NRE No. 1 Colliery Major Expansion Upland Swamp Assessment

Prepared for Gujarat NRE Coking Coal Limited

27 November 2012

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Document information

Report to:	Gujarat NRE Coking Coal Limited
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Biosis matter no.:	15094

Document Information:

Version/date	Internal review by	Date sent to client
Draft version 01	Brett Morrisey	-
Draft version 02	-	21/09/12
Final version 01	-	05/10/12
Final version 02	-	31/10/12
Final version 03	-	27/11/2012

Project no. 15094

File name:
15094.NRE.Major.Expansion.Swamp.Mapping.FIN03.20121127.docx

Citation: Biosis Research (2012). NRE No.1 Colliery Major Expansion – Upland Swamp Assessment. Report for Gujarat NRE Coking Coal Ltd. Authors: N.Garvey, Biosis Research Pty. Ltd., Wollongong.

Acknowledgements

Biosis Pty Ltd acknowledges the contribution of the following people and organisations in undertaking this study:

- Gujarat NRE Coking Coal Ltd.: Dave Clarkson, Chris Harvey, Kamlesh Prajapati
- ERM Australia: Naomi Buchhorn, Thomas Muddle
- Geoterra Pty Ltd.: Andrew Dawkins
- Office of Environment and Heritage for access to digital data and advice on assessment approach

The following Biosis staff were involved in this project:

- Ben Coddington, Ed Cooper, Jodie Cooper for assistance in the field

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Summary

Biosis Pty Ltd was commissioned by Gujarat NRE Coking Coal Ltd to undertake a detailed assessment of upland swamps. This detailed assessment will be used as part of the Environmental Assessment (EA) being undertaken by ERM for NRE's No. 1 Major Expansion Project.

The study area is located on the Woronora plateau, approximately 8 km north of Wollongong and approximately 70 km south of the Sydney CBD.

Upland swamps were mapped using a combination of LiDAR data, to define areas requiring further investigation, ground truthing of these areas in the field to define swamp boundaries and map swamp sub-communities and use of a Geographic Information System (GIS) to spatially represent data.

Following identification of upland swamps within the study area, an impact assessment was undertaken. The impact assessment was undertaken in two stages. The first stage involved the undertaking of an impact assessment according to the Draft *Upland Swamp Environmental Impact Assessment Guidelines* (OEH 2012). The second stage involved an assessment of the potential for upland swamps of 'special significance' to be impacted based on a variety of features, including an initial risk assessment according to OEH (2012), comparative analysis of upland swamps that have previously been undermined, changes to flow accumulation and potential for fracturing of bedrock and desiccation.

This project identified a total of thirty-nine (39) upland swamps meeting the definition of the Coastal Upland Swamp Endangered Ecological Community within the Wonga East study area and forty-five (45) upland swamps within the Wonga West study area. This assessment method identified a number of previously unmapped swamps within the study area, as well as highlighted the complexity and variability of this vegetation community.

The initial stages of the impact assessment identified that seven (7) upland swamps in Wonga East and eight (8) upland swamps in Wonga West are considered to be of 'special significance' using OEH criteria. Detailed impact assessment, including an initial risk assessment, comparative analysis, groundwater assessment, flow accumulation modelling and analysis of strains and potential for fracturing of bedrock, was undertaken on these 'special significance swamps'.

This detailed impact assessment identified that:

- There is a negligible likelihood of negative environmental consequences for seven (7) upland swamps within the study area, including CRUS2, CRUS3, LCUS1, LCUS6, LCUS27, WCUS1 and WCUS4-vfs. NRE can proceed to mining and monitoring in these areas.
- There is a low likelihood of negative environmental consequences for five (5) upland swamps within the study area, including CCUS4, CCUS10, CRUS1, LCUS8 and WCUS11. NRE may wish to consider changes to longwall layout to reduce impacts to these swamps.
- There is a moderate likelihood of negative environmental consequences for two (2) upland swamps within the study area, including WCUS4-hws and WCUS7. NRE should consider implementation of suitable impact avoidance, minimisation and mitigation measures to reduce impacts to these swamps.
- There is a significant likelihood of negative environmental consequences for two (2) upland swamps within the study area, including CCUS1 and CCUS5. NRE should consider implementation of suitable impact avoidance, minimisation and mitigation measures to reduce impacts to these swamps.

A number of recommendations to avoid or minimise impacts to upland swamps considered to 'special significance' are provided in the conclusions. NRE need to consider changes to the mine layout and / or suitable impact avoidance and mitigation measures to reduce the impacts on these swamps, including:

- adjust the layout in respect of Area 1 LW3 to avoid impacts to CCUS1.
- adjust the layout in respect of Area 2 LW7 and LW8. If this is not feasible, detailed monitoring of CCUS5 should be undertaken during the extraction of Longwalls 7 and 8. Detailed triggers relating to changes in gradient, groundwater monitoring and / or observational monitoring should be developed, and if triggered measures to minimise impacts should be considered.
- adjust the layout in respect of Area 3 LW2 to minimise impacts on the headwaters of WCUS4.
- adjust the layout in respect of Area 3 LW3 and LW4 to reduce predicted strains to WCUS7 and Wallandoola Creek.

Provided the recommendations outlined in this report are implemented negative environmental outcomes for upland swamps of 'special significance' can be avoided.

1. Introduction

1.1 Project background

Biosis Pty Ltd (Biosis) was commissioned by Gujarat NRE Coking Coal Limited (NRE) to undertake a detailed assessment of upland swamps. This detailed assessment will support the Environmental Assessment (EA) being undertaken by ERM for NRE's No. 1 Major Expansion Project.

NRE is currently seeking approval for expansion of operations at the NRE No. 1 Mine, including longwall mining of two areas known as Wonga East and Wonga West (see Section 1.4). The Wonga East and Wonga West areas are located on the Woronora plateau, a deeply dissected plateau gradually declining from south to northwest (NPWS 2003). Upland swamps are a significant natural feature of the Woronora plateau.

1.1.1 Previous Assessments of Upland Swamps

A number of ecological assessments have been undertaken for the Major Expansion Project (ERM 2011, 2012). These assessments have previously identified upland swamps within the study area, based on vegetation mapping by NPWS (2003), ground-truthing and assessment of groundwater levels.

Initially, some areas mapped by NPWS (2003) as upland swamps were excluded based on low or negligible groundwater levels, a lack of humic layer, no free moisture and very shallow sandstone (ERM 2012). However review of the Final Determination for Coastal Upland Swamp Endangered Ecological Community (EEC) by the NSW Scientific Committee (2012) has highlighted that these areas are likely to be consistent with the EEC, and these areas were included as a part of the Preliminary Works Part 3A Modification for Area 2 LW4 and 5 (Cardno 2012). This iterative process has resulted in some upland swamps being included in previous work, then removed, and then included again.

Due to potential discrepancies between the description of Coastal Upland Swamp in the Final Determination (NSW Scientific Committee 2012), various literature and geomorphological processes, it was identified that a consistent approach to identification and impact assessment was required.

The approach of this assessment is to identify all areas of the Coastal Upland Swamp EEC (NSW Scientific Committee 2012) within the study area. All areas meeting the definition of the Coastal Upland Swamp EEC (upland swamp) were included for further analysis.

To allow for comparison to previous mapping of upland swamps, Table 1 reconciles current naming and previous naming.

Table 1: Current naming of upland swamps compared to previous naming

Swamp Name - Current	Swamp Name - Previous
BCUS1	-
BCUS10	-
BCUS11	-
BCUS2	-
BCUS3	-
BCUS4	-
BCUS5	-

Swamp Name - Current	Swamp Name - Previous
BCUS6	-
BCUS7	-
BCUS8	-
BCUS9	-
CCUS1	CChs1
CCUS10	-
CCUS11	-
CCUS12	-
CCUS13	-
CCUS14	-
CCUS15	-
CCUS16	-
CCUS17	-
CCUS18	-
CCUS19	-
CCUS2	CChs2
CCUS20	-
CCUS21	-
CCUS22	-
CCUS23	-
CCUS3	CChs3
CCUS4	CChs4
CCUS5	-
CCUS6	-
CCUS7	-
CCUS8	-
CCUS9	-
CRUS1	CRhs1
CRUS2	CRhs2
CRUS3	CRhs3
CRUS4	-
CRUS5	-
LCUS1	LCvfs1

Swamp Name - Current	Swamp Name - Previous
LCUS10	-
LCUS11	-
LCUS12	-
LCUS13	-
LCUS14	-
LCUS15	-
LCUS16	-
LCUS17	-
LCUS18	LChs3
LCUS19	-
LCUS2	-
LCUS20	-
LCUS21	-
LCUS22	-
LCUS23	-
LCUS24	-
LCUS25	LChs4
LCUS26	LChs6
LCUS27	LChs6
LCUS28	LChs5
LCUS29	LChs5
LCUS3	-
LCUS30	-
LCUS31	-
LCUS32	LChs5
LCUS33	-
LCUS4	LCvfs2
LCUS5	-
LCUS6	LChs2
LCUS7	-
LCUS8	-
LCUS9	-
WCUS1	WCvfs1

Swamp Name - Current	Swamp Name - Previous
WCUS10	-
WCUS11	WChs2
WCUS12	-
WCUS2	-
WCUS3	-
WCUS4	WChs1 / WCvfs1
WCUS5	-
WCUS6	-
WCUS7	WCvfs2
WCUS8	-
WCUS9	-

1.2 Upland Swamps

1.2.1 Formation

On the floors of low gradient / low flow valleys or in seepage zones along benched slopes, upland swamps form due to the obstruction of drainage and subsequent trapping of sediment. Upland swamps are formed by a positive feedback mechanism, where sediment is accumulated in valley floors though some type of initial blockage (e.g. rock benches, obstruction by large logs etc.). This results in impeded drainage, waterlogging of the soil, increased soil moisture, killing of trees due to waterlogging and an increase in dense hydrophilic vegetation. This process reduces the transpiration capacity of the vegetation, which allows the water table to rise more frequently than if trees were present, reinforcing the process (Young 1982, Keith *et al.* 2006, Tompkins & Humphrey 2006, NSW Scientific Committee 2012).

1.2.2 Hydrology, Soils and Vegetation

Soils and vegetation communities within upland swamps are strongly associated with the distribution of water (both surface water flows and groundwater) within upland swamps (Keith *et al.* 2006, Tompkins & Humphrey 2006, NSW Scientific Committee 2012).

In areas of frequent waterlogging / high groundwater levels and / or permanent moisture, soils contain a high organic content, are generally deeper and tend to support areas of Tea-tree Thicket dominated by Tea-tree *Leptospermum* spp., *Melaleuca squarrosa* and *Acacia rubida*, with an understorey of Coral Fern *Gleichenia* spp.. In areas of intermittent waterlogging and / or moisture, soils consist of a mix of organic material and mineral sands, and tend to support Cyperoid heath, dominated by dense stands of large sedges from the Cyperaceae family including *Gymnoschoenus sphaerocephalus*, *Lepidosperma limicola*, *Chorizandra sphaerocephala* and *Baumea rubiginosa*. In the driest parts of upland swamps, soils can vary in depth and composition, with driest areas supporting mineral sands of a few centimetres in depth. These areas intergrade with deeper, wetter soils mentioned above. These drier areas support a mix of Restioid Heath, Sedgeland and Banksia Thicket. Sedgeland, located in areas subject to periodic waterlogging and seepage, is comprised of a low dense cover of sedges such as *Leptocarpus tenax, Schoenus brevifolius* and *S. paludosus* with some small shrubs such as *Baeckea imbricata, Sprengelia incarnata* and *Actinotus minor*. Restioid Heath, located on swamp margins and upper slopes where the water table rarely reaches the surface, is comprised of a low shrub layer of *Banksia oblogifolia*, *Banskia robur*, *Epacris obtusifolia* and a dense ground cover of species such as *Empodisma minus, Lepyrodia scariosa, Leptocarpus tenax* and *Schoenus brevifolius*. Banksia Thicket, located on swamp margins and upper slopes where the water table rarely reaches the surface, forms a dense heath, often on the margins of upland swamps or in smaller swamps located along benched terraces (N. Garvey pers. obs.).

As demonstrated above, hydrology plays a key role in the formation and maintenance of upland swamps, and changes in hydrology play a significant role in determining the spatial variation in vegetation sub-communities within upland swamps. Some upland swamps are reliant on the perched ephemeral water table to maintain moisture dependent vegetation communities, which in turn assists in the development of a deep layer of organic material, which in turn traps more moisture. However, other swamps are reliant on rainfall and surface water flows, and perched ephemeral water tables may be absent or may dry out during periods of low rainfall. These differences in reliance on groundwater versus rainfall lead to differences in susceptibility to impacts.

1.2.3 Legislative Status

Upland swamps within the study area are currently listed under the NSW *Threatened Species Conservation Act 1995* (TSC Act) as the Coastal Upland Swamp in the Sydney Basin Bioregion EEC.

Upland Swamps within the study area are not representative of the Temperate Highland Peat Swamps on Sandstone (THPSS) EEC listed under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The listing advice for the THPSS EEC (TSSC 2005) contains a number of criteria not met by the upland swamps within the study area, as outlined in Table 2.

Table 2: Criteria for THPSS and Comparison with Upland Swamps within the Study Area

THPSS Criteria	Upland Swamps within the Study Area
Altitudinal range of 600 – 1100 m ASL.	Altitudinal range of 350 m – 300 m ASL.
Distributional components, as defined in Table 2 of DSEWPaC (2012) and mapped by DEH (2005).	No Woronora swamps are listed as components of the THPSS. No Woronora swamps are mapped within the geographic boundaries of the EEC.
Soils are generally black to grey coloured acid, peaty soils, with a moderate to high organic matter content.	Only some swamps generate peat. Associated with waterlogged swamps.

On the basis of the criteria assessed in Table 1 upland swamps within the study area are not representative of the THPSS EEC. We understand that the Department of Sustainability, Environment, Water, Population and Communities (DSEWPaC) are currently reviewing the listing of upland swamps, and that the new listing advice is likely to cover swamps on the Woronora plateau.

1.2.4 Potential Impacts

Subsidence associated with longwall mining has potential to result in changes to hydrological processes within upland swamps. There are two broad mechanisms by which subsidence can result in impacts to upland swamps, as summarised in Table 3 below.

Table 3: Mechanisms for and Impacts to Upland Swamp Resulting from Subsidence

Broad mechanism	Potential Impacts
Fracturing of bedrock as a result of tensile and	Lowering of the water table below a swamp, leading

Broad mechanism	Potential Impacts
compressive strains, resulting in increased transportation of water through this fracture network.	to dewatering and drying of the swamp and lower levels of soil moisture. This can in turn, result in changes to vegetation composition within swamps.
Changes in gradients within a swamp, as a result of tilts associated with subsidence, leading to potential for redistribution of water within a swamp.	Changes to the gradients within a swamp can lead to increased accumulation of water in some areas and reduced accumulation in other areas. This, in turn, can result in changes to vegetation composition within swamps.
	Changes in flow regimes within swamps result in the re-concentration of flows within a swamp, potential for development of nick points and potential for scouring and erosion.

Vegetation sub-communities within upland swamps that are reliant on certain hydrological regimes differ in their susceptibility to impact. Vegetation sub-communities reliant on permanent water are most likely to be reliant on shallow groundwater flows or accumulation of surface water against flow impeders such as rockbars, accumulation of logs or other obstructions. These sub-communities, including Tea-tree Thicket (MU43) and Cyperoid Heath MU44c), are particularly susceptible to impacts resulting from fracturing of the bedrock and a decrease in soil moisture (Keith *et al.* 2006). Changes in gradient within a swamp, resulting in increased water accumulation are likely to favour transition from drier sub-communities, such as Banksia Thicket (MU42), Sedgeland (MU44a) and Restioid Heath (MU44b), to wetter sub-communities such as Cyperoid Heath (MU44c) and Tea-tree Thicket (MU43; Keith *et al.* 2006). Changes in gradient resulting in more rapid transportation of water and less pooling are likely to favour transition from wetter sub-communities to drier ones (Keith et al. 2006).

Valley infill swamps are considered more susceptible to scouring and erosion due to increased flow rates through these swamps (Earth Tech 2003, PAC 2010, OEH 2012). Headwater swamps are likely to be less susceptible to impact for a variety of reasons, including:

- lower flow rates within the swamp, resulting from more dispersed sheet flow of water across the swamp;
- less reliance on perched ephemeral groundwater systems when compared with valley infill swamps; and,
- less susceptibility to non-conventional subsidence effects, such as valley closure, buckling and shearing.

Scour pools within a swamp are a good indicator of susceptibility to erosion (Tomkins & Humphrey 2006).

For these reasons, impacts to upland swamps resulting from subsidence associated with longwall mining are considered a 'major concern' (PAC 2010).

1.3 Scope of assessment

NRE has engaged Biosis to undertake a detailed and comprehensive assessment of upland swamps within their Wonga East and Wonga West study areas, to allow a detailed and comprehensive impact assessment to be undertaken.

The objectives of this assessment are to:

- Accurately map the boundaries of upland swamps within the Wonga East and Wonga West areas.
- Undertake detailed mapping of vegetation sub-communities within upland swamps.
- Undertake an impact assessment to determine those significant upland swamps considered at significant risk from subsidence associated with longwall mining of Wonga East and Wonga West.

1.4 Location of the study area

The study area is located on the Woronora plateau, approximately 8 km north of Wollongong and approximately 70 km south of the Sydney CBD (Figure 1).

The NRE No1 Major Expansion Project includes longwall mining of the Wongawilli seam in two areas referred to as Wonga East and Wonga West (Figure 2). The study area is defined as an area incorporating a 600 m buffer from the edge of secondary extraction.

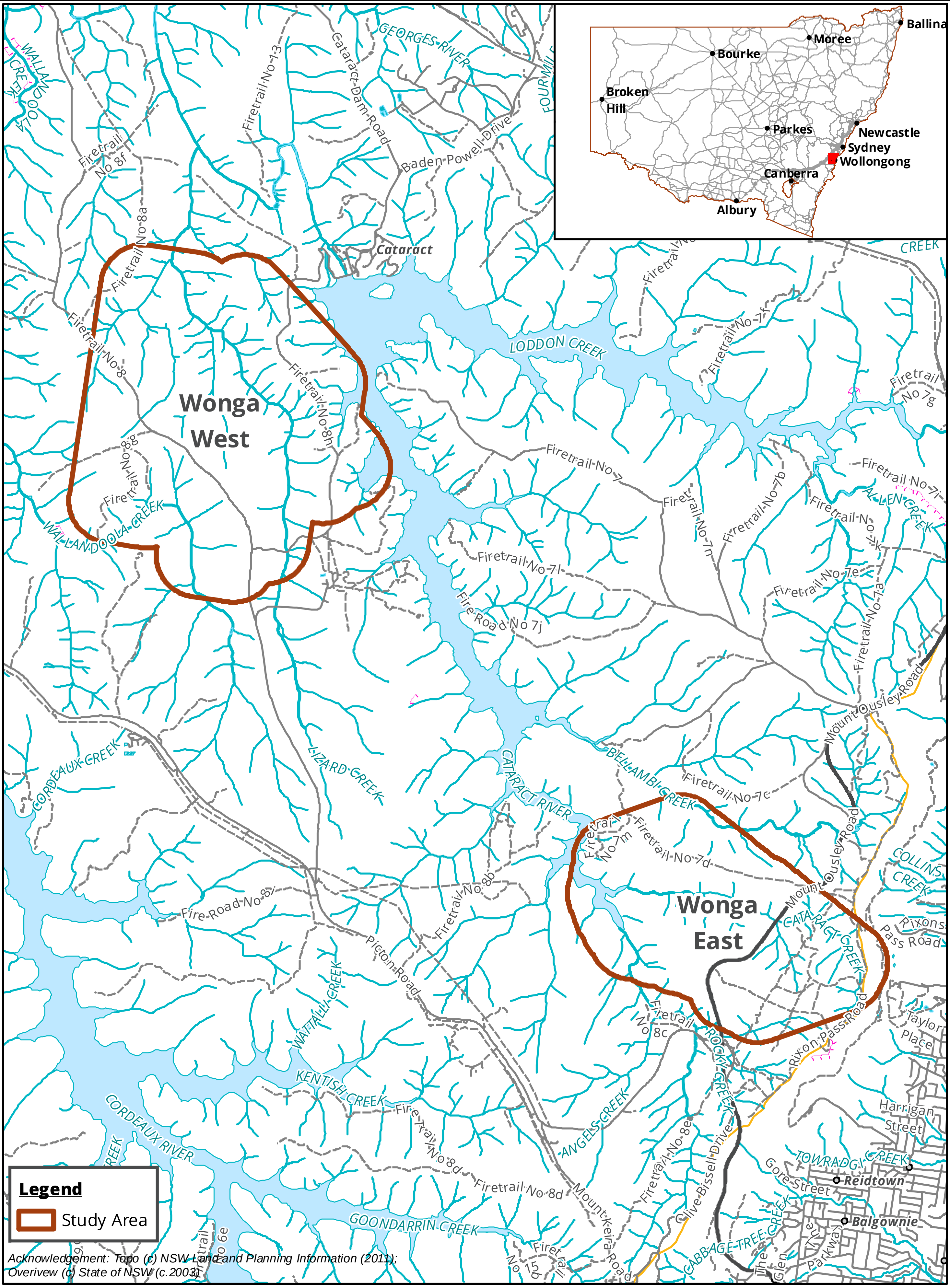

Figure 1: Location of the study area, in a regional context

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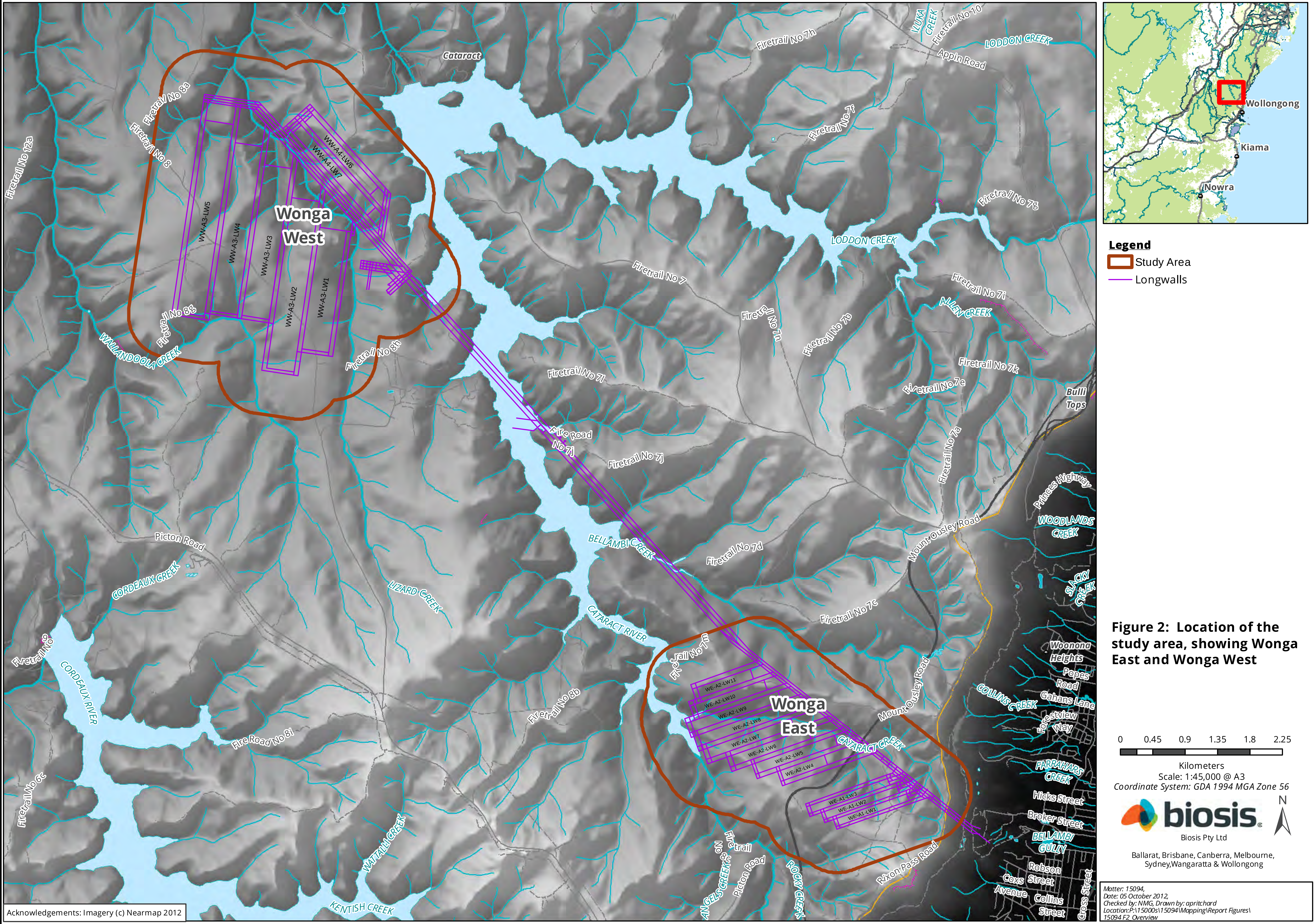

Legend

- Study Area
- Longwalls

Figure 2: Location of the study area, showing Wonga East and Wonga West

0 0.45 0.9 1.35 1.8 2.25
Kilometers
Scale: 1:45,000 @ A3
Coordinate System: GDA 1994 MGA Zone 56

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2. Methods

2.1 Detailed Mapping of Upland Swamps

Upland swamps were mapped using a combination of Light Detection and Ranging (LiDAR) data, to define areas requiring further investigation, ground truthing of these areas in the field to define swamp boundaries and map swamp sub-communities and use of a Geographic Information System (GIS) to spatially represent data. This methodology is outlined further below.

2.1.1 Mapping of 'Potential Wetlands'

LiDAR data was obtained by AAM Group (previously AAM Hatch) using Airborne Laser Scanning (ALS) from a fixed wing aircraft on 20 October 2009.

Initial areas of 'Potential Wetland' were determined in an automated process using a series of GIS analysis tools in ArcGIS, which were combined into a single ArcGIS Model Builder geoprocessing model.

A CSV file, containing the raw LiDAR non-ground returns, was converted into a point feature class with one point for every captured non-ground return. The points were converted to a raster using the 'Topo to Raster' geoprocessing tool within ArcGIS Spatial Analyst to convert the points to a continuous raster surface. The matching CSV file, containing the raw LiDAR ground points, was converted to point data. The points were converted to a raster DEM using the same tool and parameters as the non-ground. A Canopy Height Model (CHM) was developed by subtracting the values of the ground raster from the non-ground raster. This CHM was then run through the 'Focal Statistics' tool in ArcGIS to produce a focal range raster. The output raster created by this tool represents the rate of change in the height of vegetation within a 1m^2 neighbourhood. It was taken that a high rate of change within this relatively small area would be likely to signify the boundary of a swamp.

The range values were then reclassified into categories in order to create hard breaklines between what was possibly swamp and what was likely taller, fringing vegetation. After discussion with experts on upland swamps within Biosis and some testing and evaluation of data in areas of known swamp it was decided that a rate of change greater than 2 m within a 1 m neighbourhood appeared to give the best indication of a potential swamp boundary. Although there may be instances where different vegetation communities within a swamp create a change greater than 2 m height within 1 m of travel, this option gave the closest representation of the boundary of the previously mapped control swamps whilst filtering out 'background noise' in the data.

The range raster by itself showed many areas where the rate of change was less than 2 m within a 1 m neighbourhood outside swamp areas due to thick canopy coverage of mature trees of similar height. To remove these areas the range raster it was run through the Conditional (Con) geoprocessing tool within ArcGIS to only retain areas of the range raster where the total vegetation height was less than 6 m. This was considered representative of swamps where vegetation rarely exceeds 6 m in height. The con raster was then converted to polygons representing a first cut of potential swamp land.

Following the automated process of LiDAR data into potential wetland polygons, further manual 'cleaning' of the polygons was required to further filter out false positives. The polygons were dissolved so any with overlapping or coincident boundaries were treated as a single swamp. After comparison with the known swamp control dataset, it was decided that only polygons over 1000 m^2 should be kept in order to filter out further 'background noise'. Any obvious false positives, including areas such as clearings, rods and waterbodies, were manually removed from the dataset using aerial imagery interpretation.

The polygons were then loaded on GIS capable field computers for field staff to locate and ground-truth.

2.1.2 Detailed Ground Truthing and Mapping of Vegetation Sub-communities

Following automated mapping of 'Potential Wetlands' these areas were ground-truthed to determine whether areas mapped were representative of upland swamps. A team of botanists experienced with the identification of upland swamps on the Woronora plateau visited all potential upland swamps.

Some areas mapped as 'Potential Wetland' consisted of rocky outcropping, mallee, dry heath vegetation or sparse canopy. These areas were excluded from further analysis.

Areas of upland swamp were assessed in detail. Boundaries of all swamps were mapped accurately using a combination of LiDAR data, ground-truthing using a handheld GPS and aerial photo interpretation (API). Where boundaries obtained during the automated processing of LiDAR data did not accurately reflect swamp boundaries these boundaries were revised using API and marked on printed field maps.

Vegetation sub-communities present within swamps were mapped using a combination of ground-truthing using a handheld GPS and API. Sub-communities were mapped according to community profiles contained within *The Native Vegetation of the Woronora, O'Hares and Sydney Metropolitan Catchments* (NPWS 2003), and included those communities considered part of the Coastal Upland Swamp EEC (NSW Scientific Committee 2012), including:

- MU 42 Upland Swamps: Banksia Thicket;
- MU43 Upland Swamps: Tea-tree Thicket;
- MU44 Upland Swamps: Sedgeland Heath Complex;
    - MU44(a) Sedgeland;
    - MU44(b) Restioid Heath;
    - MU44(c) Cyperoid Heath.

The NSW Scientific Committee Final Determination for Coastal Upland Swamp EEC (NSW Scientific Committee 2012) was also used as a key reference when classifying upland swamps.

Photos were taken of each swamp and photo points were recorded using a hand held GPS.

Following field assessment the results of detailed ground-truthing were digitised in a GIS. Boundaries of upland swamps and of sub-communities within swamps were refined, in collaboration with GIS staff using API. Where swamp boundaries continue beyond the Study Area polygons have been created based on a combination of aerial photo interpretation and NPWS (2003) vegetation mapping.

2.1.3 Classification and Naming of Upland Swamps

Upland swamps were classified into headwater swamps or valley infill swamps. Headwater swamps form in the headwater tributaries with gentle gradients less than 10 degrees, where plateau incision is weak. Valley infill swamps are formed in the incised valleys of second or third order streams and tend to elongate along the valley (Tompkins & Humphrey 2006, DoP 2008).

However, these traditional concepts for differentiation of upland swamps were difficult to implement as a part of this study, particularly for upland swamps in Wonga West where a number of what appeared to be narrow valley infill swamps were located on first order streams in low gradient areas, while complex mosaics of headwater and valley infill swamps occurred in other areas. In addition, the majority of upland swamps within the study area were found to occur on slopes less than 10 degrees. An alternate method for the classification of upland swamps was required.

To attempt to differentiate upland swamp types an analysis of slope and flow accumulation modelling (Section 2.2) was undertaken to define the slope and / or flow accumulation that delineated these two swamp types. Interpretation of mean flow accumulation indicated that swamps appeared to differentiate at a mean flow accumulation of 25,000 m^2, with upland swamp located in second and third order drainage lines having flow accumulations higher than this value. Using this differentiation point, each of the vegetation sub-communities was assigned to either headwater or valley infill swamp type.

Upland swamps were then grouped for naming and further analysis. Initially, areas of upland swamp vegetation connected by Fringing Eucalypt Woodland (MU45) or Mallee Heath (MU46), or upland swamp vegetation separated by rocky outcropping, were grouped and considered part of the one upland swamp complex. In areas where connectivity between proximate upland swamps was not obvious, slope and flow accumulation modelling were used to identify whether these swamps are independent or whether these swamps should be considered as the one upland swamp complex. Where upland swamps were located in close geographic proximity and were part of the same flow pathway and / or located along terraced slopes they were grouped together. Following an initial classification using this method, further refinement of swamp groups was undertaken, as initial observation indicated that some swamps that would otherwise be considered part of the same swamp were, in fact, located along different flow pathways. An extreme example of this is shown in Figure 3.

Swamps were then named based on the catchment they were positioned within, generally working from the upstream to downstream extent. Where a valley infill and headwater swamp were connected this was considered to form one functional unit, and therefore considered part of the same upland swamp. However, due to potential differences in type and degree of impacts they have been considered separately where appropriate.

2.2 Analysis of Upland Swamp Using a Geographic Information System

GIS analysis was undertaken using 1 m LiDAR data to create a number of analytical surfaces using ESRI ArcGIS 10.1 Spatial Analyst tools to produce layers and statistics used to categorise the terrain and water flow through individual swamp vegetation communities. The steps used to create this data are outlined below.

2.2.1 Slope and Flow Analysis

One metre thinned ground LiDAR data was converted to a continuous raster digital elevation model (DEM) using the Topo to Raster tool which interpolates point and contour data into a hydrologically corrected, continuous elevation surface that is the basis for many other analyses. The DEM was run through the Spatial Analyst slope tool to produce a surface showing degree of slope across the Study Area. Slope statistics pertaining to the boundaries of vegetation communities within coastal upland swamps previously modelled and ground-truthed by Biosis, were calculated using the Zonal Statistics as Table tool. This produced a table showing the minimum, maximum, sum, mean and standard deviations of slope within each of the vegetation patches. The table was joined to the original swamp vegetation community polygons, which were then symbolised along a range using these statistics in order to characterise the relationship between the vegetation communities and slope.

The 1 m DEM was run through the Fill tool in Spatial Analyst to create a depression-less DEM. This tool fills any sinks in the DEM created by errors in the data or natural areas of pooling to remove barriers to flow through these areas and allow analysis of flow paths and accumulation across the DEM. A flow direction surface was created from the depression-less DEM as an intermediate step required for analysing flow accumulation. A flow accumulation surface was produced from the flow direction model. The flow accumulation model shows for each cell in the accumulation raster, how many cells upstream of the subject cell flow into any given point across the model. This effectively represents how large the catchment area of any given point on the surface and the path the accumulated water will take from its source to its outfall. Although flow accumulation models flow pathways through the landscape based on flow direction, it does not provide a representation of creeks per se, and should not be taken as such.

Similarly, to the slope analysis, statistics of minimum, maximum, mean, total and standard deviation of flow through each mapped upland swamp vegetation community were calculated using the Zonal Statistics tool. The resulting statistics table was joined back to the swamp polygons for further analysis.

2.2.2 Subsidence Calculations

The predicted effects of modelled 'upper bound scenario' mining subsidence were investigated by creating additional slope and flow surfaces using a DEM adjusted to show surface levels following modelled subsidence. The methods used to create these surfaces are as follows:

- Predicted mining subsidence 'worst case scenario' contours provided by Seedsman (2012) were interpolated using the 'Topo to Raster' tool to produce a predicted subsidence surface;
- This subsidence surface was subtracted from the DEM modelled from the LiDAR data to produce a predictive DEM showing adjusted surface levels following 'worst case scenario' vertical shift due to mine subsidence;
- The adjusted DEM was converted to a slope surface as per the method use to model the unadjusted DEM; and
- The adjusted DEM was converted to a flow accumulation layer using the same methods and parameters applied to the original DEM.

Zonal statistics were calculated for each swamp community using the predicted post mining subsidence flow accumulation surface. The resulting data was then joined back to the original swamp vegetation community boundaries polygon layer. The matching pre-mining statistical values were then subtracted from the post mining statistic values. This resulted in negative values where a net loss of flow and positive values where a net gain in flow through a community was predicted. The resulting values were also used to represent the magnitude of the change in water flowing through a given community.

Spatial layers of the flow accumulation models were created to show darkening colour along an identical scale so that pre and post mining flow scenarios could be visually compared to show diversion of water through individual swamps and communities.

2.3 Comparison to Regional Vegetation Mapping (NPWS 2003)

Upland swamp mapping undertaken for this project was compared with mapping of upland swamps from *The Native Vegetation of the Woronora, O'Hares and Sydney Metropolitan Catchments* (NPWS 2003). NPWS (2003) acknowledge the limitations of the mapping, and the data contained within is only meant to provide a guide and should not be relied upon for detailed impact assessment.

Two regional upland swamp mapping layers were created using a Geographic Information System. The first layer included all upland swamp communities representative of the Coastal Upland Swamp EEC, and included:

- MU 42 Upland Swamps: Banksia Thicket;
- MU43 Upland Swamps: Tea-tree Thicket;
- MU44 Upland Swamps: Sedgeland Heath Complex;
  - MU44(a) Sedgeland;
  - MU44(b) Restioid Heath; and
  - MU44(c) Cyperoid Heath.

This layer was cropped at the boundaries of the study area.

A second layer was created where boundaries between vegetation sub-communities were dissolved to create a Coastal Upland Swamp EEC layer. From this layer the number of upland swamps in each area, the total area of upland swamp and the total area for each vegetation sub-community were calculated.

Comparisons were then made between swamp mapping from NPWS (2003) and data obtained as a part of this assessment.

2.4 Significance and Impact Assessment

The impact assessment was undertaken in two stages. The first stage involved the undertaking of an impact assessment according to the Draft *Upland Swamp Environmental Impact Assessment Guidelines* (OEH 2012).

The second stage involved an assessment of the potential for upland swamps of 'special significance' to be impacted based on a variety of features, including an initial risk assessment according to OEH (2012), comparative analysis of upland swamps that have previously been undermined, changes to flow accumulation and potential for fracturing of bedrock and desiccation.

2.4.1 Assessment of 'Special Significance'

The assessment of 'special significance' of upland swamps was undertaken according to OEH (2012). This document sets out five criteria for determining whether upland swamps are considered of 'special significance', including:

- Statutory thresholds;
- Substantial size;
- Unusual complexity;
- Closely proximal habitat (swamp clusters); and,
- Scientific research importance.

An upland swamp is considered to be 'special significance' if it meets three out of the five 'special significance' criteria (OEH 2012).

All upland swamps mapped as a part of this assessment form part of the Coastal Upland Swamp EEC, and therefore meet the statutory threshold criterion. In addition, a number of upland swamps within the study area are, either known to support threatened species and / or provide potential habitat for threatened species.

There are four key clusters of upland swamps on the Woronora plateau; Maddens Plain; Wallandoola Creek; North Pole; and Stockyard. Upland swamps within the study area form part of the Wallandoola Creek cluster, and therefore meet this criterion.

OEH (2012) defines upland swamps as being of scientific research importance if they are important reference sites, contain unique features or resources for scientific study, are part of a network of research sites or are part of a research project. OEH (2012) maps upland swamps of scientific research importance. Upland swamps within the study area are not considered of scientific research importance.

All upland swamps with a size greater than 7.4 ha are considered substantial in size. This size threshold represents the top 10% of upland swamps on the Woronora plateau.

To meet the criterion for unusual complexity (biodiversity), swamps must contain Tea-Tree Thicket (MU43) or contain all vegetation sub-communities. If the assessment is relying solely on NPWS (2003) mapping, the presence of Tea-Tree Thicket (MU43) is used to indicate that other vegetation sub-communities are likely to be present. If independent assessment of vegetation sub-communities is undertaken then an upland swamp must contain all vegetation sub-communities, including Banksia Thicket (MU42), Tea-tree Thicket (MU43) and Sedgeland-Heath Complex (MU44), to be considered unusually complex. As all upland swamps were ground-truthed, and detailed mapping of vegetation sub-communities undertaken, upland swamps must contain all vegetation sub-communities to be considered unusually complex.

2.4.2 Assessment of Potential for Impact

Those upland swamps considered to be of 'special significance' were subject to an impact assessment to determine whether an impact to these upland swamps is predicted to occur.

OEH (2012) requires proponents to undertake a preliminary prediction of subsidence levels under upland swamps and compare this to subsidence criteria outlined in PAC (2010) to determine upland swamps considered to be at risk of negative environmental consequences. These criteria include:

- all swamps subject to systematic tensile strains > 0.5 mm / m;
- all swamps subject to systematic compressive strains > 2 mm / m;
- all swamps with depth of cover less than 1.5 times longwall panel width;
- all swamps subject to tilt (transient or final) > 4 mm/ m;
- all swamps subject to valley closure of > 200 mm / m; and,
- all swamps subject to a maximum observed closure strain > 7.0 mm / m.

However, given the inexact nature of subsidence predictions OEH (2012) also request that a comparative analysis of subsidence levels from past mining operations and observed impacts to upland swamps is undertaken.

Due to the difficulty with obtaining subsidence data on previous mining operations in conjunction with monitoring data from upland swamps an alternate approach was considered warranted by the current assessment. Hydrology, particularly shallow groundwater and surface water flows, is a key component in the formation and maintenance of upland swamps. As detailed in Section 1.2.4, changes in hydrology resulting from subsidence associated with longwall mining have potential to result in impacts to upland swamps. Thus it was deemed that an assessment of hydrology was critically important to undertaking any risk assessment.

For this reason the following work was also undertaken to inform the risk assessment:

- Hydrological assessment undertaken by Geoterra Pty Ltd;
- Analysis of flow accumulation pre- and post-mining, taking into account subsidence predictions (Seedsman 2012); and,
- Predicted compressive and tensile strains to determine areas that may be subject to fracturing of bedrock.

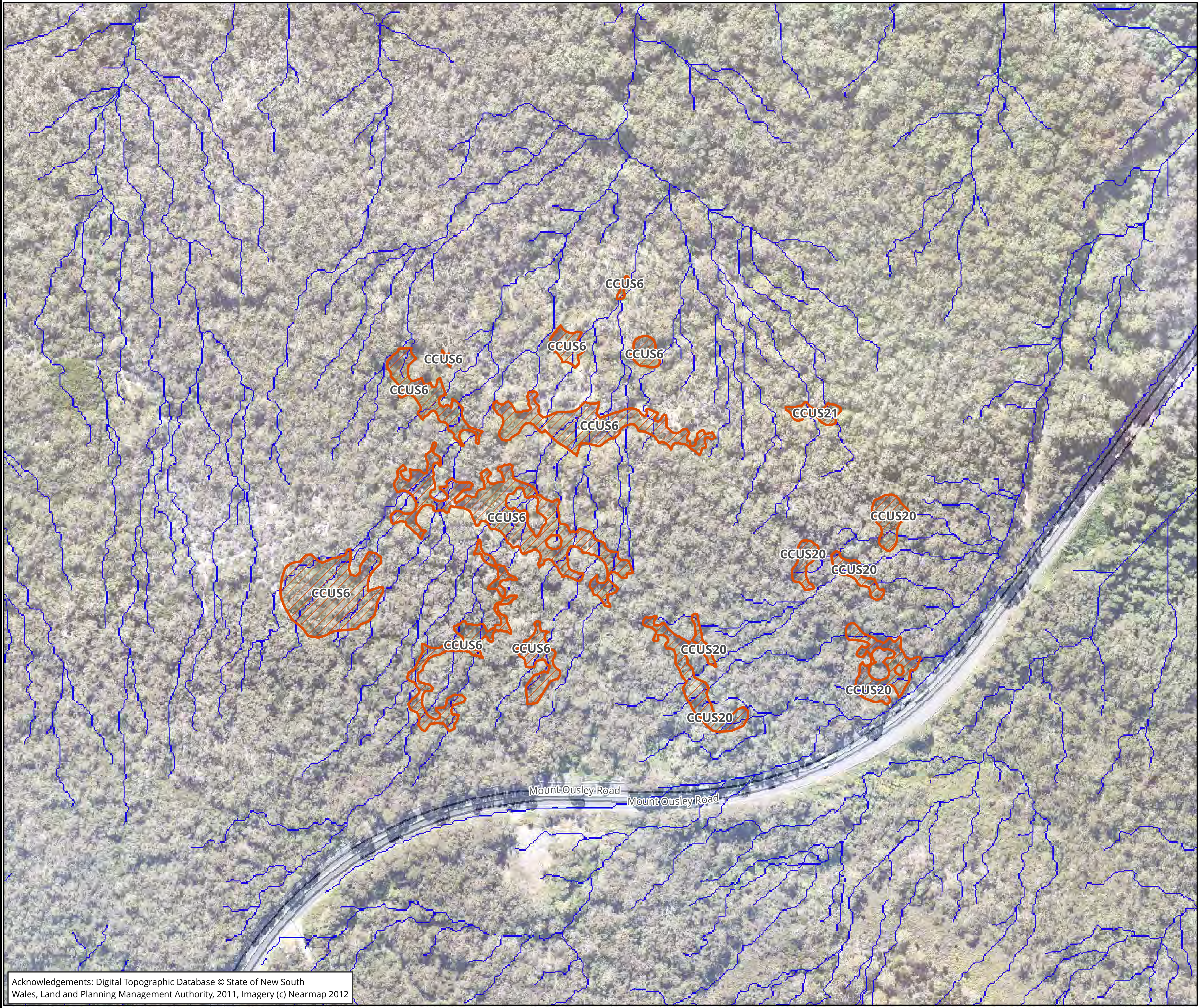
It was deemed that these analyses, considered in conjunction, would provide best practice predictions for upland swamps considered at risk of impact as a result of longwall mining in Wonga East and Wonga West.

2.5 Qualifications

Areas of Upland Swamp: Fringing Eucalypt Woodland (MU45) were not mapped as a part of this assessment. At the margins of swamps this vegetation community intergrades with surrounding Eucalypt woodland, and is difficult to differentiate in many areas. In addition, the methods used for this project to map upland swamps excluded areas of this community due to presence of a tree layer greater than 6 m in height.

Flow accumulation modelling does not provide an assessment of streams within the study area, and should not be used as such. Flow accumulation models flow pathways from the start of a catchment and models catchment areas. Flow accumulation modelling provides an indication of changes to catchment areas and potential pathways.

Subsidence predictions are inexact and provide a guide for understanding potential subsidence effects. Analysis based on these will also have the same level of uncertainty and provide a guide only.



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Legend

Upland Swamp

Flow Accumulation

Nil

Flow Accumulation

Figure 3: Swamp CCUS6, CCUS20 and CCUS21 showing how slope and flow accumulation can be used to group swamps

0 30 60 90 120 150

Meters

Scale: 1:3,000 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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3. Results

3.1 Description Classification of Upland Swamps

3.1.1 Wonga East

A total of thirty-nine (39) upland swamps were recorded within Wonga East (Figure 4). Of these, fourteen (14) are within the predicted limits of subsidence.

Size ranged from 0.04 ha to 9.84 ha with an average of 1.26 ha. All swamps within Wonga East are headwater swamps.

The majority of upland swamps in Wonga East (34/39) support Banksia Thicket (MU42), with twenty (20) upland swamps supporting only this vegetation sub-community. Ten (10) upland swamps support Tea-tree Thicket (MU43). Six (6) upland swamps support a complete range of upland swamp vegetation sub-communities (MU42, MU43 and MU44).

Seven (7) uplands swamp in Wonga East are considered to be of 'special significance' according to criteria set out in OEH (2012) (see Section 4.1). All swamps within Wonga East meet criteria for statutory thresholds (Coastal Upland Swamp EEC) and closely proximate habitat (all are part of the Wallandoola Creek cluster). CRUS1 is considered to be of 'special significance' based on size in addition to the criteria above, while CCUS1, CCUS4, CCUS5, CCUS10, CRUS2 and CRUS3 are considered to be of 'special significance' due to the complexity of vegetation sub-communities within these swamps, as all support Banksia Thicket (MU42), Tea-tree Thicket (MU43) and Sedgeland-Heath Complex (MU44a,b,c). Of these significant swamps, five (5) have potential to be subject to subsidence (CCUS1, CCUS4, CCUS5, CCUS10 and CRUS1).

A detailed description of each upland swamp within Wonga East is provided in Appendix 1.

3.1.2 Wonga West

A total of forty-five (45) upland swamps were recorded within Wonga West (Figure 5). Of these, thirty-six (36) are within the predicted limits of subsidence.

Size ranged from 0.06 ha to 129.89 ha with an average of 4.79 ha. Wonga West contains a mix of headwater and valley infill swamps, with four upland swamps (LCUS1, LCUS6, LCUS8 and WCUS4) containing both headwater and valley infill swamp types. However, as these swamps are functioning as one larger swamp they have been named as such.

Upland swamps in Wonga West are diverse in the vegetation sub-communities they support. Restioid Heath (MU44b) was the most abundant vegetation sub-community, with twenty-seven (27) upland swamp supporting this community of which thirteen (13) supporting only this community. Twenty-six (26) upland swamps support Banksia Thicket (MU42), with twelve (12) upland swamps supporting only this vegetation sub-community. Thirteen (13) upland swamps support Tea-tree Thicket (MU43). Six (6) upland swamps support a complete range of upland swamp vegetation sub-communities (MU42, MU43 and MU44).

Eight (8) upland swamps in Wonga West are considered of 'special significance' according to criteria set out in OEH (2012) (see Section 4.1). All swamps within Wonga West meet criteria for statutory thresholds (Coastal Upland Swamp EEC) and closely proximate habitat (all are part of the Wallandoola Creek cluster). WCUS4 is considered to be of 'special significance' based on size in addition to the criteria above. LCUS6, LCUS8, LCUS27, WCUS7 and WCUS11 are considered to be of 'special significance' due to the complexity of vegetation sub-communities within these swamps, as all support Banksia Thicket (MU42), Tea-tree Thicket (MU43) and Sedgeland-Heath Complex (MU44a, b, c). LCUS1 and WCUS1 are considered to be of 'special significance' due to size and complexity. Of these significant swamps, seven (7) are predicted to be subject to subsidence.

A detailed description of each upland swamp within Wonga West is provided in Appendix 1.

3.2 Comparison with Regional Vegetation Mapping (NPWS 2003)

Comparison between mapping of upland swamp with that by NPWS (2003) indicated that upland swamps are more complex, more numerous and differ in extent when compared to data from NPWS (2003). The limitations of the sampling, analysis and mapping are however acknowledged by NPWS (2003).

Summary statistics are provided in Table 4 and Table 5. A visual comparison is provided in Figure 4 and Figure 5.

Table 4: Comparison of upland swamp mapping by Biosis (2012) and NPWS (2003) for Wonga East (600 m buffer)

	Biosis (2012)	NPWS (2003)
Total No. of Upland Swamps	39	28
Total area of Upland Swamps	49.06 ha	68.04 ha
Area of Banksia Thicket (MU42)	35.15 ha	48.35 ha
Area of Tea-tree Thicket (MU43)	5.20 ha	0 ha
Area of Sedgeland-Heath (MU44)	8.71 ha	19.69 ha

Table 5: Comparison of upland swamp mapping by Biosis (2012) and NPWS (2003) for Wonga West (600 m buffer)

	Biosis (2012)	NPWS (2003)
Total No. of Upland Swamps	45	18
Total area of Upland Swamps	72.13 ha	50.79 ha
Area of Banksia Thicket (MU42)	15.76 ha	4.86 ha
Area of Tea-tree Thicket (MU43)	13.92 ha	1.67 ha
Area of Sedgeland-Heath (MU44)	42.44 ha	44.26 ha

Mapping of upland swamp undertaken for this project:

- located an additional eleven (11) upland swamps at ten (10) locations in Wonga East;
- found that two areas mapped as upland swamp by NPWS (2003) in Wonga East were not upland swamp;

- located an additional twenty-six (26) upland swamps at twenty-two (22) location in Wonga West;
- found that there was 18.98 ha less upland swamp within Wonga East than mapped by NPWS (2003);
- found that there was 21.34 ha more upland swamp in Wonga West than mapped by NPWS (2003);
- found that all Banksia Thicket (MU42) and Sedgeland-Heath Complex (MU44) were less prevalent in Wonga East than mapped by NPWS (2003) but there was Tea-tree Thicket (MU43) that had not been mapped;
- found that Banksia Thicket (MU42) and Tea-tree Thicket (MU43) were more prevalent in Wonga West than mapped by NPWS (2003) but Sedgeland-Heath Complex (MU44) was equivalent in extent;
- found that upland swamp are much more complex than reflected by NPWS (2003) with areas mapped as one large swamp by NPWS (2003) were often comprised of several discrete swamps separated by areas of forest or reliant upon surface flows from different locations; and,
- found that the extent and location of vegetation sub-communities was much more complex than as shown by NPWS (2003), with swamps mapped as containing one or two areas of each sub-community were actually comprised of numerous, smaller units of each vegetation sub-community.

Detailed mapping of upland swamp using LiDAR to indicate areas for further investigation, followed by ground-truthing and detailed mapping of vegetation sub-communities within each swamp has shown that mapping of upland swamps by NPWS (2003) does not accurately represent the extent or complexity of upland swamps. As per the limitations of this mapping outlined in Section 2.3, this is to be expected based on a more detailed assessment of vegetation communities within the study area.

This, in turn, means that impact assessments based on data obtained by NPWS (2003) are unlikely to be capable of accurately predicting impacts to upland swamps. Based on observed and predicted impacts to upland swamps this lack of understanding of the micro-scale changes in soil moisture within a swamp and thus the sub-communities reliant upon it, are likely to inhibit the ability of proponents to reliably predict impacts to upland swamps. For example, this project has found that Tea-tree Thicket MU43 was much more prevalent than as mapped by NPWS (2003), with this community more dependant on permanent waterlogging and thus more susceptible to impact. In addition, mapping of Sedgeland-Heath Complex MU44 by NPWS (2003) does not reflect changes between Sedgeland (MU44a), Restioid Heath (MU44b) and Cyperoid Heath (MU44c). As Cyperoid Heath (MU44c) is reliant on intermittent waterlogging when compared to other communities within this complex to accurately predict areas most at risk proponents, need to understand this micro-scale change and complexity.

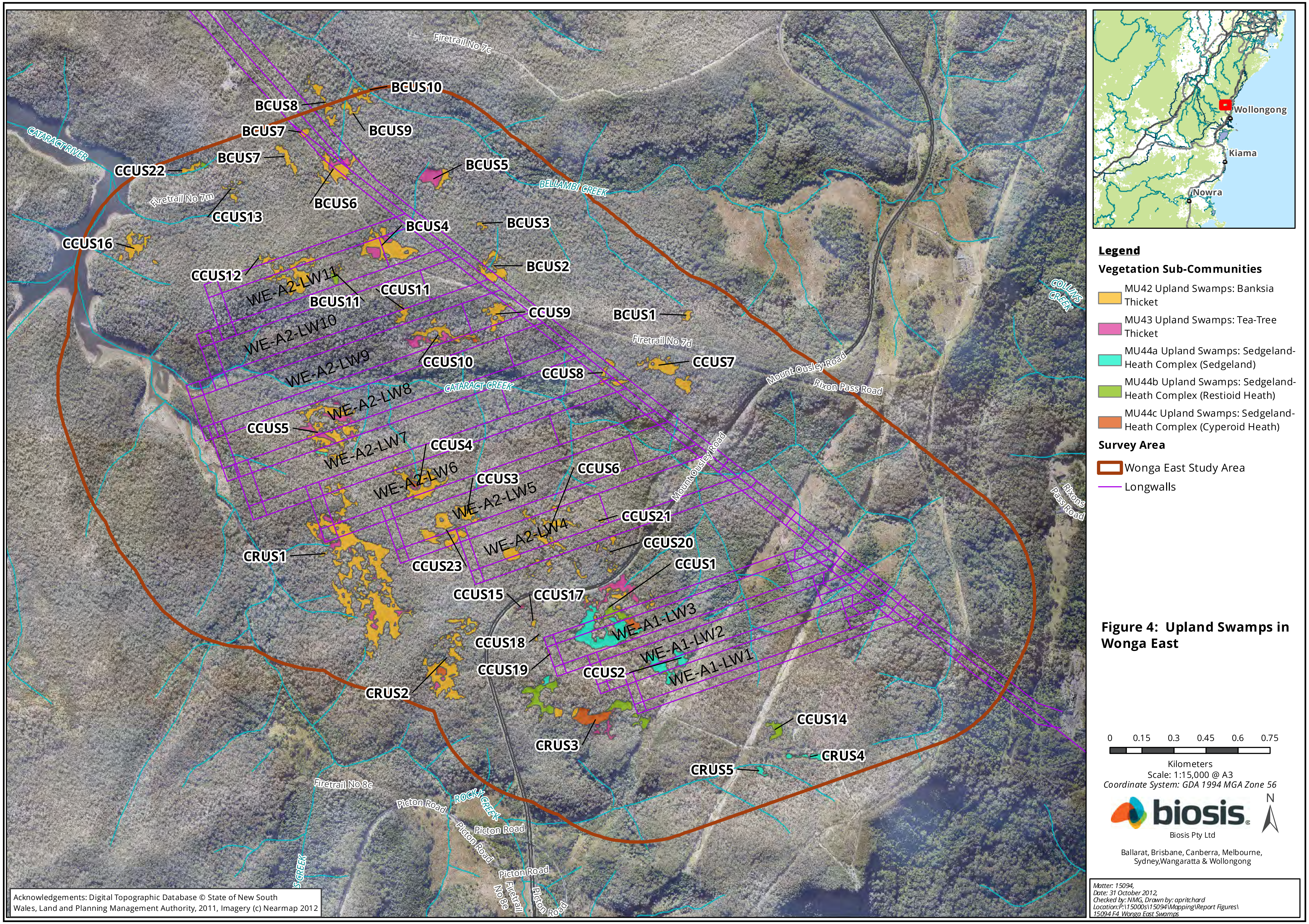
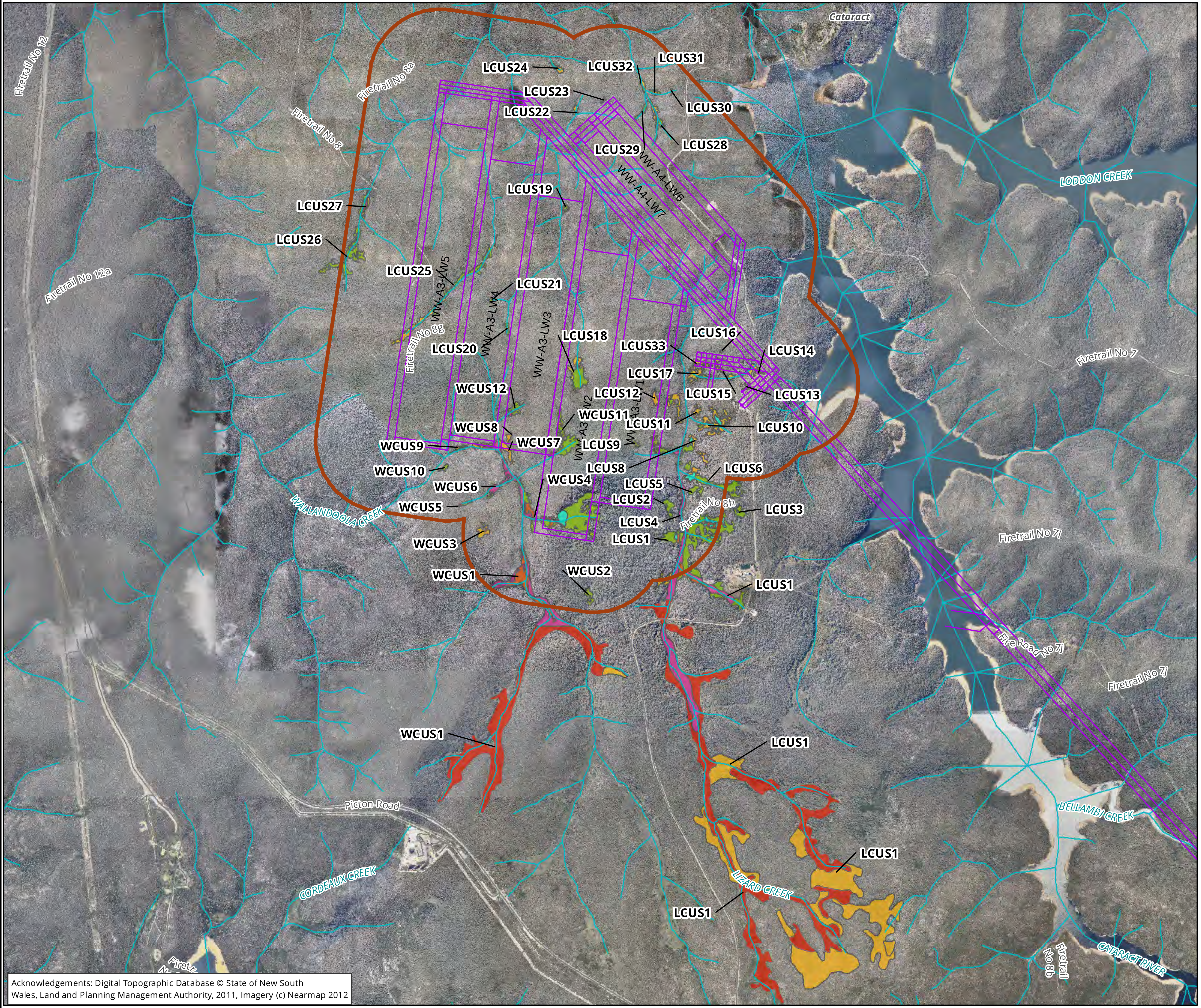


Figure 4: Upland Swamps in Wonga East



Legend

Vegetation Sub-Communities

- MU42 Upland Swamps: Banksia Thicket
- MU43 Upland Swamps: Tea-Tree Thicket
- MU44a Upland Swamps: Sedgeland-Heath Complex (Sedgeland)
- MU44b Upland Swamps: Sedgeland-Heath Complex (Restioid Heath)
- MU44c Upland Swamps: Sedgeland-Heath Complex (Cyperoid Heath)

Vegetation Outside Current Study Area (NPWS 2003)

- MU44 Upland Swamps: Sedgeland-Heath Complex

Survey Area

- Wonga West Study Area
- Longwalls

Figure 5: Upland Swamps in Wonga West

0 0.3 0.6 0.9 1.2 1.5

Kilometers

Scale: 1:30,000 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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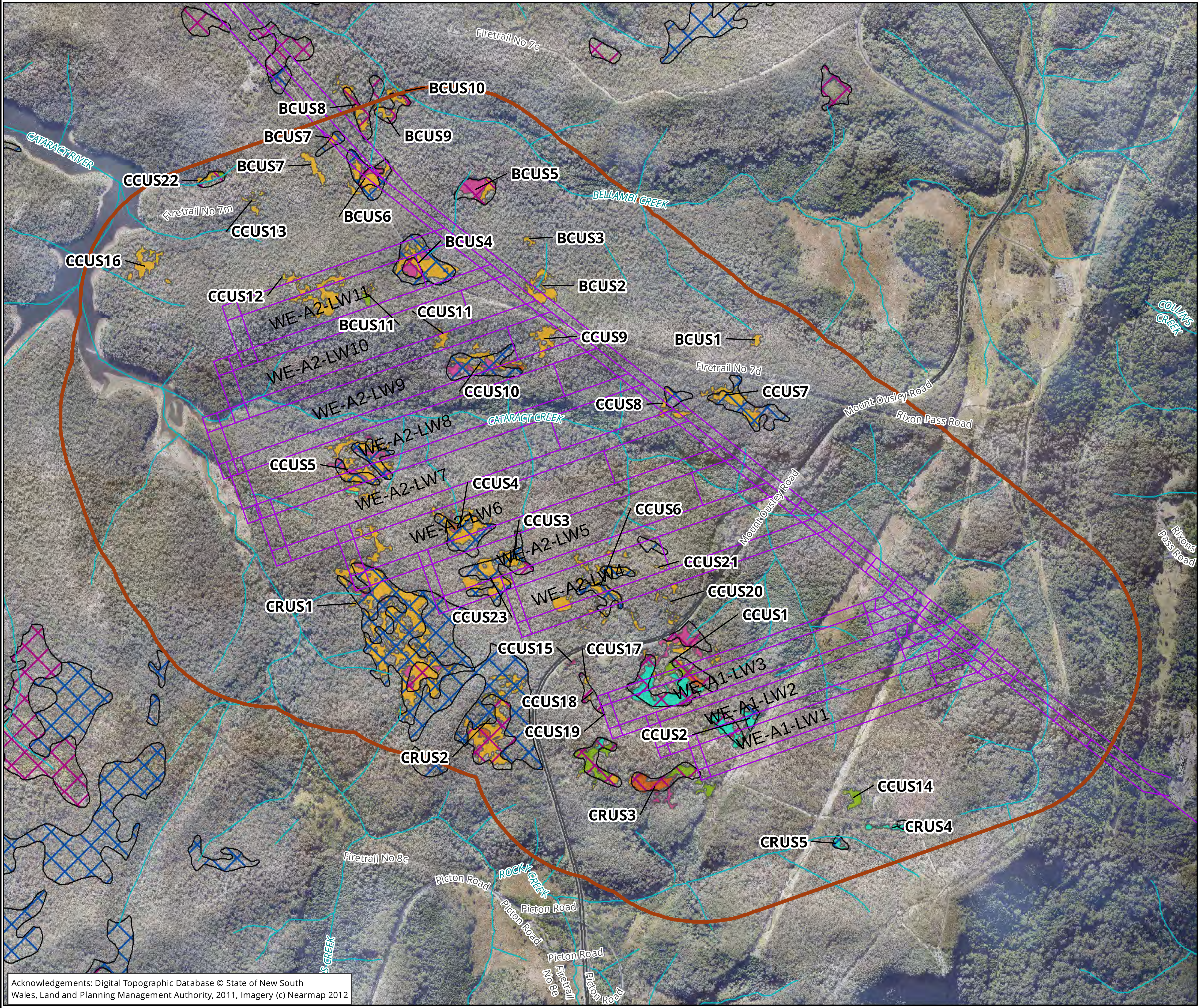

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Vegetation Sub-Communities

- MU42 Upland Swamps: Banksia Thicket
- MU43 Upland Swamps: Tea-Tree Thicket
- MU44a Upland Swamps: Sedgeland-Heath Complex (Sedgeland)
- MU44b Upland Swamps: Sedgeland-Heath Complex (Restioid Heath)
- MU44c Upland Swamps: Sedgeland-Heath Complex (Cyperoid Heath)

Vegetation Communities (NPWS 2003)

- MU42 Upland Swamps: Banksia Thicket
- MU43 Upland Swamps: Tea-Tree Thicket
- MU44 Upland Swamps: Sedgeland-Heath Complex

Survey Area

- Wonga East Study Area
- Longwalls

Figure 6: Comparison of upland swamps mapped in Wonga East with those mapped by NPWS (2003)

0 0.15 0.3 0.45 0.6 0.75
Kilometers
Scale: 1:15,000 @ A3
Coordinate System: GDA 1994 MGA Zone 56

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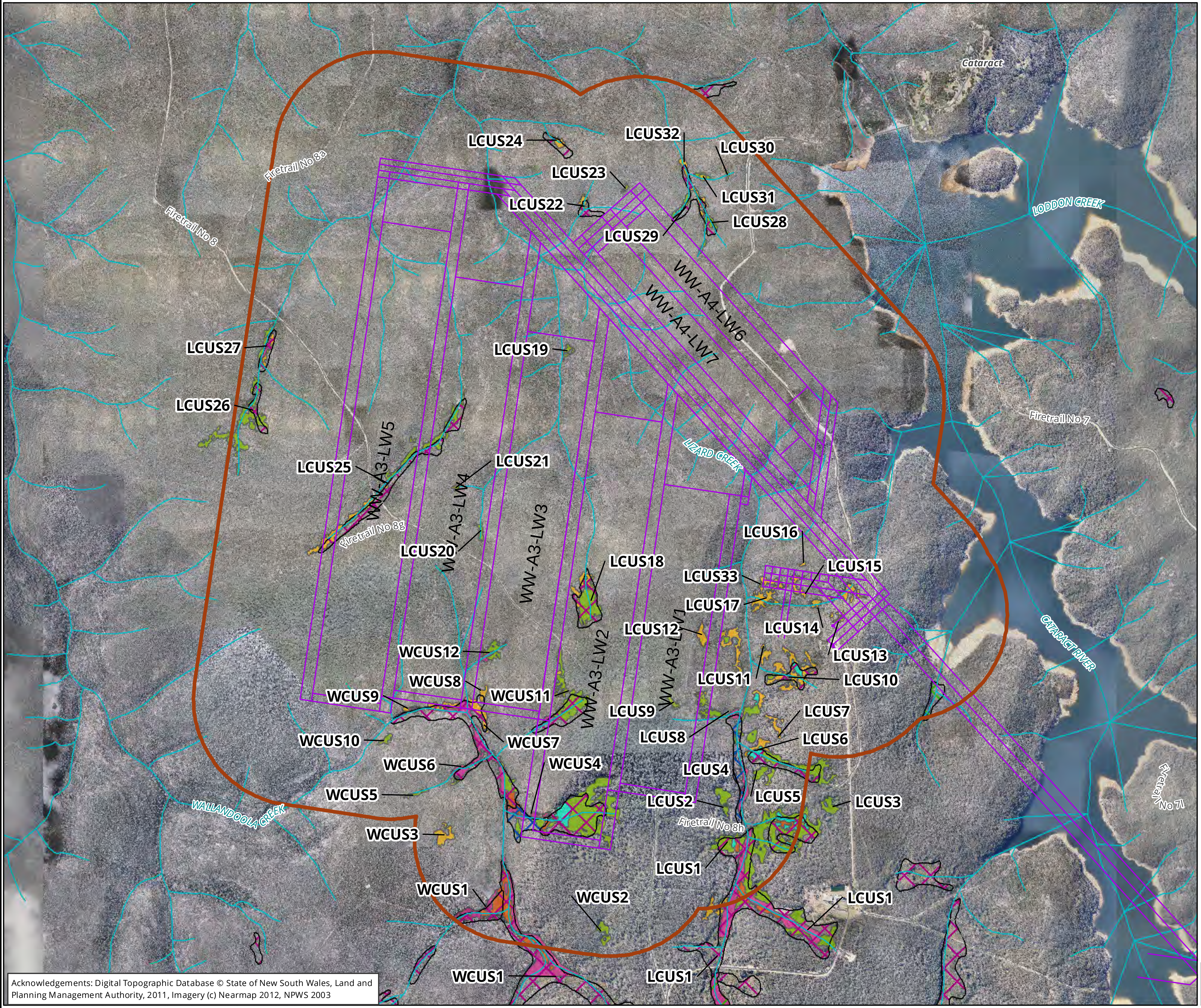

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Legend

Vegetation Sub-Communities

- MU42 Upland Swamps: Banksia Thicket
- MU43 Upland Swamps: Tea-Tree Thicket
- MU44a Upland Swamps: Sedgeland-Heath Complex (Sedgeland)
- MU44b Upland Swamps: Sedgeland-Heath Complex (Restioid Heath)
- MU44c Upland Swamps: Sedgeland-Heath Complex (Cyperoid Heath)

Vegetation Communities (NPWS 2003)

- MU42 Upland Swamps: Banksia Thicket
- MU43 Upland Swamps: Tea-Tree Thicket
- MU44 Upland Swamps: Sedgeland-Heath Complex

Survey Area

- Wonga West Study Area
- Longwalls

Figure 7: Comparison of upland swamps mapped in Wonga West with those mapped by NPWS (2003)

0 0.2 0.4 0.6 0.8 1

Kilometers

Scale: 1:20,000 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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4. Upland Swamp Significance and Impact Assessment

This section provides an assessment of impacts to upland swamps based on:

- Significance criteria set out in the *Draft Upland Swamp Environmental Impact Assessment Guidelines* (OEH 2012);
- An initial risk assessment based on subsidence criteria outlined in PAC (2010) and OEH (2012);
- A comparative analysis of previous mining and observed impacts to upland swamps;
- An analysis of groundwater levels obtained from piezometers within the study area (GeoTerra Pty Ltd);
- Analysis of slope and flow accumulation pre- and post-mining; and,
- Compressive tilts and strains and potential impacts to upland swamps.

The goal of the impact assessment was to determine upland swamps of 'special significance' considered to be at significant risk of impact as a result of subsidence associated with longwall mining.

4.1 Assessment of 'Special Significance'

All upland swamps within the study area fulfil two out of the five criteria listed in OEH (2012) for determining whether upland swamps are considered to be of 'special significance'. All upland swamps form part of the Coastal Upland Swamp EEC, and all upland swamps are part of the Wallandoola Creek cluster of upland swamps. Thus all upland swamps are considered significant on the basis of statutory thresholds and closely proximate habitat. No upland swamps within the study area are considered to be significant due to the scientific research importance criteria.

The size and complexity for all upland swamps was assessed and level of significance determined. Any upland swamp meeting three out of the five criteria listed in OEH (2012) are considered to be of 'special significance'.

The assessment of 'special significance' identified that seven (7) upland swamps in Wonga East and eight (8) upland swamps in Wonga West are of 'special significance'. Analysis for significant swamps is presented in Table 6 and Table 7. Significant swamps are shown in Figure 8 and Figure 9.

Table 6: Assessment of 'Special Significance' - Wonga East

Swamp Name	Statutory	Size (ha)	Complexity	Cluster	Scientific	Significant	Reason
CCUS1	*Coastal Upland Swamp EEC*	4.81	*MU42, MU43, MU44b, MU 44c*	*Wallandoola*	No	Yes	Statutory threshold, Closely proximate habitat, Complexity
CCUS10	*Coastal Upland Swamp EEC*	1.63	*Yes - MU42, MU43, MU44c*	*Wallandoola*	No	Yes	Statutory threshold, Closely

Swamp Name	Statutory	Size (ha)	Complexity	Cluster	Scientific	Significant	Reason
							proximate habitat, Complexity
CCUS4	*Coastal Upland Swamp EEC*	1.77	*MU42, MU43, MU44c*	*Wallandoola*	No	Yes	Statutory threshold, Closely proximate habitat, Complexity
CCUS5	*Coastal Upland Swamp EEC*	3.45	*MU42, MU43, MU44a*	*Wallandoola*	No	Yes	Statutory threshold, Closely proximate habitat, Complexity
CRUS1	*Coastal Upland Swamp EEC*	*9.84*	MU42, MU43	*Wallandoola*	No	Yes	Statutory threshold, Closely proximate habitat, Size
CRUS2	*Coastal Upland Swamp EEC*	3.12	*MU42, MU43, MU44c*	*Wallandoola*	No	Yes	Statutory threshold, Closely proximate habitat, Complexity
CRUS3	*Coastal Upland Swamp EEC*	3.42	*MU42, MU43, MU44a, MU44b, MU44c*	*Wallandoola*	No	Yes	Statutory threshold, Closely proximate habitat, Complexity

Table 7: Assessment of 'Special Significance' - Wonga West

SwampName	Statutory	Size (ha)	Complexity	Cluster	Scientific	SigAss	Reason
LCUS1	*Coastal Upland Swamp EEC*	*129.9*	*MU42, MU43, MU44b*	*Wallandoola*	No	Yes	Statutory threshold,

SwampName	Statutory	Size (ha)	Complexity	Cluster	Scientific	SigAss	Reason
							Closely proximate habitat, Size, Complexity
LCUS27	*Coastal Upland Swamp EEC*	1.04	*MU42, MU43, MU44b*	*Wallandoola*	No	Yes	Statutory threshold, Closely proximate habitat, Complexity
LCUS6	*Coastal Upland Swamp EEC*	3.74	*MU42, MU43, MU44a, MU44b, MU44c*	*Wallandoola*	No	Yes	Statutory threshold, Closely proximate habitat, Complexity
LCUS8	*Coastal Upland Swamp EEC*	2.09	*MU42, MU43, MU44a, MU44b*	*Wallandoola*	No	Yes	Statutory threshold, Closely proximate habitat, Complexity
WCUS1	*Coastal Upland Swamp EEC*	*36.16*	*MU42, MU43, MU44c*	*Wallandoola*	No	Yes	Statutory threshold, Closely proximate habitat, Size, Complexity
WCUS11	*Coastal Upland Swamp EEC*	2.79	*MU42, MU43, MU44b*	*Wallandoola*	No	Yes	Statutory threshold, Closely proximate habitat, Complexity
WCUS4	*Coastal Upland Swamp EEC*	*11.08*	MU43, MU44a, MU44b, MU44c	*Wallandoola*	No	Yes	Statutory threshold, Closely proximate habitat, Size
WCUS7	*Coastal Upland Swamp EEC*	1.97	*MU42, MU43, MU44c*	*Wallandoola*	No	Yes	Statutory threshold,

SwampName	Statutory	Size (ha)	Complexity	Cluster	Scientific	SigAss	Reason
							Closely proximate habitat, Complexity

Full results are presented in the Swamp matrix shown in Appendix 2. Upland swamps of 'special significance' are considered further below.

4.2 Assessment of Potential Impacts

4.2.1 Initial Risk Assessment

An initial risk assessment on upland swamps of 'special significance' was undertaken according to subsidence criteria outlined in PAC (2010) and OEH (2012). Results are presented in Table 8 and Table 9.

Table 8: Initial Risk Assessment for Wonga East (Figures in bold are greater than criteria outlined in OEH 2012)

SwampName	Ratio Depth of cover : Panel width	Tensile Strain	Compressive Strain	Max Tilt
CCUS1	2.47	**2.65**	**-6.79**	**11.38**
CCUS4	1.91	**4.63**	**-8.03**	**21.04**
CCUS5	1.89	**4.74**	**-8.03**	**21.30**
CCUS10	1.92	**4.60**	**-8.74**	**21.39**
CRUS1	1.85	**4.34**	**-7.20**	**17.51**
CRUS2	-	0.00	0.00	0.00
CRUS3	-	0.00	0.00	0.00

Table 9: Initial Risk Assessment for Wonga West (Figures in bold are greater than criteria outlined in OEH 2012)

SwampName	Ratio Depth of cover : Panel width	Tensile Strain	Compressive Strain	Max Tilt
LCUS1	-	0.00	0.00	0.00
LCUS6	-	0.00	0.00	1.93
LCUS8	**1.27**	**2.75**	**-2.64**	9.15

SwampName	Ratio Depth of cover : Panel width	Tensile Strain	Compressive Strain	Max Tilt
LCUS27	-	0.00	0.00	0.00
WCUS1	-	0.00	0.00	0.00
WCUS4	**1.28**	**5.03**	**-6.97**	10.58
WCUS7	**1.31**	**5.45**	-0.01	10.70
WCUS11	**1.31**	**5.35**	**-3.81**	8.02

Based on this initial risk assessment according to subsidence criteria outlined in PAC (2010) and OEH (2012) 'special significance' upland swamps CCUS1, CCUS4, CCUS5, CCUS10 and CRUS1 in Wonga East and LCUS8, WCUS4, WCUS7 and WCUS11 in Wonga West can be considered at risk of negative environmental consequences based on these subsidence criteria.

Special significance upland swamps CRUS2 and CRUS3 in Wonga East and LCUS1, LCUS6, LCUS27 and WCUS1 in Wonga West are considered not at risk of negative environmental consequences based on these subsidence criteria.

4.2.2 Comparative Analysis

Due to the inexact nature of subsidence predictions OEH (2012) requires an assessment of past mining and subsidence with impacts to upland swamps resulting from this subsidence. In this regard there is a significant paucity of data available to undertake such a comparative analysis.

Impacts to a very small number of upland swamps, located above mining areas, have been observed. The most notable and widely reported include Swamp 37 (Drillhole Swamp) and Swamp 18 in the Avon catchment (EarthTech 2003; Tomkins and Humphrey 2006) and Flatrock Swamp in the Woronora catchment (Tompkins and Humphrey 2006). Although hypothesised to be a contributing factor, subsidence has not been determined to be a sole reason for any observed impacts to upland swamps; however subsidence effects are believed to be a contributing factor.

The following summarises EarthTech (2003), Tompkins and Humphrey (2006) and other relevant the reports and assessments.

EarthTech (2003)

EarthTech (2003) provides an analysis of seven (7) upland swamps where longwall mining has occurred as well as eleven (11) upland swamps where bord and pillar or shortwall mining has been undertaken. These upland swamps, including a mix of headwater and valley infill swamps, were located in proximity to the former Elouera Colliery. Mining in this area has been undertaken across an extensive period of time, with bord and pillar mining being undertaken prior to the extraction of coal from the Elouera mine commencing in 1993 and extending northwards under a number of upland swamps.

Swamps 17, 18, 19, 26 and 27 are located directly above longwalls mined as part of the former Elouera colliery, while Swamps 21a and 31 are located in close proximity to these longwalls. Of these upland swamps, six (6) were found to have been subject to subsidence effects, including subsidence, cracking or collapse of underground workings. Of these, one (1) upland swamp (Swamp 18) was found to have undergone observable impacts including scouring and erosion. Swamp 19 was hypothesised to have undergone some impacts including development of scour pools; however this is likely to be a natural part of cut and fill events within this dynamic vegetation community and is not considered to be an impact per se (see below). Maximum vertical subsidence associated with the extraction of these longwalls was 1.2 m. Earth Tech (2003) hypothesised that impacts to Swamp 18 resulted from drying due to fracturing of bedrock below the swamp and a change in gradient through the swamp resulting in the re-distribution of water within the swamp. Contributing factors include the size of the swamp and alignment perpendicular to, and spanning, longwalls. Swamps where impacts were not observed (Swamps17, 21a, 26 and 27) were smaller and generally aligned with longwalls or were not located directly above longwalls.

Swamps 20, 21b, 22, 24, 28a, 28b, 29, 30, 37a, 37b and 37c are located either partially or wholly above bord and pillar or shortwall workings. Of these upland swamps nine (9) have been subject to known subsidence effects, including subsidence, cracking or collapse of underground workings, while two may have been subject to subsidence effects. Of these, one (1) upland swamp (Swamp 37a) was found to have undergone observable changes including gully erosion and scouring. Although maximum subsidence associated with Swamp 37a was 2.4m, which is comparable to vertical subsidence from longwall extraction, mechanical disturbance (to Swamp 37a formation of a road through the swamp) occurred prior to erosion and scouring. The presence of this form of disturbance confounds any attempts to make a conclusion on the impacts of mining.

Based on data from this report we can cautiously conclude that subsidence of 1.2 m is known to have resulted in dewatering of one (1) out of five (5) upland swamps located directly above the former Elouera colliery. This subsidence effect, in conjunction with other factors such as fire and intense rainfall, may have contributed to the erosion and scouring of Swamp 18. However, a lack of impact to four subsided swamps indicates that mining-induced subsidence is not a sole cause of erosion of upland swamps.

Tompkins and Humphrey (2006)

Tompkins & Humphrey (2006) undertook an assessment of three (3) upland swamps within the Avon and Woronora catchments to assess the causes and triggers for erosion of upland swamps.

Tompkins and Humphrey looked at past aerial photography, swamp stratigraphy, subsidence effects and fire history of Swamp 18, Swamp 37a (Drillhole Swamp) and Flatrock Swamp. All of these swamps have undergone erosion, scouring and gully formation and all have been undermined, either by longwall mining or bord and pillar mining.

By looking at swamp stratigraphy Tompkins and Humprhrey (2006) were able to deduce that the erosion and filling of upland swamps is part of a natural process and that the development of scour pools is the first indication of the potential for such an event. What causes the initial formation of scour pools is not known, but is likely to be triggered by heavy rainfall.

Tompkins and Humphrey (2006) also concluded that upland swamps erode as a result of a unique set of circumstances where internal thresholds are breached. It is likely that a combination of factors, including prior erosion, fire, anthropomorphic impacts and heavy rainfall breach these thresholds.

Tompkins and Humphrey (2006) concluded that dewatering and drying of upland swamps as a result of fracturing of the bedrock may have increased the erosion potential of these upland swamps. This drying, in conjunction with fire and substantial rainfall, is likely to have increased the susceptibility of upland swamps, particularly Swamp 18, to erosion. However, they also found that no single factor could be directly implicated in the erosion of these upland swamps. The presence of scour pools was a likely indicator of future erosion.

Dendrobium Area 2 and 3A

Impacts to groundwater levels around two upland swamps within BHP Billiton's (BHPB) Dendrobium Area 3A mine have been recorded (Comur Consulting 2012). Groundwater levels in four piezometers located within Swamp 12 have exhibited a lack of sustained groundwater recovery following mining of Longwall 7. Groundwater levels in two piezometers have shown a reduced recovery of groundwater following mining of Longwall 7. This lack of sustained groundwater is concurrent with observed fracturing of creeks below both upland swamps. To date no observable impacts to these upland swamps have resulted from this reduction in groundwater levels. Longwall 7 has resulted in a maximum vertical subsidence of 1.4 m, maximum tilt of -14 mm / m and maximum strain of 7 mm / m (MSEC 2012).

At Swamp 1 in Dendrobium Area 2 a reduction if groundwater levels in piezometers located in proximity to Swamp 1 coincides with observations of surface fracturing within this upland swamp (Biosis 2011). Despite these observable subsidence effects, no erosion of Swamp 1 has been observed. Changes in flora species composition within Swamp 1 appears to be changing at a faster rate than control swamps, with species richness and diversity declining since this area was undermined (Biosis 2012). However, this decline in species richness and diversity is to be expected following fire, with obligate seeding shrubs out-competing other species and curtailing their growth (Keith *et al.* 2006).

It is too early to tell whether reductions in groundwater in Swamps 12 and 15a will result in impacts to these swamps. Observed changes in flora composition at Swamp 1 are confounded by the fire history of this swamp, with post-fire successional change occurring as predicted by Keith *et al.* (2006). Future monitoring will provide additional information.

Other Reports

The Bulli Seam Operations PAC Report (PAC 2010) stated that impacts to a number of upland swamps has been observed, including Swamp 18 (see above), Swamp 1 in Dendrobium Area 2 and Swamp 32. Also recorded in PAC (2010) is "*the panel observed that multiple swamps either side of an undermined (and severely impacted) reach of Lizard Creek appeared to be dry and undergoing compositional change from invasion by wattles and eucalypts*" (p. 88).

No specific data on the location of any impacts, or subsidence measurements was available for this report.

Conclusion

Based on literature review completed as a part of this comparative analysis, subsidence of greater than 1.2 m may result in reductions in groundwater and resultant dewatering and drying of upland swamps. Drying of swamps may increase their sensitivity to other natural factors, such as fire and scouring, lowering thresholds for erosion events. However, this drying must be concurrent with these other contributing factors for erosion to occur.

To date there is little evidence as to whether this drying of upland swamps results in changes to the size of, or species composition within, upland swamps. Additional data is required to determine the impacts of reductions in groundwater on upland swamps.

4.2.3 Groundwater

Groundwater data is available for a limited number of upland swamps of special significance within the study area. Data is presented in Table 10 and Table 11.

Table 10: Groundwater data from upland swamps of 'special significance' in Wonga East

Upland Swamp	Peizometer	
CCUS1	-	-
CCUS4	PCc4	Shallow groundwater recharges to surface following rainfall. No drying of piezometer recorded from limited data.
CCUS5	PCc5a, PCc5b	Shallow groundwater recharges to near surface following rainfall. No drying of piezometer recorded from limited data.

Upland Swamp	Peizometer	
CCUS10	-	-
CRUS1	PCr1	Shallow groundwater recharges following rainfall. However, one month following rainfall piezometer appears to dry out.
CRUS2	-	-

Table 11: Groundwater data from upland swamps of 'special significance' in Wonga West

Upland Swamp	Peizometer	
LCUS1	PL1a, PL1b	Shallow groundwater recharges following rainfall. Groundwater has taken 3-4 months to dry out following rainfall.
LCUS6	-	-
LCUS8	-	-
LCUS27	-	-
WCUS1	PW1	Groundwater saturated. Moderated response to rainfall as piezometer is in direct contact with stream seepage along Wallandoola Creek valley.
WCUS4	PW4	Shallow groundwater recharges following rainfall. Groundwater has taken 3-4 months to dry out following rainfall.
WCUS7	-	-
WCUS11	PW11	Shallow groundwater recharges following rainfall. Groundwater has taken 3-4 months to dry out following rainfall.

Based on this assessment of groundwater upland swamps in Wonga East and West have input from seepage associated with shallow ephemeral groundwater systems. However these upland swamps appear to dry out following periods of low rainfall, with the time to drying out varying between one (CRUS1) to several (LCUS1, WCUS4 and WCUS11) months. Drying time is also likely to be strongly influenced by climatic factors, with drying time influenced by top up events. Only one upland swamp currently monitored (WCUS1) was found to be saturated throughout the monitoring period; this upland swamp is in direct contact with stream seepage along Wallandoola Creek.

Assessment by Geoterra Pty Ltd has indicated that shallow ephemeral groundwater that is resent in upland swamps is hydraulically separated, and that upland swamps are more responsive to rainfall and /drying cycles that regional aquifers.

Based on this data we can conclude that WCUS1 is saturated due to direct contact with stream seepage. Upland swamps CCUS4, CCUS5, LCUS1, WCUS4 and WCUS11 are recharged following rainfall events, but dry out during periods of extended low rainfall when the shallow groundwater table is not recharged. CRUS1 appears to dry out rapidly following recharge.

4.2.4 Flow Accumulation

Detailed analysis of flow accumulation for upland swamps determined to be of 'special significance' was undertaken, and is presented below.

Table 12: Discussion of changes in flow accumulation pre- versus post-mining for upland swamp of 'special significance' in Wonga East

Upland Swamp	Discussion of changes in flow accumulation
CCUS1	Flow accumulation modelling pre-mining indicates the presence of two main flow pathways through this upland swamp – one exiting the swamp in the northeast section of the swamp and one in the southeast section of the swamp. These exit points coincide with area of Tea-tree Thicket (MU43) and Cyperoid Heath (MU44c), with both sub-communities reliant on permanent to intermittent water logging. Flow accumulation modelling post-mining indicates that tilts associated with Area 1 LW3 may result in changes to flow pathways, particularly for the southern section of the swamp. The area of Cyperoid Heath (MU44c) in the southeast section may be subject to a significant reduction in flow accumulation. This reduction in water availability could result in less waterlogging and potential for changes to vegetation composition.
CCUS4	Flow accumulation modelling pre-mining indicates the presence of two main flow pathways through this upland swamp. One minor flow accumulation passes through the eastern section of the swamp, while the main flow pathway passes through the western section of the swamp. The western flow pathway corresponds with areas of Tea-tree Thicket (MU43) and Cyperoid Heath (MU44c). Post-mining, only negligible changes in the eastern flow accumulation pathway are predicted to occur. The western flow pathway changes slightly in response to changes in gradient within the swamp. The upper section of Tea-tree Thicket (MU43) is expected to undergo a reduction in flow accumulation and potential reductions in groundwater availability; however, flow accumulation in lower sections of Tea-tree Ticket (MU43) and Cyperoid Heath (MU44c) are predicted to undergo increases in flow accumulation and potentially increased wetting and waterlogging. Any resultant changes are likely to be small in scale and decreases in flow accumulation are likely to be offset by increases in other areas.
CCUS5	Pre-mining flow accumulation modelling indicates that this upland swamp has a dispersed flow accumulation, with numerous flow pathways through the swamp. There is a significant flow pathway through the eastern section of the swamp, corresponding with an area of Tea-Tree Thicket (MU43). Substantial benching within this swamp

Upland Swamp	Discussion of changes in flow accumulation
	appears to be correlated with vegetation sub-communities; with areas of Tea-Tree Thicket (MU43) corresponding with the location of rockbars within the swamp, and it is likely that community composition in this swamp relates to a combination of flow and these rockbars allowing pooling of water at these locations. Post-mining the flow pathway is still quite dispersed, with flow pathways throughout the swamp. However, changes in gradient, particularly across the top of the swamp at the edge of Area 2 LW8, result in a diversion of the flow pathway in the eastern section of the upland swamp around the exterior of the swamp. This results in a significant reduction in flow accumulation through this eastern section, and may result in a reduction if waterlogging in these areas.
CCUS10	Flow accumulation modelling pre-mining indicates a dispersed flow accumulation across this upland swamp. This swamp has a small catchment area. Vegetation sub-communities appear to correspond with area of benching down the slope, with these rockbars resulting in accumulation of water in these areas. Post-mining flow accumulation modelling indicates that there is not predicted to be a significant change in flow accumulation or pathways across the swamp.
CRUS1	Only the upper northern section of CRUS1 is located above Area 2 LW6. As a result there is little change in flow accumulation, either across the swamp or within thus upper section. No significant changes are expected to result from changes in flow accumulation.
CRUS2	CRUS2 is located outside of the predicted limits of subsidence. Pre- and post mining flow accumulation modelling indicates that there is not predicted to be any significant changes in flow accumulation or pathways within CRUS2.
CRUS3	CRUS3 is located outside of the predicted limits of subsidence. Pre- and post mining flow accumulation modelling indicates that there is not predicted to be any significant changes in flow accumulation or pathways within CRUS3.

Table 13: Discussion of changes in flow accumulation pre- versus post-mining for upland swamp of 'special significance' in Wonga West

Upland Swamp	Discussion of changes in flow accumulation
LCUS1	Although LCUS1 is not located above any of the longwalls, combined Bulli and Wongawilli subsidence predictions indicate that subsidence extends southeast of the longwall and may impact on the downstream reach of this swamp. LCUS1 is a mix of headwater and valley infill swamp. Pre-mining flow accumulation modelling indicates that there is a disperse flow across areas of headwater swamp, with flow accumulation increasing significant through the main channel of Lizard Creek, which supports Tea-tree Ticket (MU43). Post-mining flow accumulation modelling indicates that there will be a significant increase in flow accumulation in the downstream reach of LCUS1, particularly within the main

Upland Swamp	Discussion of changes in flow accumulation
	channel. This increase in flow accumulation is not predicted to result in any significant changes to LCUS1.
LCUS6	Although LCUS6 is not located above any of the longwalls, combined Bulli and Wongawilli subsidence predictions indicate that subsidence extends east of the longwall and may impact on this swamp. LCUS6 is a mix of headwater and valley infill swamp. Pre-mining flow accumulation modelling indicates that the headwater swamp section of LCUS6 supports only very small flow accumulation. Valley infill areas are located along the main channel of Lizard Creek and support more substantial flows accumulation. Post-mining, flow accumulation modelling indicates that there will be reduction if flow accumulation with headwater sections of this swamp, but that these changes will be so small as to be negligible. Valley infill sections will be subject to significant increases in flow accumulation, which may result in increases in species reliant on and resilient to increases in waterlogging.
LCUS8	LCUS8 is a mix of headwater and valley infill swamp, with two areas of headwater swamp located on either side of a valley infill swamp which spans the main channel of Lizard Creek. Pre-mining flow accumulation indicates that areas of headwater swamp are subject to a diversified flow accumulation, with no significant flow pathways. The area of valley infill swamp is subject to substantial flow accumulation from Lizard Creek. Post-mining areas of headwater swamp undergo very small changes in flow accumulation and these are not predicted to be significant. Observed changes to flow accumulation modelling for areas of valley infill swamp indicate an increase in flow accumulation in this area. Any changes in flow accumulation are not predicted to result in any significant changes to this upland swamp.
LCUS27	LCUS27 is located outside of the predicted limits of subsidence. Pre- and post mining flow accumulation modelling indicates that there is unlikely to be any significant changes in flow accumulation or pathways within LCUS27.
WCUS1	Although WCUS1 is not located above any of the longwalls, combined Bulli and Wongawilli subsidence predictions indicate that subsidence extends south of the longwall and may impact on this swamp. Comparison of pre- and post-mining flow accumulation indicates that, as this swamp is located parallel to predicted subsidence there will be negligible changes to flow accumulation pathways. Some minor and localised changes to flow pathways may occur, but these are not predicted to result in a significant effect on this swamp.
WCUS4	WCUS4 consist of a mix of headwater and valley infill swamp. The section of headwater swamp is located above Area 3 LW2, while valley infill areas are located outside of longwalls.

Upland Swamp	Discussion of changes in flow accumulation
	Pre-mining flow accumulation modelling indicates that areas of headwater swamp have diversified flows, but a main flow pathway occurs along the northern boundary of the headwater swamp. This main channel corresponds with areas of Tea-tree Thicket (MU43). The area of valley infill swamp is located along the main channel of Wallandoola Creek. Post-mining flow accumulation modelling indicates that areas of headwater swamp may undergo a small shift in flow pathway further to the north, with vegetation sub-communities along the southern boundary likely to experience low flow accumulation, including an area of Cyperoid Heath (MU44c). However, this area of Cyperoid Heath appears to correspond with a minor bench and this minor change in flow pathway is not predicted to result in any significant effect. For areas of valley infill swamp there is likely to be only minor changes in flow accumulation and no impacts are expected to occur.
WCUS7	WCUS7 is a valley infill swamp located along the main channel of Wallandoola Creek. Comparison of pre- and post-mining flow accumulation modelling indicates that there may be a minor change in flow pathway along Wallandoola Creek. However, any changes in flow accumulation are likely to be constrained by the main channel of Wallandoola Creek, and may be unlikely to occur. No significant effects on WCUS7 are predicted to occur.
WCUS11	Pre-mining flow accumulation modelling indicates that there are two main flow pathways through each arm of this upland swamp. The main flow pathway is through the south-eastern arm, largely due to Fire Road 8 re-directing flows around the north-western arm and into the south-eastern arm. Significant flow accumulation at the downstream extent of WCUS11 corresponds with an area of Tea-tree Thicket (MU43). Post-mining flow accumulation indicates that there will be little change in flow accumulation through WCUS11. No significant effects are predicted to occur.

Flow accumulation modelling for upland swamps meeting criteria for 'special significance' (OEH 2012) has been completed. This modelling predicts flow accumulation (catchment) and flow pathways through upland swamps.

Overall, areas of valley infill swamp in Wonga West are not predicted to undergo significant changes in flow accumulation, largely due to the fact that they are located along the main channels of Lizard and Wallandoola Creek, are not located above longwalls and are thus largely subject to minimal levels of subsidence.

Headwater swamps are likely to be more susceptible to changes in flow accumulation, as vegetation sub-communities reliant on permanent or frequent waterlogging are likely to occur in areas of increased flow accumulation (as in CCUS1 and CCUS4) and along rockbars created by benching of the sandstone.

Flow accumulation modelling indicated that upland swamps CCUS1, CCUS4 , CCUS5 and WCUS4 may undergo changes in flow accumulation that may result in changes in groundwater availability. This change in groundwater availability could result in changes in vegetation communities within these swamps.

4.2.5 Compressive and Tensile Strains

Compressive and tensile strains can be used to predict where fracturing of bedrock may occur, and thus where potential for dewatering and drying of upland swamps may occur.

There are a number of risk factors that may contribute to the fracturing of an upland swamp, particularly the type of swamp (headwater versus valley infill), location and orientation of an upland swamp and the vegetation sub-communities within a swamp.

Valley infill swamps are much more susceptible to impacts (DoP 2008). Valley infill swamps tend to be much more reliant on groundwater flows, and are usually located within lower sections of catchment where flow accumulation is much higher. They tend to support larger areas of vegetation sub-communities reliant on permanent or temporary waterlogging, and as such any loss in groundwater is likely to have a more significant effect on these swamps when compared to headwater swamps. Headwater swamps usually have much lower flow accumulation throughout the swamp, and any areas of wetter vegetation sub-communities are likely to occur in areas of increased flow accumulation, rockbars resulting from benching of sandstone terraces or seepage from perched ephemeral groundwater systems. Thus, unless fracturing results in significant changes in flow accumulation or loss of groundwater, or fracturing of rockbars impacts to headwater swamps are less likely to occur.

The location and orientation of a swamp in relation to longwall geometry is also likely to alter a swamps susceptibility to impact (EarthTech 2003). Swamps located parallel to a longwall and in areas of low tilts and strains are less likely to undergo changes in gradient due to tilts and / or fracturing resulting from strains. Swamps spanning multiple longwall panels undergo significant and multiple changes in gradient and strains, and are most susceptible to impact.

Finally, the vegetation sub-communities within a swamp also determine a swamps susceptibility to impact. Vegetation sub-communities reliant on permanent (Tea-tree Thicket MU43) or frequent (Cyperoid Heath MU44c) waterlogging are most susceptible to losses of groundwater flows (Keith *et al.* 2006). Other vegetation communities are less reliant on groundwater flows and are likely to be able to withstand some losses in groundwater, provided there is a sufficient surface flow and water build up during times of high rainfall to kill any trees that may grow.

Table 14: Assessment of risk factors for swamps of 'special significance' in Wonga East

Upland Swamp	Swamp type	Location and orientation	Vegetation sub-communitues	Max compressive strain (mm / m)	Max tensile strain (mm / m)
CCUS1	Headwater	Spanning Area 1 LW3 and adjacent pillar. Flow pathway oriented along longwall panel.	MU42, MU43, MU44b, MU 44c	-6.79	2.65
CCUS4	Headwater	Spanning Area 2 LW6. Flow pathway oriented perpendicular to longwall panel.	MU42, MU43, MU44c	-8.03	4.63
CCUS5	Headwater	Spanning Longwalls 7 and 8, straddling	MU42, MU43, MU44a	-8.03	4.74

Upland Swamp	Swamp type	Location and orientation	Vegetation sub-communitues	Max compressive strain (mm / m)	Max tensile strain (mm / m)
		pillar. Flow pathway oriented perpendicular to longwall panel.			
CCUS10	Headwater	Spanning Area 2 LW 9 and adjacent pillar. Flow pathway oriented perpendicular to longwall panel.	MU42, MU43, MU44c	-8.74	4.60
CRUS1	Headwater	Majority of swamp is located outside longwalls, with only small upper reaches located above Area 2 LW6. No substantial flow above longwall.	MU42, MU43	-7.20	4.34
CRUS2	Headwater	Not located above longwalls.	MU42, MU43, MU44c	0	0
CRUS3	Headwater	Not located above longwalls.	MU42, MU43, MU44a, MU44b, MU44c	0	0

Table 15: Assessment of risk factors for swamps of 'special significance' in Wonga West

Upland Swamp	Swamp type	Location and orientation	Vegetation sub-communitues	Max compressive strain (mm / m)	Max tensile strain (mm / m)
LCUS1	Headwater / valley infill	Not located above longwalls.	MU42, MU43, MU44b	0	0
LCUS6	Headwater /	Not located	MU42, MU43, MU44a, MU44b,	0	0

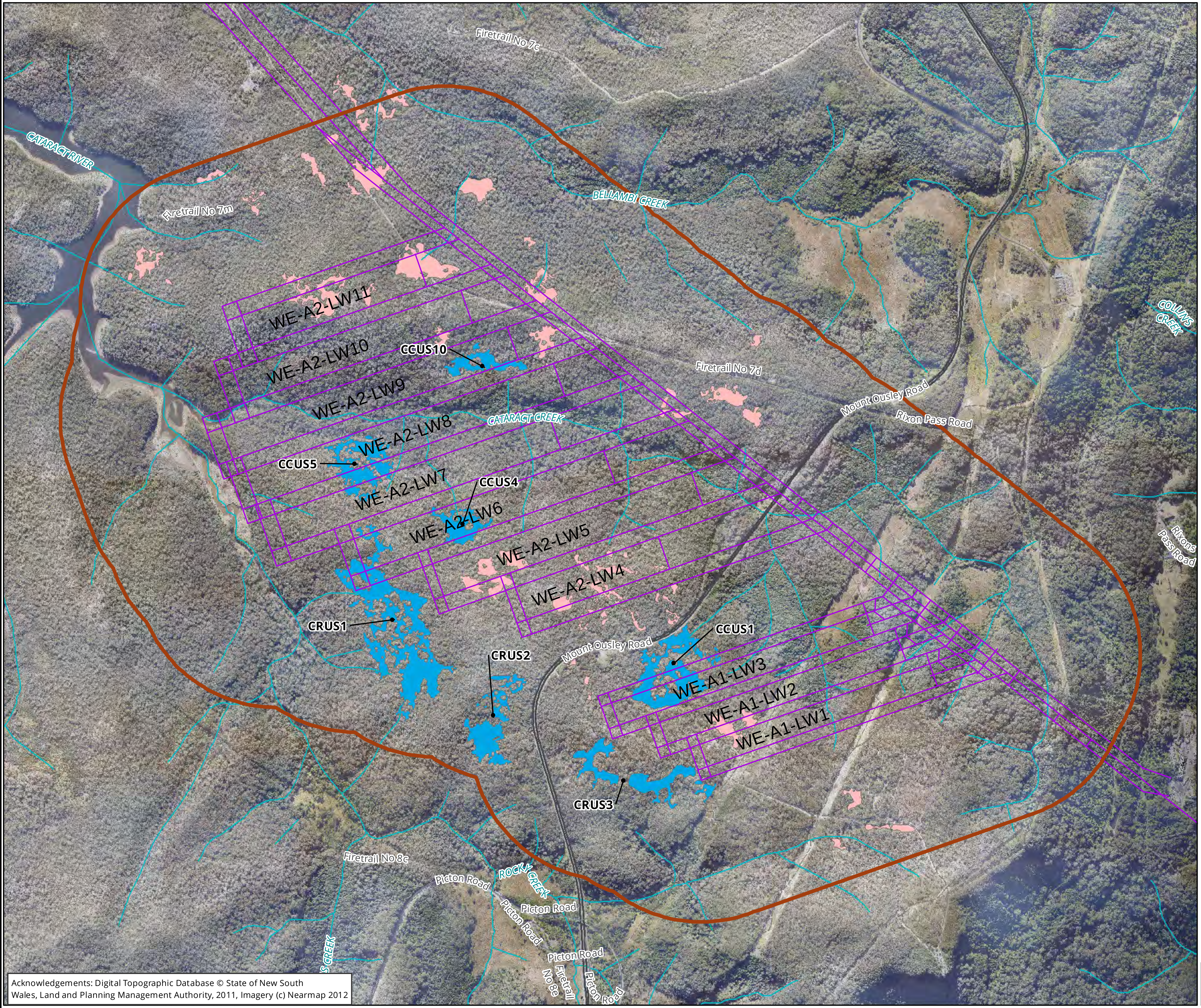
Upland Swamp	Swamp type	Location and orientation	Vegetation sub-communitues	Max compressive strain (mm / m)	Max tensile strain (mm / m)
	valley infill	above longwalls.	MU44c		
LCUS8	Headwater / valley infill	Upper extent of headwater swamp located above Area 3 LW1 (mostly above pillar). Flow pathway oriented perpendicular to longwall panel.	MU42, MU43, MU44a, MU44b	-2.64	2.75
LCUS27	Headwater	Not located above longwalls.	MU42, MU43, MU44b	0	0
WCUS1	Valley infill	Not located above longwalls.	MU42, MU43, MU44c	0	0
WCUS4	Headwater / valley infill	Headwater swamp located above Area 3 LW2, with flow pathway oriented perpendicular to longwall. Valley infill swamp not located above longwall.	MU43, MU44a, MU44b, MU44c	-6.97	5.03
WCUS7	Valley infill	Located above pillar for Longwalls 14 and 15. Flow pathway oriented perpendicular to longwalls.	MU42, MU43, MU44c	-0.01	5.45
WCUS11	Headwater	Located above western extent of	MU42, MU43, MU44	-3.81	5.35

Upland Swamp	Swamp type	Location and orientation	Vegetation sub-communitues	Max compressive strain (mm / m)	Max tensile strain (mm / m)
		Area 3 LW2. Flow pathway oriented parallel to longwall.			

Based on this assessment risk factors relating to compressive and tensile strains, and comparison of data above to strains observed at other locations, we can make the following conclusions:

- Upland swamps CRUS1, CRUS2, CRUS3, LCUS1, LCUS6, LCUS27, WCUS1, and valley infill section of WCUS4 do not show significant risk factors that would indicate susceptibility to impact.
- Upland swamps CCUS1 may be subject to strains that would result in fracturing of the bedrock below this swamp. Areas of Cyperoid Heath (MU44c) located above Area 1 LW3, are particularly susceptible to any loss of groundwater in this area.
- Upland swamp CCUS4 may be subject to strains that would result in fracturing of the bedrock below this swamp. However, the location of the base of this swamp in areas subject to lower levels of strains indicates that impacts may be reduced.
- Upland swamp CCUS5 may be subject to strains that would result in fracturing of the bedrock below this swamp. This upland swamp spans two longwalls and a degree of compressive and tensile strains. Further, vegetation sub-communities within this swamp are reliant on benching in the sandstone, creating rockbars that are likely to hold back sections of Cyperoid Heath (MU44c) and Tea-tree Thicket (MU43).
- Upland swamp CCUS10 may be subject to strains that would result in fracturing of the bedrock below this swamp. The swamp spans a large variation in strains and is reliant on benching of sandstone to maintain areas of Cyperoid Heath (MU44c) and Tea-tree Thicket (MU43).
- There is some potential for fracturing of the bedrock below the headwater section of LCUS8; however, it is likely to be limited in extent and degree given the location of this swamp largely above the pillar for Area 3 LW1. Further, this section of the swamp supports sub-communities that are less reliant on presence of permanent and frequent groundwater, and provided surface flows are maintained to a sufficient level to inhibit growth of trees impacts are unlikely to be significant.
- Upland swamp WCUS4 may be subject to strains that would result in fracturing of the bedrock below this swamp. The lower sections of the headwater swamp are subject to greatest strains, and these areas are particularly susceptible to impact as they support areas of Tea-tree Thicket (MU43) and Cyperoid Heath (MU44c).
- Upland swamp WCUS7 is likely to be subject to tensile strains sufficient to result in fracturing of bedrock below this swamp. This could result in fracturing of bedrock along Wallandoola Creek. There is substantial iron staining in this section of Wallandoola Creek. The cumulative impacts of mining cannot be adequately assessed.
- Upland swamp WCUS11 may be subject to strains that would result in fracturing of the bedrock below this swamp. However, this swamp supports only small areas of Tea-tree Thicket (MU43) at the base of the swamp that will be subject to small tensile strains. Areas subject to maximum strains support sub-communities that are less reliant on presence of permanent and frequent groundwater, and provided

surface flows are maintained to a sufficient level to ensure trees are killed impacts are not predicted to be significant.



Acknowledgements: Digital Topographic Database © State of New South Wales, Land and Planning Management Authority, 2011, Imagery (c) Nearmap 2012

Legend

Special Significance

- Yes
- No

Survey Area

- Wonga East Study Area
- Longwalls

Figure 8: Upland Swamps of 'Special Significance' in Wonga East

0 0.15 0.3 0.45 0.6 0.75

Kilometers

Scale: 1:15,000 @ A3

Coordinate System: GDA 1994 MGA Zone 56

N

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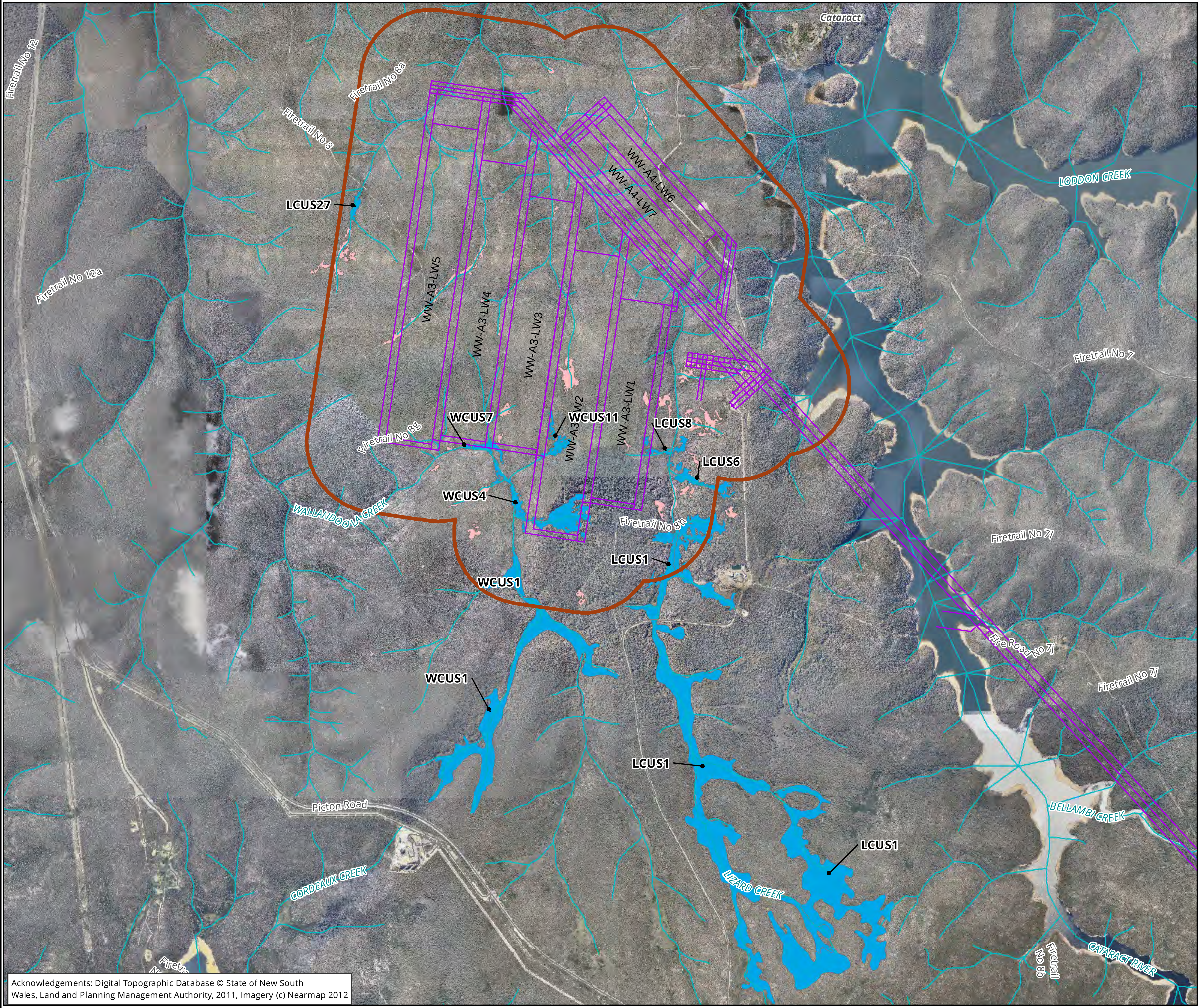
Matter: 15094,
Date: 05 October 2012,
Checked by: NMG, Drawn by: apritchard
Location:P:\15000s\15094\Mapping\Report Figures\15094 F8 Wonga East Significance



Acknowledgements: Digital Topographic Database © State of New South Wales, Land and Planning Management Authority, 2011, Imagery (c) Nearmap 2012

Legend

Special Significance

- Yes
- No

Survey Area

- Wonga West Study Area
- Longwalls

Figure 9: Upland Swamps of 'Special Significance' in Wonga West

0 0.3 0.6 0.9 1.2 1.5

Kilometers

Scale: 1:30,000 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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5. Conclusions and Recommendations

An analysis of potential impacts to upland swamps based on data located above is provided below, along with conclusion on the risk of negative environmental consequences.

OEH (2012), summarising PAC (2009, 2010) and DoP (2008), states that negative environmental consequences for upland swamps considered to be of 'special significance' are undesirable. If negative environmental consequences to upland swamps of 'special significance' are predicted to occur mine plans should be adjusted so that negative environmental consequences are unlikely.

Table 16 provides recommendations for all upland swamps within the study area. Recommendations are based on reduction of impacts for all upland swamps to ensure objectives outlined in OEH (2012) can be achieved and negative environmental consequences for upland swamps of 'special significance'

Table 16: Conclusion of Risk Assessment and Recommendations

Upland Swamp	Conclusion	Recommendation
CCUS1	The initial risk assessment indicated that subsidence criteria were sufficient to indicate a risk of negative environmental consequences according to OEH (2012). A comparative analysis using limited available data indicated that vertical movement in CCUS1 would be unlikely to trigger negative environmental consequences. Flow accumulation modelling indicates that a reduction in flow accumulation, particularly to an area of Cyperoid Heath (MU44c) in the southeast, could occur. There is potential for this to result in drying of this area and change in vegetation composition. Risk factors that indicate potential for dewatering of CCUS1 are present. Strains are greatest beneath an area of Cyperoid Heath (MU44c) and fracturing of bedrock beneath this swamp is considered likely to occur. CCUS1 is considered to be at *significant* risk of negative environmental consequences.	Adjust the layout in respect of Area 1 LW3 to avoid and minimise impacts to CCUS1.
CCUS4	The initial risk assessment indicated that subsidence criteria were sufficient to indicate a risk of negative environmental consequences according to OEH (2012). A comparative analysis using limited available data indicated that vertical movement in CCUS4 would be unlikely to trigger negative environmental consequences. Groundwater monitoring data indicates presence of shallow groundwater levels, with recharge following rainfall to near surface. No drying observed.	Potential for impacts is considered low. Detailed monitoring of groundwater and vegetation in CCUS4 should be undertaken, particularly in areas subject to greatest change. Detailed triggers relating to changes in gradient, groundwater monitoring and / or observational monitoring should be

Upland Swamp	Conclusion	Recommendation
	Flow accumulation modelling indicates that there is a small potential for changes (both decreases and increases in flow accumulation) and that this may result in small scale changes to the distribution of vegetation sub-communities. Risk factors that indicate potential for dewatering of CCUS4 are present. However, the base of this swamp, where water dependent vegetation communities occur and rockbar is present, will be subject to lower levels of strains and risk of fracturing. CCUS1 is considered to be at *low* risk of negative environmental consequences.	developed, and if triggered measures to minimise impacts should be considered.
CCUS5	The initial risk assessment indicated that subsidence criteria were sufficient to indicate a risk of negative environmental consequences according to OEH (2012). A comparative analysis using limited available data indicated that vertical movement in CCUS5 would be unlikely to trigger negative environmental consequences. Groundwater monitoring data indicates presence of shallow groundwater levels, with recharge following rainfall to near surface. No drying observed. Flow accumulation modelling predicts that the western and middle sections of the swamp will undergo minimal changes in flow accumulation. The eastern section of this swamp will undergo a significant reduction in flow accumulation and changes in vegetation composition may result due to drying of these areas. Strains are sufficient to induce fracturing of the bedrock beneath CCUS5. The presence of rockbars holding back areas of Cyperoid Heath (MU44c) and Tea-tree Thicket (MU43) indicate a greater risk of potential for harm to this swamp if fracturing occurs. CCUS5 is considered to be at *significant* risk of negative environmental consequences.	Adjust the layout in respect of Area 2 LW7 and LW8 to avoid and minimise impacts to CCUS5. If this is not feasible, detailed monitoring of CCUS5 should be undertaken during the extraction of Longwalls 7 and 8. Detailed triggers relating to changes in gradient, groundwater monitoring and / or observational monitoring should be developed, and if triggered measures to minimise impacts should be considered.
CCUS10	The initial risk assessment indicated that subsidence criteria were sufficient to indicate a risk of negative environmental consequences according to OEH (2012). A comparative analysis using limited available data indicated that vertical movement in CCUS10 would be unlikely to trigger negative environmental consequences. Flow accumulation modelling indicates that there is unlikely	Potential for impacts is considered to be low, minor changes to layout will reduce the potential for impacts to CCUS10. If this is not feasible, detailed monitoring of CCUS10 should be undertaken during the extraction of

Upland Swamp	Conclusion	Recommendation
	to be a significant change post-mining. Strains in CCUS10 are sufficient to result in fracturing of bedrock beneath this swamp. CCUS10 is considered to be at *low* risk of negative environmental consequences.	Area 2 LW9. Detailed triggers relating to changes in gradient, groundwater monitoring and / or observational monitoring should be developed, and if triggered measures to minimise impacts should be considered.
CRUS1	The initial risk assessment indicated that subsidence criteria were sufficient to indicate a risk of negative environmental consequences according to OEH (2012). A comparative analysis using limited available data indicated that vertical movement in CRUS1 would be unlikely to trigger negative environmental consequences. Groundwater data indicates presence of shallow groundwater, recharging after rainfall but drying rapidly during periods of low rainfall. Flow accumulation modelling indicates that there is unlikely to be a significant change post-mining. Analysis of swamp type, location and orientation of the swamp, vegetation sub-communities ad compressive tilts and strains indicates that this upland swamp does not contain risk factors increasing the risk of fracturing and dewatering. CRUS1 is considered to be at *low* risk of negative environmental consequences.	Potential for impacts is considered low. Minor changes to layout will reduce predicted impact to negligible.
CRUS2	The initial risk assessment indicated that CRUS2 was not at risk of negative environmental consequences. A comparative analysis using limited available data indicated that vertical movement in CRUS2 would be unlikely to trigger negative environmental consequences. Flow accumulation modelling indicates that there is unlikely to be a significant change post-mining. Analysis of swamp type, location and orientation of the swamp, vegetation sub-communities ad compressive tilts and strains indicates that this upland swamp does not contain risk factors increasing the risk of fracturing and dewatering. CRUS2 is considered to be at *negligible* risk of environmental consequences.	Proceed to mining and monitoring.

Upland Swamp	Conclusion	Recommendation
CRUS3	The initial risk assessment indicated that CRUS3 was not at risk of negative environmental consequences. A comparative analysis using limited available data indicated that vertical movement in CRUS3 would be unlikely to trigger negative environmental consequences. Flow accumulation modelling indicates that there is unlikely to be a significant change post-mining. Analysis of swamp type, location and orientation of the swamp, vegetation sub-communities ad compressive tilts and strains indicates that this upland swamp does not contain risk factors increasing the risk of fracturing and dewatering. CRUS3 is considered to be a *negligible* risk of negative environmental consequences.	Proceed to mining and monitoring.
LCUS1	The initial risk assessment indicated that LCUS1 was not at risk of negative environmental consequences. A comparative analysis using limited available data indicated that vertical movement in LCUS1 would be unlikely to trigger negative environmental consequences. Groundwater monitoring data indicates presence of shallow groundwater, that will dry out following periods of low rainfall. Flow accumulation modelling predicted a significant increase in flow accumulation in the downstream section of the valley infill swamp, but that due to high levels of flow accumulation currently this is unlikely to result in any changes to this swamp. Analysis of swamp type, location and orientation of the swamp, vegetation sub-communities ad compressive tilts and strains indicates that this upland swamp does not contain risk factors increasing the risk of fracturing and dewatering. LCUS1 is considered to be a *negligible* risk of negative environmental consequences.	Proceed to mining and monitoring.
LCUS6	The initial risk assessment indicated that LCUS6 was not at risk of negative environmental consequences. A comparative analysis using limited available data indicated that vertical movement in LCUS6 would be unlikely to trigger negative environmental consequences.	Proceed to mining and monitoring.

Upland Swamp	Conclusion	Recommendation
	Flow accumulation modelling predicted a significant increase in flow accumulation in the downstream section of the valley infill swamp, but that due to high levels of flow accumulation currently this is unlikely to result in any changes to this swamp. Analysis of swamp type, location and orientation of the swamp, vegetation sub-communities ad compressive tilts and strains indicates that this upland swamp does not contain risk factors increasing the risk of fracturing and dewatering. LCUS6 is considered to be a *negligible* risk of negative environmental consequences.	
LCUS8	The initial risk assessment indicated that subsidence criteria were sufficient to indicate a risk of negative environmental consequences according to OEH (2012). A comparative analysis using limited available data indicated that LCUS8 will be subject to vertical movement (SMax) similar to that seen in previously impacted upland swamps. Flow accumulation modelling predicted a significant increase in flow accumulation in the downstream section of the valley infill swamp, but that due to high levels of flow accumulation currently this is unlikely to result in any changes to this swamp. Analysis of strains indicated that the headwater sections of this swamp may be subject to fracturing. However the location of the swamp above the pillar for Area 3 LW1 and the drier sub-communities within this swamp indicate that impacts are unlikely to be significant. LCUS8 is considered to be at a *low* risk of negative environmental consequences.	Potential for impacts is considered low. Detailed monitoring of groundwater and vegetation in LCUS8 should be undertaken, particularly in areas subject to greatest change. Detailed triggers relating to changes in gradient, groundwater monitoring and / or observational monitoring should be developed, and if triggered measures to minimise impacts should be considered.
LCUS27	The initial risk assessment indicated that LCUS8 was not at risk of negative environmental consequences. A comparative analysis using limited available data indicated that vertical movement in LCUS27 would be unlikely to trigger negative environmental consequences. Flow accumulation modelling indicates that there is unlikely to be a significant change post-mining. Analysis of swamp type, location and orientation of the swamp, vegetation sub-communities ad compressive tilts	Proceed to mining and monitoring.

Upland Swamp	Conclusion	Recommendation
	and strains indicates that this upland swamp does not contain risk factors increasing the risk of fracturing and dewatering. LCUS27 is considered to be at a *negligible* risk of negative environmental consequences.	
WCUS1	The initial risk assessment indicated that WCUS1 was not at risk of negative environmental consequences. A comparative analysis using limited available data indicated that vertical movement in WCUS1 would be unlikely to trigger negative environmental consequences. Groundwater monitoring indicates this swamp is in direct contact with stream seepage along Wallandoola Creek. Flow accumulation modelling indicates that there is unlikely to be a significant change post-mining. Analysis of swamp type, location and orientation of the swamp, vegetation sub-communities ad compressive tilts and strains indicates that this upland swamp does not contain risk factors increasing the risk of fracturing and dewatering. WCUS1 is considered to be at a *negligible* risk of negative environmental consequences.	Proceed to mining and monitoring.
WCUS4	The initial risk assessment indicated that subsidence criteria were sufficient to indicate a risk of negative environmental consequences according to OEH (2012). A comparative analysis using limited available data indicated that WCUS4 will be subject to vertical movement (SMax) similar to that seen in previously impacted upland swamps. Groundwater monitoring data indicates presence of shallow groundwater, that will dry out following periods of low rainfall. Flow accumulation modelling indicated that mining may result in a change in flow accumulation pathways, resulting in reduction in flow accumulation along the southern boundary of this swamp. This may impact on an area of Cyperoid Heath (MU44c). However, the localised occurrence of this vegetation sub-community is the result of a rockbar at this location and any is unlikely to result in a significant effect.	Adjust the layout in respect of Area 3 LW2 to avoid and minimise impacts on headwaters of WCUS4.

Upland Swamp	Conclusion	Recommendation
	Analysis of swamp type, location and orientation of the swamp, vegetation sub-communities ad compressive tilts and strains indicates that the valley infill section of this upland swamp does not contain risk factors increasing the risk of fracturing and dewatering. However headwater sections of this swamp are likely to be impacted by fracturing of bedrock and areas of Tea-tree Thicket (MU43) and Cyperoid Heath (MU44c) are likely to be susceptible to impact and potential for change. WCUS4 valley infill swamp is considered to be at *negligible* risk of environmental consequences. WCUS headwater swamp is considered to be at *moderate* risk of negative environmental consequences.	
WCUS7	The initial risk assessment indicated that subsidence criteria were sufficient to indicate a risk of negative environmental consequences according to OEH (2012). A comparative analysis using limited available data indicated that WCUS7 will be subject to vertical movement (SMax) similar to that seen in previously impacted upland swamps. Flow accumulation modelling indicates that there is unlikely to be a significant change post-mining. There is potential for fracturing of bedrock beneath this upland swamp. There is iron staining within this section of Wallandoola Creek and the cumulative impacts of subsidence cannot be adequately ascertained. Taking a precautionary approach there WCUS7 is considered to be at a *moderate* risk of negative environmental consequences.	Adjust the layout in respect of Area 3 Longwalls 3 and 4 to reduce predicted strains to WCUS7 and Wallandoola Creek.
WCUS11	The initial risk assessment indicated that subsidence criteria were sufficient to indicate a risk of negative environmental consequences according to OEH (2012). A comparative analysis using limited available data indicated that WCUS11 will be subject to vertical movement (SMax) similar to that seen in previously impacted upland swamps. Groundwater monitoring data indicates presence of shallow groundwater, that will dry out following periods of low rainfall. Flow accumulation modelling indicates that there is unlikely	Potential for impacts is considered low. Detailed monitoring of groundwater and vegetation in WCUS11 should be undertaken, particularly in areas subject to greatest change. Detailed triggers relating to changes in gradient, groundwater monitoring and / or observational monitoring should be developed, and if triggered measures to minimise impacts

Upland Swamp	Conclusion	Recommendation
	to be a significant change post-mining. Strains are longwall orientation indicate potential for fracturing of bedrock beneath this swamp. However areas likely to be subject to greatest impact do not support vegetation sub-communities reliant on permanent or frequent waterlogging. WCUS11 is considered to be at *low* risk of negative environmental consequences.	should be considered.

The final risk of impact for upland swamps of 'special significance' within the study area is shown in Figure 10 and Figure 11.

Based on an analysis of potential impacts to upland swamps within the study area using multiple criteria we conclude:

- There is a negligible likelihood of negative environmental consequences for seven (7) upland swamps within the study area, including CRUS2, CRUS3, LCUS1, LCUS6, LCUS27, WCUS1 and WCUS4-vfs. NRE can proceed to mining and monitoring in these areas.
- There is a low likelihood of negative environmental consequences for five (5) upland swamps within the study area, including CCUS4, CCUS10, CRUS1, LCUS8 and WCUS11. NRE may wish to consider undertaking monitoring in conjunction with minor changes to longwall layout to reduce impacts to these swamps.
- There is a moderate likelihood of negative environmental consequences for two (2) upland swamps within the study area, including WCUS4-hws and WCUS7. NRE should consider implementation of suitable impact avoidance, minimisation and mitigation measures to reduce impacts to these swamps.
- There is a significant likelihood of negative environmental consequences for two (2) upland swamps within the study area, including CCUS1 and CCUS5. NRE to consider changes to the mine layout and / or suitable avoidance and mitigation measures to reduce the impacts to these swamps.

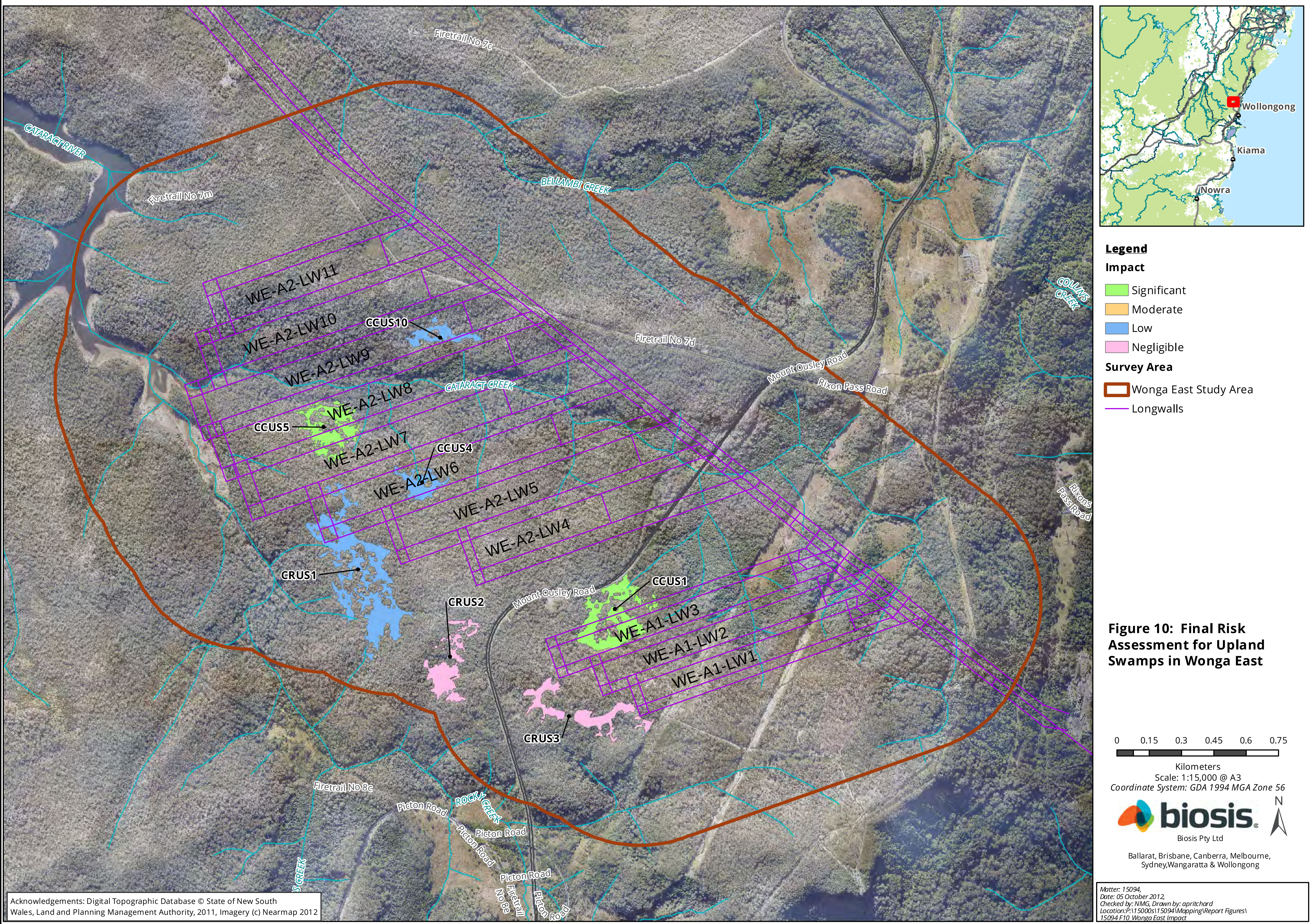
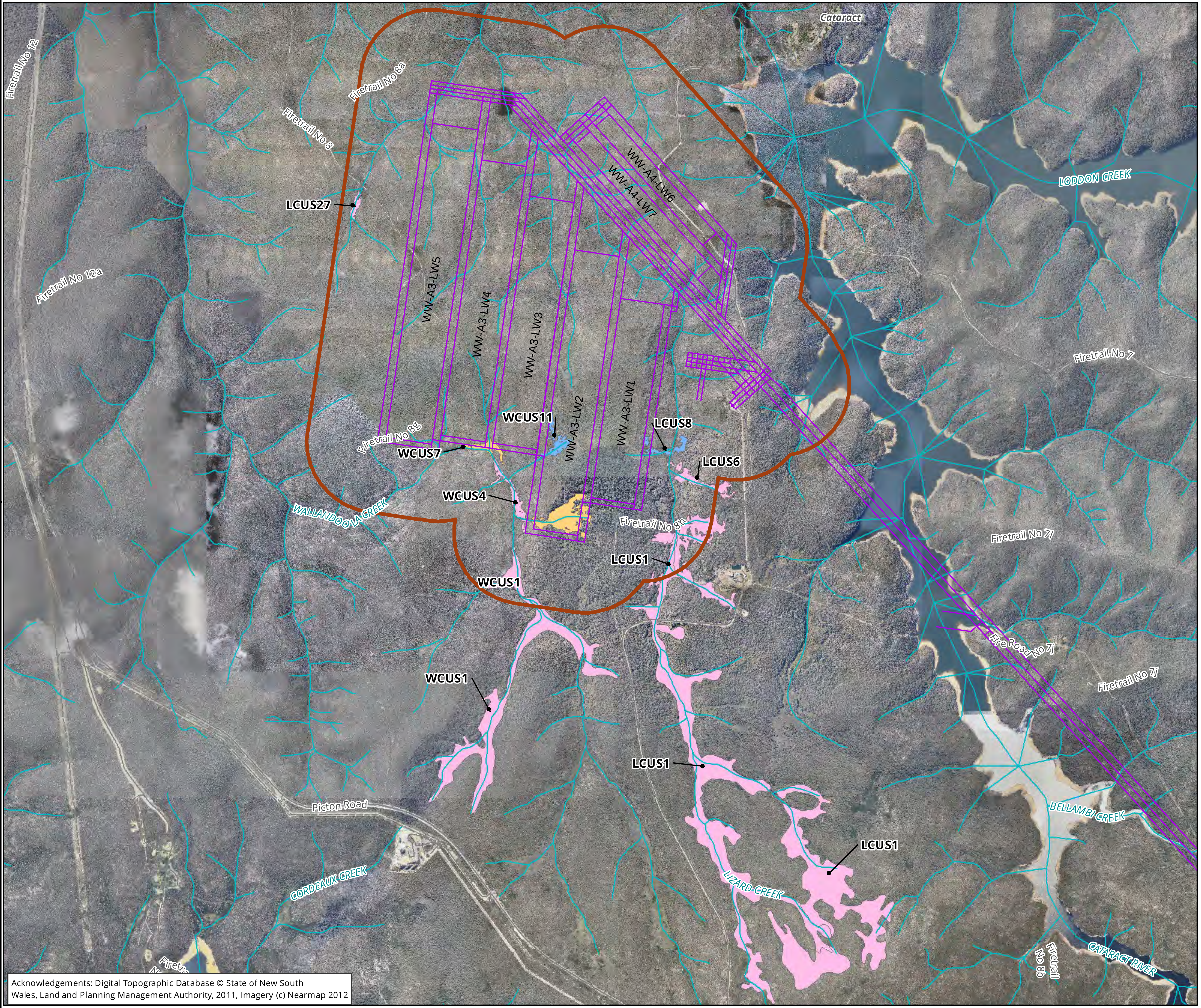


Figure 10: Final Risk Assessment for Upland Swamps in Wonga East



Legend

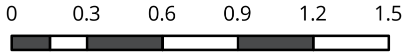
Impact

- Significant
- Moderate
- Low
- Negligible

Survey Area

- Wonga West Study Area
- Longwalls

Figure 11: Final Risk Assessment for Upland Swamps in Wonga West



Scale: 1:30,000 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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