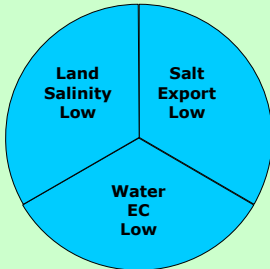


1. Hawkesbury Hydrogeological Landscape

LOCALITIES	LUCAS HEIGHTS, MENAI, WEDDERBURN, APPIN	
TYPE AREA	WEDDERBURN	
GRID REFERENCE	299000 mE 6221000 mN (Z 56)	
GEOLOGY SHEET	PENRITH 1:100 000; PORT HACKING 1:100 000; WOLLONGONG 1:100 000; SYDNEY 1:100 000	
CONFIDENCE LEVEL	MEDIUM	

OVERVIEW

The Hawkesbury Hydrogeological Landscape (HGL) is characterised by plateaux, scarps, benches and hills on sandstone in the areas encompassing Lucas Heights and Woronora Plateau.

Landscape features plateaux, cliffs within escarpment, rises, hills and low hills, plains, slopes and benches within/on Hawkesbury Sandstone or Narrabeen Sandstone; rises, floodplains, swamps and levees on Tertiary and Quaternary Alluvium; and occasionally rises. The local relief is variable - typically 40–200 m with slopes of 20–70% and rock outcrops of 0–50%.

This HGL comprises sedimentary rocks from the Triassic Hawkesbury Sandstone and Narrabeen Group as well as minor outbreaks of Tertiary Basalt and Jurassic Volcanics. The Hawkesbury Sandstone is composed of medium to coarse-grained quartz sandstone with minor shale and laminitic lenses. The Narrabeen Group contains quartz and quartz-lithic sandstone, shale, claystone and minor conglomerate. These have been intruded by isolated Jurassic volcanic pipes containing basaltic breccia. Unconsolidated colluvial sediments derived from the surrounding Triassic sedimentary rocks have been deposited on the slopes of this HGL.

Soils are: Rudosols (Lithosols, Siliceous Sands) and Tenosols (Earthy Sands) on crests and ridges; Kandosols (Brown Earths, Yellow Earths), Yellow and Red Kurosols (Yellow and Red Podzolic Soils) and Leptic Rudosols (Lithosols) on steep slopes; and Brown and Yellow Kandosols (Brown and Yellow Earths) and Yellow Dermosols (Yellow Podzolic Soils) on less steep sideslopes.

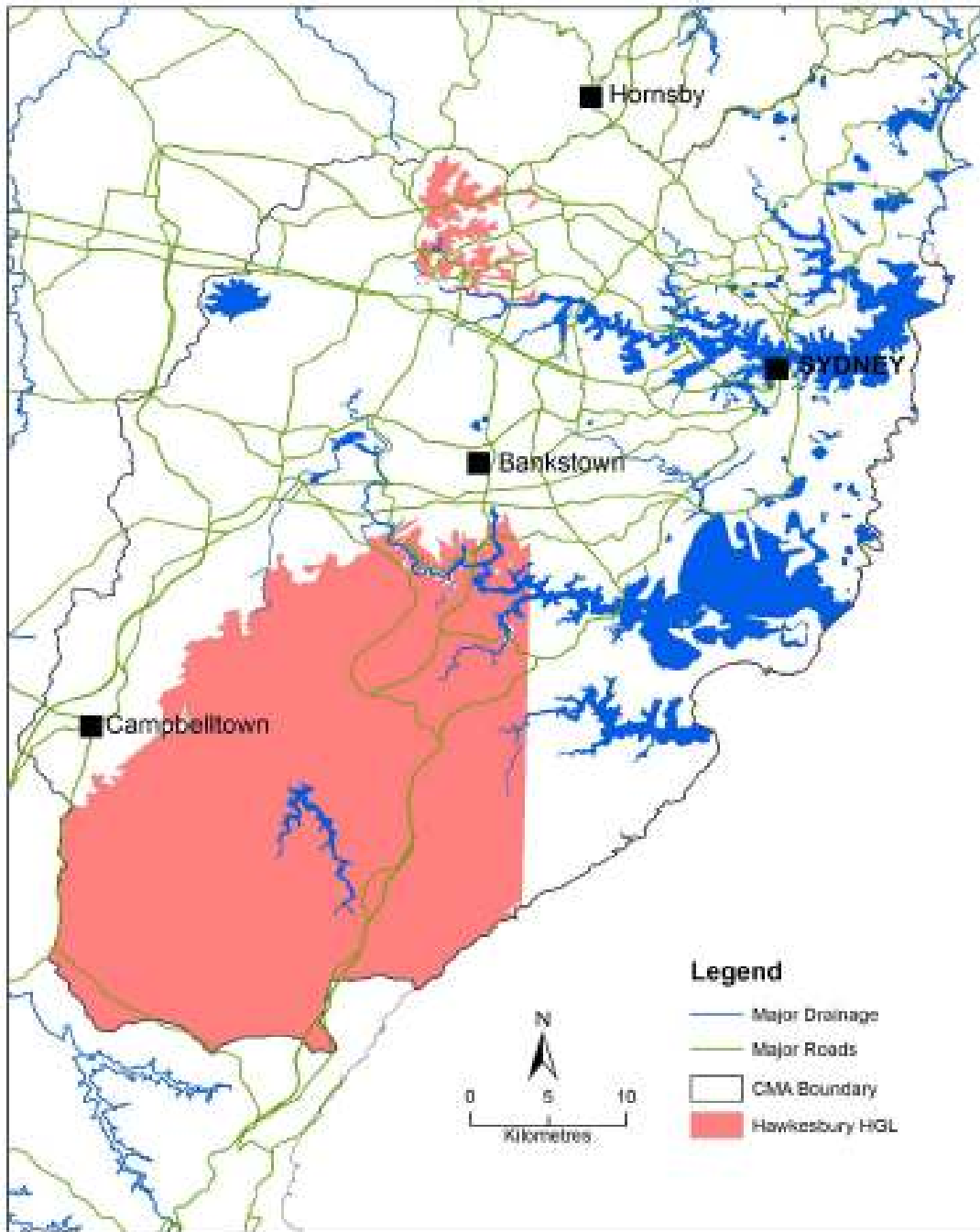
Water infiltrates vertically through interbedded sandstone and sandstone fractures (primary and secondary porosity) and laterally along bedding planes. The residence time of water moving through this landscape is likely to be relatively low due to the steep gradient and short flow path. Therefore, salt accumulation within groundwater is likely to be reduced.

Land salinity and water EC are low. Salts are flushed from the porous sandstone matrix which prevents salt accumulation at the surface. Salinity expression at the contact between basalts or Jurassic Volcanics may be higher due to salts being flushed out from the basalt.

Land use across this HGL is mostly uncleared bushland reserved for recreation, nature conservation and drinking water supply catchment area. National Parks include the Royal National Park.

Limitations to land use are caused by potential landslip and rock falls and sheet and rill erosion, particularly during storms or after disturbance such as following bushfires.

Significant features of this landscape are the frequent rock outcrops, rocky benches, plateaux and scarps which are typical of a sandstone bedrock.



Hawkesbury HGL Distribution Map

SALINITY

OCCURRENCE (LAND)	Land salinity is low. This is largely due to the shallow sandy soils and deeply fractured bedrock associated with the sandstone dominated geology.
EXPORT (LOAD)	Salt export is low. Sandstone geologies carry low salt loads and associated regolith does not store salt. A low level of salts will be present within the sandstone aquifers which have largely originated from precipitation.
WATER (EC)	Water EC is low. Water quality is fresh.

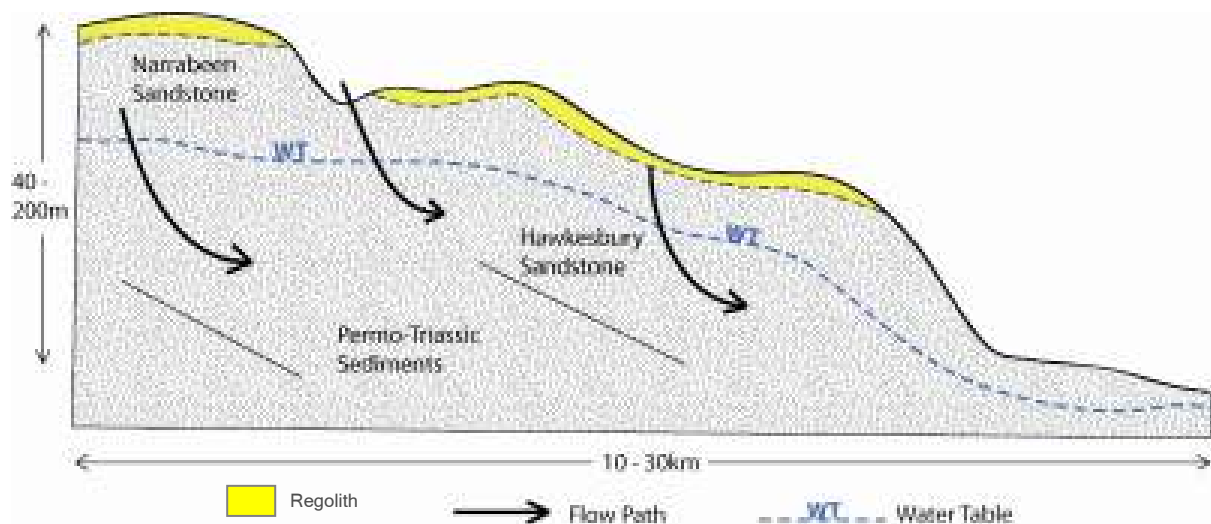
SALT MOBILITY

	AVAILABILITY		
SALT STORE	LOW	MODERATE	HIGH
HIGH			
MODERATE			
LOW			Hawkesbury

HAZARD

HAZARD ASSESSMENT	Limited potential impact	Significant potential impact	Severe potential impact
High likelihood of occurrence			
Moderate likelihood of occurrence			
Low likelihood of occurrence	Hawkesbury		

LANDSCAPE ATTRIBUTES



Conceptual Hawkesbury Hydrogeological Landscape cross-section showing the distribution of regolith, landforms, salt sites and flow paths.

<p>LITHOLOGY</p> <p><i>(Sherwin & Holmes 1986; Jones & Clarke 1991; Geoscience Australia 2009)</i></p>	<p>This HGL comprises consolidated sedimentary rocks from the Permian and Triassic periods. The key lithologies are:</p> <ul style="list-style-type: none"> • Wianamatta Group (minor) – sandstone, siltstone and shale • Hawkesbury Sandstone – medium to coarse-grained quartz sandstone with minor shale and laminite lenses • Narrabeen Group – quartz and quartz-lithic sandstone, grey shale, red-brown claystone, minor conglomerate <p>Unconsolidated colluvial sediments derived from the surrounding Triassic sedimentary rocks have been deposited on the slopes of this HGL.</p>
<p>ANNUAL RAINFALL</p>	<p>800–1600 mm</p>
<p>REGOLITH-LANDFORMS</p>	<p>Plateaux, cliffs within escarpment, rises, hills and low hills, plains, slopes and benches within/on moderately weathered Hawkesbury Sandstone and Narrabeen Sandstone; and rises, floodplains, swamps and levees on Tertiary and Quaternary Alluvium; and occasionally rises. The local relief is variable - typically 40–200 m with slopes of 20–70% and rock outcrops of 0–50%</p> <p>Regolith is largely unweathered sandstone, vegetated massive 90% quartzite structured formations; apart from rock fall boulder deposits from upper escarpment to talus slope and valley floor. Occasional occurrences of alluvium, sand, colluvium and sandstone-quartz, breccia, sedimentary, siltstone/mudstone and sandstone-quartz also exist.</p>



Typical Hawkesbury HGL – shallow soil with rock outcrops and Dry Sclerophyll Forest vegetation. Photo taken at Wedderburn (Photo: DECCW/Marion Winkler).



Typical Hawkesbury HGL, sandstone escarpment, Wedderburn Gorge (Photo: DECCW/Marion Winkler).



Typical Hawkesbury HGL vegetation and rocky gully, Wedderburn (Photo: DECCW/Marion Winkler).



Hawkesbury HGL – Bedrock exposed along Parramatta River, Meadowbank, bordering Glenhaven HGL. Photo taken from Ryde Bridge looking north-east towards Parsonage Street, Meadowbank (Photo: DECCW/Marion Winkler).



Hawkesbury HGL – Sandstone bedrock cutting boundary with Glenhaven HGL under rail bridge at Victoria Road, West Ryde (Photo: DECCW/Marion Winkler).



Hawkesbury HGL, salt outbreak in sandstone rocks, northern side of Wedderburn Gorge (Photo: DECCW/Marion Winkler).

<p>SOIL LANDSCAPES</p>	<p>Soil compositions on crests and ridges consist of; Rudosols (Lithosols, Siliceous Sands) and Tenosols (Earthy Sands). On steep slopes, Kandosols (Brown Earths, Yellow Earths), Yellow and Red Kurosols (Yellow and Red Podzolic Soils) and Leptic Rudosols (Lithosols), with Brown and Yellow Kandosols (Brown and Yellow Earths) and Yellow Dermosols (Yellow Podzolic Soils) on less steep sideslopes.</p>
<p>RURAL LAND CAPABILITY</p>	<p>Rural land capability VII (VIII).</p>
<p>LAND USE</p>	<p>Land use across this HGL is mostly uncleared bushland reserved for recreation, nature conservation and drinking water supply catchment area. National Parks include the Royal National Park and Sydney Catchment Authority Special Area.</p> <p>There are some major urban developments in the Lucas Heights, Wedderburn, Appin and Menai areas.</p>
<p>KEY LAND DEGRADATION ISSUES</p>	<p>Limitations:</p> <ul style="list-style-type: none"> • Severe sheet erosion often occurs during storms and after ground cover is destroyed by bushfires (Atkinson 1983). • Minor gully erosion occurs along unpaved tracks and fire trails. • Severe sheet erosion also occurs following bushfires which disturb the stabilising vegetation and litter layer. Minor gully erosion occurs along unpaved or poorly maintained roads and fire trails. • Moderate sheet erosion is common on steep hillslopes. • Landslip and rock fall are widespread and evident on steep slopes with wet, unstable and disturbed soils. • Parts of this landscape have been permanently inundated

	<p>by construction of Woronora Dam to supply drinking water to Sydney.</p> <ul style="list-style-type: none"> Some tracks have minor sheet and rill erosion.
VEGETATION	<p>Hawkesbury HGL retains a large amount of native vegetation which is distinctive of this HGL. Communities include <i>Sydney Hinterland Transition Woodland</i> on the edge of the Sydney Basin; <i>Coastal Sandstone Ridgetop Woodland</i> on ridge tops and <i>Hinterland Sandstone Gully Forest</i> along sandstone gullies.</p> <p>Dominant tree species include <i>Corymbia gummifera</i> (red bloodwood), <i>Eucalyptus punctata</i> (grey gum), <i>Angophora costata</i> (smooth-barked apple), <i>Syncarpia glomulifera</i> (turpentine), <i>E. sieberi</i> (silvertop ash) and <i>E. racemosa</i> (narrow-leaved scribbly gum), <i>Banksia serrata</i> (old man banksia) and <i>Eucalyptus piperita</i> (Sydney peppermint).</p> <p>Signature: <i>Sydney Hinterland Transition Woodland</i>, <i>Coastal Sandstone Ridgetop Woodland</i> and <i>Hinterland Sandstone Gully Forest</i></p> <p>These three communities align with the boundary of the Hawkesbury HGL and form a definitive vegetation signature.</p>

VEGETATION ASSEMBLAGES

Sydney Hinterland Transition Woodland, a eucalypt woodland dominated by *Corymbia gummifera*, *Eucalyptus punctata*, *Angophora costata* and *Syncarpia glomulifera* with an open understorey of sclerophyll shrubs, sedges, forbs and grasses. Shrub species include *Phyllanthus hirtellus*, *Persoonia linearis*, *Leptospermum trinervium*, *Acacia ulicifolia*, *Persoonia levis*, *Acacia linifolia*, *Banksia spinulosa* and *Pimelea linifolia*. This transition woodland encircles the Cumberland Plain rainshadow, on loamy soils typically derived from sediments belonging to the Hawkesbury or Mittagong formations.

Coastal Sandstone Ridgetop Woodland is a low eucalypt forest dominated by *Corymbia gummifera*, *E. sieberi* and *E. racemosa* with a diverse sclerophyll shrub layer including *Leptospermum trinervium*, *Lambertia formosa*, *Persoonia levis*, *Banksia serrata*, *Platysace linearifolia*, *Acacia suaveolens*, *Isopogon anemonifolius*, *Dillwynia retorta*, *Petrophile pulchella*, *Banksia spinulosa*, *Bossiaea heterophylla*, *Banksia ericifolia*, *Acacia ulicifolia*, *Monotoca scoparia* and *Hakea dactyloides* and an open groundcover of sedges.

Hinterland Sandstone Gully Forest is an open eucalypt forest dominated by *Angophora costata*, *Corymbia gummifera*, *Banksia serrata* and *Eucalyptus piperita* with an abundant sclerophyll shrub stratum of *Persoonia linearis*, *P. levis*, *Phyllanthus hirtellus*, *Leptospermum trinervium*, *Lomatia silaifolia*, *Banksia spinulosa*, *Platysace linearifolia*, *Ceratopetalum gummiferum*, *Acacia ulicifolia* and *Acacia terminalis*, and a groundcover dominated by sedges. This forest surrounds the Cumberland plain, occurring along the western portion of the Woronora plateau.

Endangered ecological communities in Hawkesbury HGL

FORMATION (Keith 2004)	STATE CLASS (Keith 2004)	LOCAL CLASS (NPWS 2002)	ENDANGERED ECOLOGICAL COMMUNITY
Dry Sclerophyll Forests (shrubby subformation)	Sydney Hinterland Dry Sclerophyll Forests	<i>Sydney Hinterland Transition Woodland</i>	n/a
		<i>Hinterland Sandstone Gully Forest</i>	n/a

	Sydney Coastal Dry Sclerophyll Forests	<i>Coastal Sandstone Ridgetop Woodland</i>	n/a
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HYDROGEOLOGY

Groundwater flow in this HGL is unconfined along structures (bedding, joints, faults) in the fractured bedrock. Flow also occurs through connected pore spaces in the sandstones. Lateral flow occurs through colluvial sediments on slopes. Flow will occur across the land surface where bedrock is exposed. Hydraulic conductivity is high. Transmissivity is moderate to high.

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

Residence times are short to medium. These landscapes have a fast to medium response time to changes in land management.

AQUIFER TYPE	Unconfined in fractured rock and through sandstone pores (dual porosity) Lateral flow through unconsolidated colluvial sediments on slopes Significant overland flow where bedrock is exposed
HYDRAULIC CONDUCTIVITY	High Range: >10 m/day
AQUIFER TRANSMISSIVITY	Moderate to high Range: 2→100 m ² /day
SPECIFIC YIELD	Moderate to high Range: 5→15%
HYDRAULIC GRADIENT	Moderate to steep Range: 10→30%
GROUNDWATER SALINITY	Fresh Range: <0.8 dS/m.
DEPTH TO WATER TABLE	Deep Range: >8 m
TYPICAL CATCHMENT SIZE	Medium (100–1000 ha)
SCALE (FLOW LENGTH)	Local to intermediate Flow length: <15 km (short to intermediate)

RECHARGE ESTIMATE	High
RESIDENCE TIME	Short to medium (months to years)
RESPONSIVENESS TO CHANGE	Fast to medium (months to years)

MANAGEMENT OPTIONS

The overarching salinity management strategies have specific biophysical outcomes. These outcomes are achieved by implementing a series of targeted land management actions taking into account the opportunities and constraints of the particular HGL. The actions recognise the need for diffuse and specific activities within the landscape that are required to impact on salinity issues.

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

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

Where in some rural cases a land use change has occurred and the landscape has been altered (e.g. clearing of vegetation), a balance could occur. Where a balance does not occur it can result in the expression of salinity at various points in the landscape. In urban situations, where the landscape is altered further in shape (such as road and building construction including cut and fill practices) and water movement is impeded and/or water use is increased, salinity may emerge.

Emerging saline effects within the Sydney Metropolitan catchment have occurred in areas underlain by Wianamatta shales. Possible causes of urban salinity in western part of the catchment are shown in the cross-sectional diagram for this HGL. The increased occurrence of salinity is related to:

- A decrease in deep-rooted vegetation
- Over-irrigation of crops, improved pastures and private gardens and lawns
- Alteration of natural drainage patterns by the construction of houses, roads, railways, channels etc.
- Creation of wet zones of waterlogged soil by impeded drainage
- Leakage of standing water bodies, pools, lakes and service pipes
- Exposure of susceptible soils
- Irrigation of sports grounds, golf courses, parks and gardens.

Where salinity is likely to occur in areas of urban development, the following overarching principles should apply:

- Land managers should clearly demonstrate what measures will be employed to ensure the salinity hazard does not increase (both on site and on adjoining land) as a result of a development.
- Identify and manage sensitive soils (e.g. sodic soils, reactive soils, type of salts, salt loads).
- New houses, buildings or infrastructure (including roads, pathways and retaining walls) in current or potentially salt affected areas may need to be built to withstand the effects of salinity (including the establishment of good drainage prior to construction).

- Employ deficit irrigation principles to prevent over-irrigation of sports grounds, golf courses, parks, private gardens and lawns; and limit the application of extra salt through water recycling programs or irrigation of saline groundwater.
- Implement a monitoring program (where deemed necessary) including a clear identification of responsibilities.

Landscape Function – Hawkesbury HGL

The following list details the functions this landscape provides within a catchment scale salinity context:

- **A. The landscape provides fresh water runoff as an important water source**
- **B. The landscape provides fresh water runoff as an important dilution flow source**
- **C. The landscape provides important base flow to local streams**

Landscape Management Objectives – Hawkesbury HGL

The following list details the appropriate strategies pertinent to this landscape:

- **Maintaining and maximising runoff:** This HGL contributes significant fresh water as dilution flow to the system. The fresh runoff mitigates the salt load, stream salinity and EC concentration of the local streams.

Urban Management Strategy Objectives – Hawkesbury HGL

Hawkesbury HGL is a low risk landscape for urban salinity development. The following list (in priority order) details the appropriate urban strategies relevant to this landscape:

- **Urban Vegetation (UV):** Maintain and enhance vegetation (including remnant vegetation) for the management of recharge, and as a buffer to excess water input. Waterwise gardening should be encouraged in residential areas.
- **Urban Management (UM):** The input of water into the landscape (lawns, gardens, sporting fields) including the management of recycled water requires careful management.
- **Urban Planning (UP):** Planning of sub-division layout and design is required to manage salinity consequences. Development must not increase the salinity hazard of the natural and built environment. Layout and design should consider locations of roads, infrastructure and greenspace as well as building allotments, and water sensitive urban design.
- **Riparian Management (RM):** Vegetation management in riparian areas will assist in minimising salt export to streams.
- **Urban Investigations (UI):** The landscape contains significant salinity, and geological situations that predispose salinity development. Assessment of the location, intensity and scale of salinity is needed. There are areas of sensitive sodic soils, particularly in drainage lines that need to be identified.
- **Urban Construction (UC):** Construction on saline land will require salt resistant/ resilient materials. The typical slope gradient of this HGL requires careful consideration of depth of cut and location of roads on hillslopes; and all infrastructure, including underground utilities.

Specific Land Management Opportunities

A range of specific opportunities exist for this HGL:

- Highly vegetated landscape
- Small salt sites are easily managed
- Deep drainage and high recharge reduce potential for local salinity

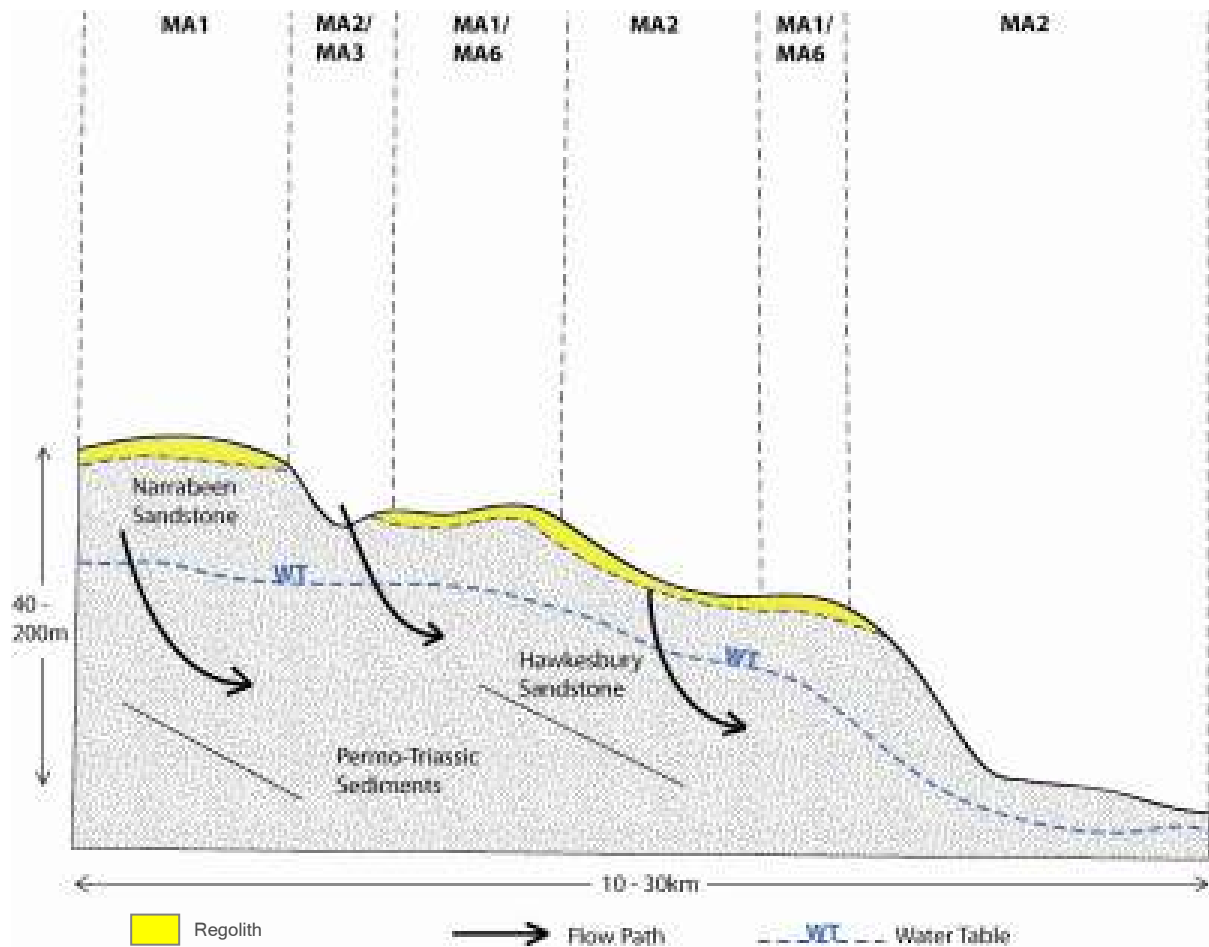
- Discharge management – integrated use of urban salinity management practices (salt resistant/resilient materials, water management) consistent with building codes would enable protection of infrastructure and dwellings.

Specific Land Management Constraints

Constraints for land management in this HGL include:

- Incidence of erosion and steep slopes may affect construction activities such as cut-and-fill, building of foundations and retaining walls.
- Locally connected aquifer systems may impact on water quality

Specific Targeted Actions



Hawkesbury HGL management cross-section (Refer to following table for explanation of codes)

MANAGEMENT AREA (MA)	ACTION (URBAN)
MA1 (RIDGES)	<p>Urban Vegetation</p> <p>Retain or establish areas of deep-rooted salt tolerant indigenous vegetation to manage recharge or discharge sites (UV1)</p>
MA2 (UPPER SLOPES EROSIONAL)	<p>Urban Vegetation</p> <p>Retain or establish areas of deep-rooted salt tolerant indigenous vegetation to manage recharge or discharge sites (UV1)</p>
MA1/6 (RIDGES AND RISES)	<p>Urban Vegetation</p> <p>Retain or establish areas of deep-rooted salt tolerant indigenous vegetation to manage recharge or discharge sites (UV1)</p> <p>Promote the retention and establishment of deep-rooted vegetation that maximises water use in new urban development areas (UV2)</p> <p>Urban Management</p> <p>Minimise leakage of standing water bodies, pools, lakes and service pipes (UM1)</p> <p>Urban Planning</p> <p>Minimise use of infiltration and detention of stormwater in hazard areas, consider lining of detention systems to prevent infiltration (i.e. reconsider WSUD implications in relation to salinity management) (UP2)</p> <p>Urban Investigations</p> <p>Investigate concentration and composition of salts in the soil profile, groundwater and surface waters during initial site assessment to determine salinity hazard (UI1)</p> <p>Identify and manage sodic soils (UI3)</p> <p>Urban Construction</p> <p>Minimise depth of cut and exposure of susceptible soils during development. Ensure fill material interface is not saline (UC1)</p> <p>Deep drainage should be minimised by maximising surface water runoff and drainage (UC2)</p>
MA10 (RIPARIAN ALLUVIAL CHANNEL)	<p>Riparian Management</p> <p>Retain or re-establish areas of effectively vegetated riparian buffer zones to manage discharge areas (preferably salt tolerant indigenous vegetation) (RM1)</p> <p>Maintain/re-establish effective vegetated riparian buffer zones (RM2)</p>

High Hazard Land Use

AT RISK MANAGEMENT AREAS	ACTION
MA1, MA2, MA1/6	<p>Avoid deep cut and exposure of erodible soils during development when establishing infrastructure and dwellings.</p> <p>Careful consideration should be given to the siting of new roads and infrastructure.</p>
MA10	<p>Avoid obstruction to surface and sub-surface drainage that will cause wet areas creating waterlogging and salt mobilisation</p>

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