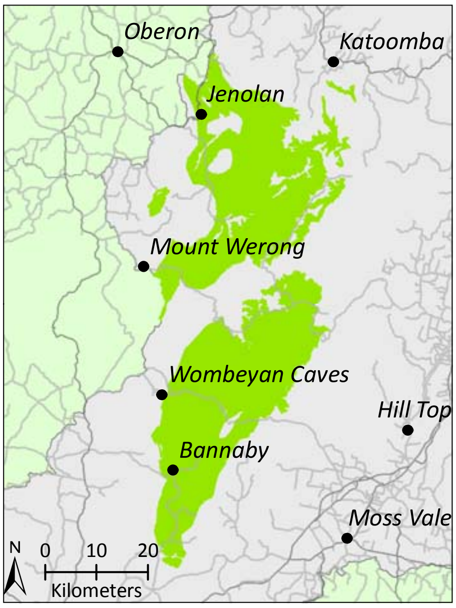
Decision rules

Defined by limited potential impact of salinity in these areas while under native forest. This hazard area incorporates HGLs of Greenwich Park, Gurrundah, Palerang, Moura Creek, Pomeroy and other areas of similar geology (Marchand et al. 2011 and Jenkins et al. 2010).

3.19 Low hazard – Area 6

L6	Steep Devonian Hills	Hazard:	Low

Figure 24 Location diagram of low hazard area 6



Overview / location

This category comprises steep, vegetated hills on Devonian aged sediments north-west of Goulburn in the southern and western regions of the Hawkesbury-Nepean Catchment.

Significance

These landscapes have limited salinity potential. They are generally under native forest and in higher rainfall areas than other parts of the catchment. Salinity expression in the landscape is minimal. Salinity development is unlikely where tree cover is maintained. Landscapes are sodic and therefore highly erosive producing sediment loss from gullies. Water quality is fresh and groundwater salinity is fresh to marginal (DLWC 2004). Off-site impacts include sedimentation in streams.

Resilience statement

Poor grazing management and clearing of native vegetation are drivers of salinity development. Variables influencing resilience in these landscapes include soil stability and percentage of groundcover.

Confidence

Poor. Limited field investigation in this area.

Decision rules

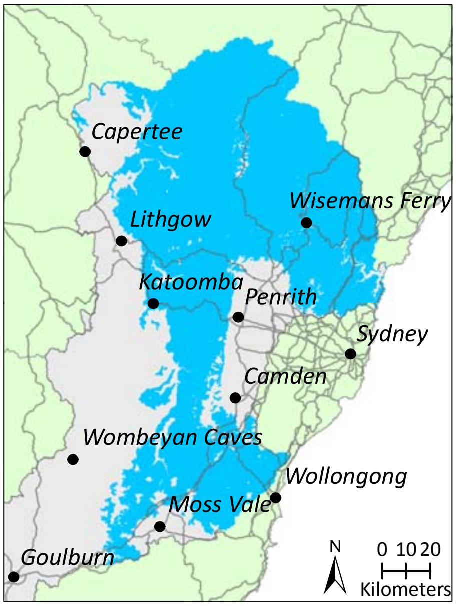
Defined by limited potential impact of salinity in these areas while under native forest. Definition of salinity hazard is based on Bannaby HGL (Marchand et al. 2011).

This hazard area incorporates Bannaby HGL and other areas of Devonian geology (Marchand et al. 2011).

3.20 Very low hazard – Area 1

VL1	**Triassic Sandstones**	**Hazard:**	**Very Low**

Figure 25 Location diagram of very low hazard area 1



Overview / location

This category comprises landscapes formed on massive sandstones of the Triassic Period. These landscapes stretch from the northern boundary of the CMA to the southern boundary, and stretch from mid-west to east across the catchment. These landscapes occur in all regions of the Hawkesbury-Nepean CMA area.

Significance

These landscapes have a very low salinity hazard but are major sources of dilution flow. The massive sandstones have low salt store. There are only rare occurrences of land salinity, often associated with pockets of clay derived from layers of rock strata, or in association with overlying basalt remnants. Drainage is deep and water is fresh.

Detail on the processes of salinity in these landscapes is covered in the Hawkesbury HGL (Winkler et al. 2011).

Resilience statement

The likelihood of salinity development is low. Drivers of salinity development may include clearing of native vegetation and urbanisation, which may alter hydrogeological pathways. There are few salinity variables that influence the resilience.

Confidence

High.

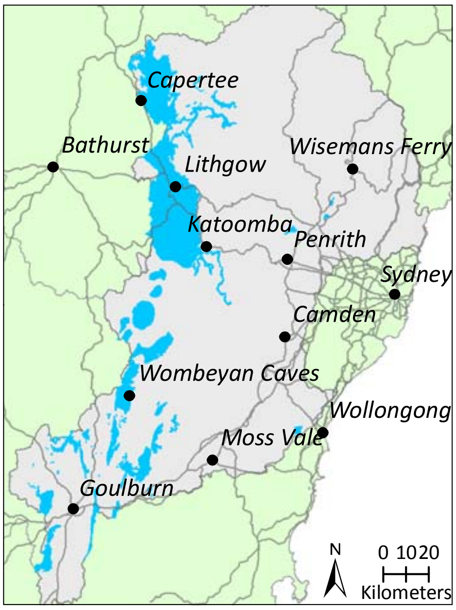
Decision rules

This category groups together the Hawkesbury and Narrabeen Sandstone landscapes within the Hawkesbury-Nepean CMA.

3.21 Very low hazard – Area 2

VL2	Mixed Geologies	Hazard:	Very Low

Figure 26 Location diagram of very low hazard area 2



Overview / location

This category comprises a range of landscapes formed on different geologies that present a very low known hazard for salinity. It extends across the Hawkesbury-Nepean catchment in all regions.

Significance

These landscapes generally have low salt store and provide dilution flow to the catchment. They are often vegetated and are generally granites under native timber; sandstones, conglomerates, unconsolidated Aeolian sands or combinations of other geologies which do not typically hold salt or generate salt load and have rare on-site impacts from salinity. Water exported from these landscapes is generally fresh.

Resilience statement

The likelihood of salinity development is low. Drivers of salinity development may include clearing of native vegetation, poor grazing management and urbanisation, which may alter hydrogeological pathways. There are few salinity variables that influence the resilience but percentage of groundcover has the most influence.

Confidence

Moderate. Sites generally not mapped or observed.

Decision rules

Defined by geologies where type, structure, rainfall and regolith factors combine to give very low salinity; mapped as HGLs of Port Macquarie HGL, Mt Walker HGL, Genowlan Mt HGL, Brogan View HGL, Hampton HGL, Hartley HGL, Mid-Coxs River HGL, Hassans Walls HGL, Megalong Valley HGL, (Nicholson et al. 2010b), Gibraltar Rocks HGL, Currawang HGL, Kowmung HGL, Mummell HGL, Mt Rae HGL (Marchand et al. 2011), and Agnes Banks HGL (Winkler et al. 2011) plus additional geologies which are likely to have similar hydrogeological and salinity processes.

4 References

Bannerman, S.M. and Hazelton, P.A. (1990). Soil Landscapes of the Penrith 1:100 000 Sheet. Soil Conservation Service of NSW, Sydney

Bryan, J. H. (1966). Sydney 1:250,000 Geological Series Sheet SI 56-5, Third Edition, New South Wales Department of Mines

Clark, N.R., and Jones, E.C., (Eds) (1991). Penrith 1:100 000 Geological Sheet 9030. New South Wales Geological Survey, Sydney.

Chapman, G.A. and Murphy, C.L. (1989). Soil Landscapes of the Sydney 1:100 000 sheet. Soil Conservation Service of N.S.W., Sydney

Cook, W., Marchand, A., Harvey, K., Nicholson, A., Jenkins, B., Wooldridge, A., Moore, L., Muller, R., Pavan, N., Winkler, M. and Shoemark, V. (2011). Hydrogeological Landscapes for the Hawkesbury-Nepean Catchment Management Authority, Goulburn Region: Volume 1 – Background, Methodology and Results, NSW Department of Environment, Climate Change & Water, Parramatta.

Department of Environment and Climate Change (2008). Soil and Land Resources of the Hawkesbury-Nepean Catchment DVD, NSW Soil and Land Resources Series, Natural Resources Information Unit, Department of Environment and Climate Change, Parramatta

Department of Environment and Conservation (2006). The Vegetation of the Western Blue Mountains, report funded by the Hawkesbury – Nepean Catchment Management Authority (unpublished). Department of Environment and Conservation, Hurstville

Department of Land and Water Conservation (DLWC) (2004). Groundwater Vulnerability Mapping. Department of Infrastructure, Planning and Natural Resources, Parramatta. Metadata Reference: http://canri.nsw.gov.au/nrdd/records/ANZNS0359000209.html

Department of Primary Industries (2009). Braidwood Geological Mapping Project www.dpi.nsw.gov.au/minerals/geological/about/mapping/braidwood-geological-mapping-project observations accessed in (2009).

Emery, K.A. (1985). Rural Land capability mapping - scale 1:100 000. Soil conservation service of NSW, Sydney (NSW).

Felton E.A. and Huleatt M.B. (1975). Braidwood 1:100 000 Geological Sheet. NSW Geological Survey: Sydney.

Fitzherbert, J.A., Thomas, O.D., Deyssing, L., Simpson, C.J., and Vassallo, K.E. In prep. Braidwood 1:100 000 Geological Sheet 8827, 2nd edition. Geological Survey of New South Wales, Orange, Maitland.

Folke, C., S. R. Carpenter, B. Walker, M. Scheffer, T. Chapin, and J. Rockström (2010). Resilience thinking: integrating resilience, adaptability and transformability. Ecology and Society 15(4): 20. [online] URL: http://www.ecologyandsociety.org/vol15/iss4/art20/

Geoscience Australia (2011) Australian Stratigraphic Units Database, Canberra, Australia

[accessed 24/02/11 <http://dbforms.ga.gov.au/www/geodx.strat_units.int>]

Geological Survey of New South Wales (1968). Bathurst 1:250,000 Geological Series Sheet SI 55-8, First Edition, Department of Mines, NSW.

Grant, S., Muller, R., Copley, S., Winkler, M., Taylor, L., Cull, V., Nicholson, A., Pavan, N., Jenkins, B. and Preston, Y. (2010). Hydrogeological Landscapes for the Hawkesbury-Nepean Catchment Management Authority, Capertee and Lithgow Valleys: Volume 3 – Maps, Data and Mapping Products, NSW Department of Environment, Climate Change and Water, Parramatta.

Grant, S., Muller, R., Winkler, M., Taylor, L., Copley, S., Cull, V., Nicholson, A., Pavan, N. and Jenkins, B. (2011a). Hydrogeological Landscapes for the Hawkesbury-Nepean Catchment Management Authority, Western Sydney Study Area: Volume 3 – Maps, Data and Mapping Products, NSW Office of Environment & Heritage, Department of Premier and Cabinet, Parramatta.

Grant, S., Muller, R., Copley, S., Winkler, M., Nicholson, A., Marchand, A., Pavan, N., and Jenkins, B. (2011b). Hydrogeological Landscapes for the Hawkesbury-Nepean Catchment Management Authority, Goulburn Region: Volume 3 – Maps, Data and Mapping Products, NSW Department of Environment, Climate Change & Water, Parramatta.

Hazelton, P.A. and Tille, P.J. 1990 Soil Landscapes of the Wollongong-Port Hacking 1:100 000 Sheet Map, Soil Conservation Service of NSW, Sydney. Herbert, C. and Helby, R., (1980). A Guide to the Sydney Basin. Department of Mineral Resources, Geological Survey of New South Wales, Sydney

Herbert, C. (1983). Geology of the Sydney 1:100 000 Sheet 9130. Geological Survey of New South Wales, Sydney

Hird, C. (1990). Soil Landscapes of the Goulburn 1:250 000 Sheet. Department of Land and Water Conservation: Sydney.

Industry & Investment NSW, Geological mapping team (in prep.). 1:100 000 Solid Geology Map Sheet, Braidwood (preliminary compilation, work in progress). Industry & Investment NSW, Sydney (NSW).

Jenkins, B.R. (1996). Soil Landscapes of the Braidwood 1:100 000 Sheet Report, Department of Land & Water Conservation, Sydney.

Jenkins, B, Nicholson, A, Moore, L, Harvey, K, Cook, W, Wooldridge, A, Shoemark, V, Nowakowski, A, Muller, R and Winkler, M (2010). Hydrogeological Landscapes for the Southern Rivers Catchment Management Authority, Braidwood 1:100 000 map sheet Volume 1 – Background, Methodology and Results, Department of Environment, Climate Change and Water, Parramatta.

Keith, D. A. (2004). Ocean Shores to Desert Dunes: the Native Vegetation of New South Wales and the ACT, Department of Environment and Conservation Hurstville (NSW).

King, D.P. (1993). Soil Landscapes of the Wallerawang 1:100 000 Sheet Map, Department of Conservation & Land Management.

King, D.P. (1993). Soil Landscapes of the Wallerawang 1:100 000 Sheet Report, Department of Conservation & Land Management, Sydney.

King, D.P. (1994). Soil Landscapes of the Katoomba 1:100 000 Sheet Map, Department of Conservation & Land Management, Sydney.

King, D.P. (1994). Soil Landscapes of the Katoomba 1:100 000 Sheet Report, Department of Conservation & Land Management, Sydney.

Kovac, M., Murphy, B.W. and Lawrie, J.W. (1990). Soil Landscapes of the Bathurst 1:250 000 Sheet Map, Soil Conservation Service of NSW, Sydney (NSW).

Kovac, M., Murphy, B.W. and Lawrie, J.W. (1990). Soil Landscapes of the Bathurst 1:250 000 Sheet Report, Soil Conservation Service of NSW, Sydney (NSW).

Marchand, A., Nicholson, A., Muller, R., Jenkins, B., Moore, L., Winkler, M., Harvey, K., Cook, W., Nowakowski, A., Wooldridge, A. and Shoemark, V. (2011). Hydrogeological Landscapes for the Hawkesbury-Nepean Catchment Management Authority, Goulburn Region: Volume 2 – Hydrogeological Landscape Units. NSW Department of Environment, Climate Change & Water, Parramatta.

Mitchell P.B. (2003). NSW ecosystems database mapping unit descriptions. Unpublished report to the NSW National Parks and Wildlife Service, Hurstville.

Moore L., Nicholson A. and Winkler M. A., (2010). Using geomorphology and stratigraphy to clarify a dryland salinity, soil sodicity and vegetation distribution puzzle at Capertee Valley, Western Blue Mountains, NSW, Proceedings of the Australian Earth Sciences Convention 2010, page 161.

Murphy, B.W. and Lawrie, J.W. (1999). Soil Landscapes of the Dubbo 1:250 000 Sheet Map, Department of Land & Water Conservation, Sydney (NSW).

Murphy, B.W. and Lawrie, J.W. (1999). Soil Landscapes of the Dubbo 1:250 000 Sheet Report, Department of Land & Water Conservation, Sydney (NSW).

Murphy, B. W. and McKenzie, D. C. (2007). Graph to predict instability to wetting in soils based on Exchangeable Sodium Percentage and Electrical Conductivity (1:5). Extension Note

Natural Resources Commission (2011). Framework for assessing and recommending upgraded catchment action plans, August 2011, NRC, Sydney

Nicholson, A., Moore, L., Pavan, N., Winkler, M., Taylor, L., Cull, V., Copley, S., Preston, Y., Muller, R., Jenkins, B., Marchand, A., (2010a). Hydrogeological Landscapes for the Hawkesbury-Nepean Catchment Management Authority, Capertee and Lithgow Valleys: Volume 1 – Background, Methodology and Results, NSW Department of Environment, Climate Change & Water, Parramatta.

Nicholson, A., Moore, L., Pavan, N., Taylor, L., Cull, V., Winkler, M., Copley, S., Preston, Y., Muller, R., Jenkins, B., Marchand, A. (2010b). Hydrogeological Landscapes for the Hawkesbury-Nepean Catchment Management Authority, Capertee Valley and Coxs River (Lithgow Valley): Volume 2 – Hydrogeological Landscape Units, NSW Department of Environment, Climate Change & Water, Parramatta.

Nicholson, A., Pavan, N., Moore, L., Taylor, L., Cull, V., Winkler, M., Copley, S., Preston, Y., Muller, R., Jenkins, B., Marchand, A. and Wooldridge, A. (2010c). Hydrogeological Landscapes for the Hawkesbury-Nepean Catchment Management Authority, Capertee and Lithgow Valleys: Volume 4 – Guidelines for Managing Salinity in the Landscape, NSW Department of Environment, Climate Change & Water, Parramatta.

Nicholson, A., Pavan, N., Winkler, M., Taylor, L., Cull, V., Copley, S., Jenkins, B., Muller, R., Wooldridge, A., Moore, L., Marchand, A. and Shoemark, V. (2011a). Hydrogeological Landscapes for the Hawkesbury-Nepean Catchment Management Authority, Western Sydney; Volume 1 – Background, Methodology and Results, NSW Department of Environment, Climate Change & Water, Parramatta.

Nicholson, A., Pavan, N., Winkler, M., Taylor, L., Cull, V., Copley, S., Muller, R., Jenkins, B., Cook, W., Shoemark, V., Nowakowski, A., Marchand, A., Moore, L., Harvey, K. and Wooldridge, A. (2011b). Hydrogeological Landscapes for the Hawkesbury-Nepean Catchment Management Authority, Western Sydney Study Area: Volume 4 – Guidelines for Managing Salinity in the Landscape, NSW Department of Environment, Climate Change & Water, Parramatta.

Pavan N., Nicholson A., Winkler M. A. and Moore L., (2010). Constraining dryland salinity hazard in the Lithgow Valley, NSW, Proceedings of the Australian Earth Sciences Convention 2010, page 103.

Rasmus, P.L., Rose, D.M. and Rose, G. (1969). Singleton, New South Wales, 1:250 000 geological series map. Sheet SI/56-01, 1st edition. Geological Survey of New South Wales

Stroud W.J., Sherwin L., Roy H.N. and Baker C.J. (1985). Wollongong - Port Hacking 1:100 000 Geological Sheet 9029-9129, 1st edition. Geological Survey of New South Wales, Sydney

Tozer, M.G., Turner, K., Keith D.A., Tindall, D., Pennay, C. and Simpson, C. (2010). Native vegetation of southeast NSW: a revised classification and map for the coast and eastern tablelands. Cunninghamia 11 (3): 359-406

Vine, C., Harvey, K. and Moore, C.L. (2008). Environmental Overview: Hawkesbury-Nepean and Sydney Metropolitan Catchment Management Authority Areas. Dryland Salinity Hazard Mitigation Program. University of Canberra.

Walker, B., C. S. Holling, S. R. Carpenter, and A. Kinzig (2004). Resilience, adaptability and transformability in social–ecological systems. Ecology and Society 9(2): 5. [online] URL: http://www.ecologyandsociety.org/vol9/iss2/art5/

Winkler, M., Nicholson, A., Pavan, N., Taylor, L., Cull, V., Copley, S., Jenkins, B., Muller, R. and Moore, L. (2011). Hydrogeological Landscapes for the Hawkesbury-Nepean Catchment Management Authority, Western Sydney: Volume 2 – Hydrogeological Landscape Units, NSW Department of Environment, Climate Change & Water, Parramatta.

Wooldridge, A., Jenkins, B., Cook, W, Marchand, A., Harvey, K., Nicholson, A., Moore, L., Muller, R., Winkler, M. and Pavan, N. (2011). Hydrogeological Landscapes for the Hawkesbury-Nepean Catchment Management Authority, Goulburn Region: Volume 4 – Guidelines for Managing Salinity in the Landscape, Department of Premier and Cabinet: Office of Environment and Heritage, Parramatta.

Appendix 1: Factors influencing resilience in Hawkesbury-Nepean CMA

Table 2: Factors influencing resilience in Hawkesbury-Nepean CMA

Drivers	Main Variables	Thresholds	Priority Actions	Evidence gaps/needs
• Increasing urbanisation • Inappropriate planning and construction methods for salinity • Inappropriate grazing management • Inappropriate vegetation management • Inappropriate cropping practices • Inappropriate irrigation practices • Decreasing depth to water table and/or rising groundwater pressures • Clearing of native vegetation • Loss of perenniality • Loss of soil via erosion • Loss of soil health (physical, biological, chemical)	• Water table depth • Groundcover percentage • Total grazing pressure • Perenniality • Soil stability (erosion, gullying, sodic soil) • Degree of soil degradation • Type of salt (salt species) • Extent of land salinity • Stream EC • Salt load in streams • Extent of potential acid sulfate soils • Climatic variability • Planning control and policy related to salinity hazard • Groundwater quality	• Land salinity develops when groundwater is within 2 m of surface • Threshold for soil salinity impacts: 2 dS/m ECe • Threshold for soil stability ESI = EC/ESP <0.02 instantaneous dispersion on wetting; <0.05 unstable (Murphy & McKenzie 2007) • Groundcover 70% • Riparian vegetation can buffer saline discharge into streams • Point where increasing recharge exceeds plant water uptake (water balance) • Loss of soil A horizon (topsoil) • Exposure and wetting of sodic soils • Exposure of acid sulfate soil (anaerobic to aerobic) • Stream salinity thresholds: human consumption (preferred) = 500 mg/L (800 EC); ecological system function threshold will depend on asset to be protected • Land management within capability / land management not within capability threshold • Building of infrastructure (irreversible)	• Water management (irrigation and flow regime) • Appropriate grazing management • Discharge management • Soil health management • Vegetation management for production • Vegetation management for ecosystem services • Soil amelioration • Urban design catering for salinity • Riparian management • Planning related to salinity hazard • Policy related to salinity hazard	• Salinity investigations in a landscape context not complete across entire CMA area • Salinity landscape management system to a landscape facet scale required for appropriate, targeted management • MERI • Time series groundwater data • Time series stream EC data • Time series load data (including flow data) • Water use of systems used in agricultural practices • Surface-groundwater connectivity information • Salinity-sedimentation relationship information • Landuse change data • Salinity outbreak data (out of date and incomplete) • Continuous spatial soil coverage (unpublished or incomplete) • Spatial Land management within Capability (LMwC) (only partial coverage)