Russell Vale Colliery Longwall 6 Referral (EPBC2014/7259):
Coastal Upland Swamp Impact Assessment Report

FINAL REPORT
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- Ashleigh Pritchard for mapping
- Monica Campbell for quality assurance

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1. Introduction

1.1 Project background

Wollongong Coal Pty Ltd (WCL) have submitted a referral (EPBC 2014/7259) under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) for the extraction of a 400 metre section of Longwall 6 in an area located west of Wollongong, NSW.

Following submission of the referral on 7 July 2014, the Commonwealth Department of the Environment has listed the Coastal Upland Swamps in the Sydney Basin Bioregion (Coastal Upland Swamps) as an Endangered Ecological Community (EEC) under the EPBC Act. This decision means the Minister (or his delegate) must now consider Coastal Upland Swamps in determining whether this referral requires assessment under the EPBC Act. The Department of the Environment have now requested additional information on Coastal Upland Swamps in the project area.

Biosis (2014a) has previously prepared an impact assessment for Coastal Upland Swamps as listed under the NSW *Threatened Species Conservation Act 1995* (TSC Act). This prior assessment follows the methodology outlined in *Upland swamp environmental assessment guidelines. Guidance for the underground mining industry operating in the southern coalfield (Draft)* (OEH 2012) to assess potential impacts to Coastal Upland Swamps. This includes six criteria to identify upland swamps at risk of negative environmental consequences that require further investigation. Further analysis, looking at the groundwater and surface water hydrology and subsidence are used to determine risk of impact.

The listing of this EEC under the EPBC Act mirrors the listing under the TSC Act (DoE 2014), including the use of six criteria to determine upland swamps at risk of negative environmental consequences. Therefore, this report relies on this prior impact assessment (Biosis 2014a).

1.2 Definition of the study area

The study area is located approximately 7.5 kilometres (km) north-west of Wollongong NSW, within the Local Government Areas (LGAs) of Wollongong and Wollondilly. Coal handling facilities are situated at the Russell Vale Site, located at the corner of the Princes Highway and Bellambi Lane, Russell Vale, approximately 7.2 km north of Wollongong, NSW.

The study area is located beneath the Woronora plateau and the Metropolitan Special Area, administered by the Sydney Catchment Authority (SCA) for Sydney’s drinking water supply. The Metropolitan Special Area is managed in accordance with the *Special Areas Strategic Plan of Management 2007* (SCA and DEC, 2007), with a vision “to protect water quality and provide high quality raw water in reservoirs, by protecting ecological integrity and natural and cultural values of the area”.

Along with other special areas and National Parks to the northwest and south, the study area forms part of the large band of native vegetation surrounding the Sydney Metropolitan Area, providing a largely connected corridor of vegetation that supports a diverse range of vegetation communities and associated flora and fauna species.

No direct impacts (i.e. disturbance) to ecological features within the study area are expected to occur. Indirect impacts resulting from subsidence will be restricted to the area within the 20 millimetre (mm) Subsidence Impact Boundary (see Biosis 2014b).
For the purpose of environmental impact assessment, a comprehensive area extending 600 metres (m) from the edge of secondary extraction (longwalls) was investigated. This area is referred to hereafter as the study area (see EPBC ecology report). The study area covers an area of 184 ha.

1.3 Objectives

The objectives of this report, as per the request from the Department of the Environment, are to:

- Provide a description of the Coastal Upland Swamps in the proposal location, the surrounding areas and the region that may be affected by the proposed action.
- Provide a description and the likelihood and consequence of any potential direct, indirect and cumulative impacts to Coastal Upland Swamps as a result of the proposed action.
- Provide a description of the feasible mitigation measures, changes to the proposed action or procedures proposed, which are intended to minimise impacts to Coastal Upland Swamps as a result of the proposed action.

This report includes an assessment of impacts to upland swamps in the study area, undertaken in several steps:

- An assessment of historic impacts to upland swamps in the study area from past mining (Section 3)
- A summary of available data on groundwater and surface water for upland swamps within the study area (Section 4.2).
- An analysis of flow accumulation based on changes in water flow due to subsidence levels (Section 4.3).
- An analysis of subsidence data, particularly tensile and compressive strains, to assess where fracturing of bedrock may occur, and potential resultant impacts to upland swamp vegetation communities (Section 4.4).
- A final risk assessment incorporating all of these factors (Section 4.5).
- An assessment of the significance of potential impacts based on the significant impact criteria for EECs (Section 4.5.2).

Following this, measures to avoid, minimise and mitigate impacts to upland swamps within the study area from the proposed action are discussed in Section 5.
2. Description of Coastal Upland Swamps

2.1 Regional distribution of Coastal Upland Swamps

Conservation advice for Coastal Upland Swamps (DoE 2014) highlights two main occurrences of this EEC, with the study area located within the southern distribution of this EEC on the Woronora plateau. For the purpose of this report, this is considered the regional distribution of this EEC.

Mapping of native vegetation across the Woronora plateau was undertaken by the NSW National Parks and Wildlife Service (NPWS 2003). The distribution of Coastal Upland Swamps on the Woronora plateau is shown in Figure 1.

A total of 4,739 hectares (ha) of upland swamp vegetation is mapped across the Woronora plateau by NPWS (2003).

2.2 Distribution of Coastal Upland Swamps in the Study Area

Mapping and characterisation of upland swamps in the study area was undertaken by Biosis (2012b). This assessment identified seven upland headwater swamps, with a total area of 21 ha and an average size of 2.96 ha (Figure 2). No valley fill swamps are present.

All upland swamps in the study area support Banksia Thicket (MU42). Four upland swamps support Tea-tree Thicket (MU43). Three upland swamps support a complete range of upland swamp vegetation sub-communities (MU42 Banksia Thicket, MU43 Tea-tree Thicket, MU44 Sedgeland–Heath Complex).

Mapping of upland swamps by Biosis (2012b) highlighted the complexity and variability of the soils and associated vegetation communities, with some swamps having a fully developed, saturated, humic sandy clay matrix up to 1.8 m deep, through to essentially dry, shallow sandy clay locations with a high degree of shallow or subcropping sandstone and a thin weathered, colluvial, sandy clay soil profile.

Upland swamps within the study area are markedly different to other upland swamps on the Woronora plateau in that they are predominantly drier, generally smaller with shallower soils, have less humic material, have more interspersed sandstone outcrops within their outlines and are less spatially continuous than a “typical” humic, saturated swamp.

Swamps in the study area have relatively small upstream catchments, with their saturation relying on rainfall recharge directly into the sandy sediments, seepage out of upslope Hawkesbury Sandstone and their organic (humic) content. The storage and water transmission characteristics of the surrounding and underlying Hawkesbury Sandstone is critical in sustaining these environments. Whilst in other areas of the Woronora plateau upland swamps occur along the riparian zone of the major creeks or in headwater valleys, upland swamps in the study area occur in headwater tributary valleys that are characteristically derived from colluvial sand erosion from Hawkesbury Sandstone dominated ridgelines only. The swamps in the study area are only located over Hawkesbury Sandstone which provides a low permeability base on which the swamp sediments and organic matter accumulate. Regional groundwater flow within the Hawkesbury Sandstone is hydraulically beneath, and separated by approximately 15 m from the surficial swamps.

The headwater swamps are predominantly located within gently sloping, shallow trough-shaped gullies although can partially extend onto steep slopes, benches or valley sides, where the plateau is
not dissected by creeks. The central axes of some swamps can become saturated after substantial recharge events, though the margins can comparatively dry out after extended dry periods.

The sand and humic material increases the swamp's water holding capacity and subsequently discharges rainfall infiltration, groundwater seeps and low-flow runoff into the local streams. Rainfall saturates the swamp after storms and with a slow, delayed discharge due to the low slopes when the recharge exceeds evaporation. Sediments below and laterally lensing into the humic material are variable in nature and can be composed of fine to medium grained sands that can contain clayey bands and comprise a grey to mottled red-orange colour due to in-situ weathering.
Figure 1: Regional distribution of Coastal Upland Swamps on the Woronora plateau

Acknowledgement: Topo (c) NSW Land and Property Information (2011); Overview (c) State of NSW (c. 2003), The Native Vegetation of the Woronora, Sydney and Western Sydney Metropolitan Catchments (NPWS, 2003)
Figure 2: Distribution of Coastal Upland Swamps in the study area

Coordinate System: GDA 1994 MGA Zone 56

Acknowledgements: Topo (c) NSW Land and Planning Information (2011); Overview (c) State of NSW (c. 2003)
3. Assessment of the Historic Impact to Upland Swamps in the Study Area

Extraction of the Bulli and Balgownie seams has occurred within the study area, with the Bulli Seam extracted via hand workings and pillar extraction between 1890 and 1960, and the Balgownie Seam extracted using continuous miner pillar extraction in 1969 and the retreat longwall mining method from 1970 to 1982.

The location of upland swamps in the study area in relation to previous mining is shown in Figure 3 (Bulli seam) and Figure 4 (Balgownie seam). Table 1 (Bulli seam), Table 2 (Balgownie seam) and Table 3 (Bulli and Balgownie seam cumulative) provide modelled subsidence data for upland swamps within the study area and assess these values against criteria identified by DoP (2010), OEH (2012) and DoE (2014) for upland swamps that may be at risk of negative environmental consequences and, thus, require further investigation.

Table 1: Incremental subsidence data from extraction of the Bulli seam for upland swamps within the study area (values in bold exceed criteria in DoP 2010, OEH 2012 and DoE 2014)

<table>
<thead>
<tr>
<th>Swamp</th>
<th>Subsidence (m)</th>
<th>Overburden Depth (m)</th>
<th>Void Width</th>
<th>Ratio of Overburden to Panel Width</th>
<th>Max Tensile Strain (mm/m)</th>
<th>Max Compressive Strain (mm/m)</th>
<th>Max Tilt (mm/m)</th>
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</thead>
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<td>5.4</td>
<td>9</td>
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<td>CRUS1</td>
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<td>300</td>
<td>310</td>
<td>0.97</td>
<td>2.5</td>
<td>5</td>
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</tr>
</tbody>
</table>

Table 2: Incremental subsidence data from extraction of the Balgownie seams for upland swamps within the study area (values in bold exceed subsidence criteria in OEH 2012)

<table>
<thead>
<tr>
<th>Swamp</th>
<th>Subsidence Used (m)</th>
<th>Overburden Depth (m)</th>
<th>Longwall Panel Width</th>
<th>Ratio of Overburden to Panel Width</th>
<th>Max Tensile Strain (mm/m)</th>
<th>Max Compressive Strain (mm/m)</th>
<th>Max Tilt (mm/m)</th>
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<td>170</td>
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<tr>
<td>CCUS6</td>
<td>1</td>
<td>295</td>
<td>170</td>
<td>1.74</td>
<td>5.1</td>
<td>10.2</td>
<td>17</td>
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</tbody>
</table>
Table 3: Subsidence data from extraction of the Bulli and Balgownie seams for upland swamps within the study area (values in bold exceed subsidence criteria in OEH 2012)

<table>
<thead>
<tr>
<th>Swamp</th>
<th>Relevant Workings</th>
<th>Subsidence Used (m)</th>
<th>Overburden Depth (m)</th>
<th>Max Tensile Strain (mm/m)</th>
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<th>Max Tilt (mm/m)</th>
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<td>CCUS3</td>
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<td>11.0</td>
<td>18</td>
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<tr>
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<td>Bulli 1st wkgs / Bg LW</td>
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<td>290</td>
<td>4.7</td>
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<td>16</td>
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<td>CCUS5</td>
<td>Bulli PE, 1st wkgs / Bg 1st wkgs</td>
<td>0.6</td>
<td>272</td>
<td>3.3</td>
<td>6.6</td>
<td>11</td>
</tr>
<tr>
<td>CCUS6</td>
<td>Bulli PE / Bg LW</td>
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<td>285</td>
<td>10.5</td>
<td>21.1</td>
<td>35</td>
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<td>CCUS10</td>
<td>Bulli PE, 1st wkgs / Bg LW</td>
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<td>280</td>
<td>3.2</td>
<td>6.4</td>
<td>11</td>
</tr>
<tr>
<td>CRUS1</td>
<td>Bulli PE</td>
<td>0.5</td>
<td>300</td>
<td>2.5</td>
<td>5.0</td>
<td>8</td>
</tr>
</tbody>
</table>

NOTE: RV = Russell Vale Colliery, BG = Balgownie, PE = Pillar Extraction, LW = Longwall

Subsidence data for upland swamps in the study area from extraction of the Bulli and Balgownie seams indicates that all upland swamps in the study area have been subject to subsidence criteria sufficient to have placed these upland swamps at risk of negative environmental consequences, according to criteria outlined in DoP (2010), OEH (2012) and DoE (2014).

This assessment of past mining in the study area indicates that natural features in the study area have been subject to subsidence resulting from extraction of the Bulli and Balgownie Seams sufficient to have placed the majority of upland swamps in the study area at risk of negative environmental consequences. This data provides a baseline against which assessments of potential impacts resulting from extraction of the Wongawilli Seam must be assessed.
Figure 3: Location of upland swamps in the study area, showing mining of the Bulli seam.
Figure 4: Location of upland swamps in the study area, showing mining of the Balgownie seam.
4. Upland Swamp Impact Assessment

This section provides an impact assessment for upland swamps within the study area. Whilst DoP (2010), OEH (2012) and DoE (2014) identify criteria to determine upland swamps at risk of negative environmental consequences, DoP (2010) states that these criteria are a "threshold for investigation – not a conclusion that the swamp will be impacted or suffer consequences" (p. 120).

To date, there is no accepted methodology for undertaking an assessment of the impacts of subsidence on upland swamps. Biosis, in consultation with hydrogeologists (GeoTerra) and experts in subsidence (SCT Operations) have developed a methodology for assessing impacts to upland swamps. The rationale for our impact assessment methodology is outlined below.

DoP (2009) identifies three potential impact mechanisms to upland swamps:

1. The bedrock below the swamp cracks as a consequence of tensile strains and water drains into the fracture zone. If the fracture zone is large enough or connected to a source of escape (e.g. a deeper aquifer or bedding shear pathway to an open hillside) then it is possible for sufficient water to drain to alter the hydrologic balance of the swamp.

2. Tilting of sufficient magnitude occurs to either re-concentrate runoff leading to scour and erosion, potentially allowing water to escape from the swamp margins (possibly affecting the whole swamp) or to alter water distribution in parts of the swamp, thus favouring some flora species associations over others.

3. Buckling and bedding shear enhances fracture connectivity in the host bedrock which promotes vertical then lateral drainage of the swamp. This mechanism is similar to redirected surface flow observed in subsidence-upsidence affected creek beds.

In the past, impact assessment for upland swamps in the Southern Coalfield has focused on the use of the criteria outlined in DoP (2010), OEH (2012) and DoE (2014) to determine the risk of negative environmental consequences. Changes in groundwater availability resulting from fracturing of bedrock beneath an upland swamp is one environmental consequence that is expected to adversely impact swamps. There is now mounting evidence to indicate that the maintenance and persistence of upland swamps in areas subject to subsidence is much more complex than has been previously recognised. Upland swamps within the study area have been subject to historic mining, and some upland swamps have been subsided twice and some show signs of fracturing (see Sections 3 and 4.2.1). Yet analysis of available data indicates these upland swamps persist and continue to support a perched water table.

In addition, DoP (2008) recognises that certain swamp characteristics mean some upland swamps are more susceptible to impacts from subsidence than others. Analysis of available piezometric data indicates that some sections of upland swamps behave, hydrologically, like surrounding sandstone environments, with little retention of groundwater following recharge. These areas often correspond with subcropping sandstone, shallow sandy soils with little humic material and support vegetation communities that are not reliant on permanent or intermittent water logging (MU42 Banksia Thicket, MU44a Sedgeland and MU44b Restioid Heath). Other piezometers indicate substantial retention of groundwater following recharge, with these areas supporting deeper, organic soils and vegetation communities reliant on intermittent and permanent groundwater (MU43 Tea-Tree Thicket and MU44c Cyperoid Heath). Changes in hydrological regimes could be posited to impact more on vegetation communities reliant on permanent and intermittent groundwater.

Further research, monitoring and assessment is required to understand the complex processes that maintain upland swamps, particularly in relation to changes brought about by longwall mining.
In previous upland swamps assessments (e.g. BHPBIC 2009) changes in water flow through an upland swamp have been assessed using a single cross-section of an upland swamp. This methodology was criticised in DoP (2010) due to the reliance on a single cross-sectional representation. Biosis (2012b) and Biosis (2014a) used flow accumulation modelling across an entire swamp to assess changes in flow through each individual upland swamp to addresses this concern.

The impact assessment methodology developed by Biosis, and used in this report, utilises the initial risk assessment criteria (DoP 2010, OEH 2012 and DoE 2014) to determine upland swamps at risk of negative environmental consequences.

In accordance with DoP (2010) we have used multiple criteria to determine the potential for impacts to upland swamps. These criteria have been developed with reference to the three potential upland swamp impact mechanisms outlined in DoP (2009) and outlined previously. This report utilises data on the hydrology of upland swamps in the study area and vegetation sub-communities within upland swamps, along with subsidence modelling and flow modelling to assess the potential for impacts to upland swamps within the study area. The swamp impact assessment methodology employed herein assesses multiple upland swamp characteristics to determine the potential for impact, in line with the recommendation of DoP (2010) that upland swamps that exceed these thresholds (indicating they are at risk of negative environmental consequences) require further investigation.

### 4.1 Initial risk assessment

An initial risk assessment has been undertaken to determine upland swamps at risk of negative environmental consequences. This initial risk assessment has been undertaken for all upland swamps within the study area. Subsidence values for upland swamps are presented in Table 4 and Figure 5.
Table 4: Initial Risk Assessment for Wonga East

Figures in bold are greater than criteria outlined in DoP (2010), OEH (2012), and DoE (2014).

<table>
<thead>
<tr>
<th>Swamp</th>
<th>Maximum subsidence within swamp boundary (m)</th>
<th>Adjacent subsidence used to calculate strains and tilts (m)</th>
<th>Overburden Depth (m)</th>
<th>Longwall panel width (m)</th>
<th>Ratio of Overburden Depth to Panel Width</th>
<th>Max Tensile Strain (mm/m)</th>
<th>Max Comp Strain (mm/m)</th>
<th>Max Tilt (mm/m)</th>
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</tbody>
</table>
Re-assessment of subsidence predictions following monitoring of Longwalls 4 and 5 indicates that past mining has resulted in the softening of the bridging capacity of the underlying rock strata, and that subsidence is largely restricted to the area immediately overlying the goaf. Whilst this means that subsidence movements occur over a smaller area, it also means that tilts and strains are greater than previously predicted (SCT Operations 2014).

The initial risk assessment has identified that six upland swamps within the study area are at risk of negative environmental consequences, including upland swamps CCUS3, CCUS4, CCUS5, CCUS6, CCUS23 and CRUS1. Upland swamps not identified to be at risk of negative environmental consequences are not discussed further.

4.2 Hydrogeological investigations

4.2.1 Swamp piezometers

Six shallow piezometers have been installed in upland swamps within the study area, with three auger holes not completed with piezometers as they were too shallow, dry or did not encounter swamp materials within a designated swamp domain. In addition, 2 shallow soil piezometers (SP1 and SP2) were installed down slope of two swamps as shown in Table 5.

Table 5: Piezometers within the study area (# indicates dry hole with no piezometer)

<table>
<thead>
<tr>
<th>Bore</th>
<th>Swamp</th>
<th>Installed</th>
<th>Easting</th>
<th>Northing</th>
<th>Total Depth (mbgl)</th>
<th>Intake Screen (m)</th>
<th>Intake Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCc3</td>
<td>CCUS3</td>
<td>Mar 12</td>
<td>302820</td>
<td>6196810</td>
<td>1.2</td>
<td>0.7 – 1.2</td>
<td>sandy clay / weathered sandstone</td>
</tr>
<tr>
<td>PCc4</td>
<td>CCUS4</td>
<td>Mar 12</td>
<td>302615</td>
<td>6196925</td>
<td>0.95</td>
<td>0.45 – 0.95</td>
<td>sandy clay / weathered sandstone</td>
</tr>
<tr>
<td>PCc5A</td>
<td>CCUS5</td>
<td>May 12</td>
<td>302110</td>
<td>6197135</td>
<td>1.24</td>
<td>0.7 – 1.2</td>
<td>humic sandy clay / weathered sandstone</td>
</tr>
<tr>
<td>CCUS5#</td>
<td>May 12</td>
<td>302135</td>
<td>6197155</td>
<td>-</td>
<td>Dry at 0.3</td>
<td>weathered sandstone</td>
<td></td>
</tr>
<tr>
<td>CCUS5#</td>
<td>May 12</td>
<td>302135</td>
<td>6197160</td>
<td>-</td>
<td>Dry at 0.5</td>
<td>weathered sandstone</td>
<td></td>
</tr>
<tr>
<td>CCUS5#</td>
<td>May 12</td>
<td>302105</td>
<td>6197130</td>
<td>-</td>
<td>Dry at 1.6</td>
<td>weathered sandstone</td>
<td></td>
</tr>
<tr>
<td>PCc5B</td>
<td>CCUS5</td>
<td>May 12</td>
<td>302245</td>
<td>6197250</td>
<td>1.31</td>
<td>0.8 – 1.3</td>
<td>humic sandy clay / weathered sandstone</td>
</tr>
<tr>
<td>PCc6</td>
<td>CCUS6</td>
<td>Mar 12</td>
<td>303165</td>
<td>6196790</td>
<td>1.2</td>
<td>0.7 – 1.2</td>
<td>weathered sast</td>
</tr>
<tr>
<td>PCr1</td>
<td>CRUS1</td>
<td>Mar 12</td>
<td>302290</td>
<td>6196625</td>
<td>0.55</td>
<td>0.3 – 0.55</td>
<td>humic sandy clay / weathered sandstone</td>
</tr>
<tr>
<td>SP1</td>
<td>No swamp</td>
<td>Mar 12</td>
<td>303245</td>
<td>6196955</td>
<td>0.60</td>
<td>0.1 – 0.6</td>
<td>sandy clay / weathered sandstone</td>
</tr>
<tr>
<td>SP2</td>
<td>No swamp</td>
<td>Mar 12</td>
<td>302830</td>
<td>6196905</td>
<td>1.05</td>
<td>0.55 – 1.05</td>
<td>sandy clay / weathered sandstone</td>
</tr>
</tbody>
</table>

NOTE: mbgl = metres below ground level
Drill hole depth and piezometer construction details are shown in Graph 1.

**Graph 1: Wonga East Swamp Piezometers**

![Graph 1](image)

### 4.2.2 Swamp water levels

The upland swamps are perched systems that are hydraulically separated from the deeper, regional groundwater table in the Hawkesbury Sandstone by an unsaturated zone. This is illustrated in two examples below.

Although they are not immediately adjacent to each other, comparison of water levels in GW1 and PCc6 in swamp CCUS6, as shown in Graph 2 and Graph 3 respectively, indicate a 6.8 – 11.9 m unsaturated sandstone separation thickness. Recharge following rain events through the sandstone to the regional aquifer is apparent, with the swamp and the regional sandstone aquifer having similar temporal, although different quantum responses to rainfall recharge.

**Graph 2: Hydrograph – Upland Swamp CCUS6**

![Graph 2](image)
Although hydraulically separated from the deeper, regional groundwater table in the Hawkesbury Sandstone, upland swamps can be connected to shallower, ephemeral seepage from the upper Hawkesbury Sandstone where bedding discontinuities or low permeabilities enhance horizontal flow into a swamp after high rainfall periods. Depending on the relative height of the ephemeral, perched and regional water tables, groundwater seepage can supplement swamp moisture or, alternatively, unsaturated swamp moisture can seep into the underlying shallow ephemeral sandstone aquifer. In turn, the shallow bedrock aquifers are also usually ephemeral, and are hydraulically disconnected via an unsaturated zone from the deeper, regional aquifers within the Hawkesbury Sandstone.

The water table within the swamps is dependent on surface inflow recharge after rain and can be supported by ephemeral seepage of near surface groundwater from the Hawkesbury Sandstone. Water storage is usually limited within the humic, clayey, rich sandy sediments, although this can allow relatively small inflows to support a highly variable ephemeral water table in the more organic layers.

Recharge into the Hawkesbury Sandstone shallow aquifer that seeps into a swamp is generally moderated by connate water stored in a swamp, which is also recharged by rainfall. Water can enter a swamp from ephemeral seeps located at the upper and lower section of any topographic or basement steps that may be present.

Episodes of inundation and surface run off within a swamp are directly related to the extent and duration of storm events, with the short term, post storm drainage occurring within indistinct channels or dispersed flow paths in the swamp.

Groundwater seepage into a swamp is usually transmitted within the more sandy or humic layers and can “daylight” where the water table extends to surface. Water accumulation within a swamp is a balance between:

- Rainfall / surface runoff recharge
- Horizontal seepage and downstream outflow
- Swamp storage capacity, based on the size and depth of the swamp, its humic organic material as well as sand and clay composition
- Vertical seepage rates into the underlying weathered sandstone
- Swamp evapotranspiration.
Groundwater levels within the upland swamps listed in Table 5 have been monitored since February 2012. Hydrographs for all monitored swamps, two shallow soil piezometers and rainfall data are presented in Graph 4 to Graph 7. Data from this monitoring indicates that swamp water levels are variable, and can range from fully saturated to dry. Some of the swamps have been essentially dry since piezometers were installed.

Analysis of the swamp hydrographs shown in Graph 4 to Graph 7 indicates:

- **PCc5A and PCC5B** in upland swamp CCUS5 overlie both first workings and pillar extraction in the Bulli Seam, as well as first workings in the Balgownie workings. CCUS5 undergoes evapotranspiration as well as gradual drainage after rainfall with overland seepage outflow to a northerly draining gully then to Cataract Creek. Evans and Peck (2014) assert that water level reduction can be accounted for by evapotranspiration loss. There is no evidence of adverse effects due to prior subsidence in this swamp.

**Graph 4: Hydrograph – Upland Swamps CCUS5**

- **PCc4** in upland swamp CCUS4 overlies first workings in the Bulli Seam as well as LW11 in the Balgownie workings. CCUS4 undergoes evapotranspiration as well as drainage after rainfall with overland seepage outflow to a northerly draining gully then to Cataract Creek. Evans and Peck (2014) concludes that water level reduction can be largely, but not fully, accounted for by evapotranspiration loss. Possible adverse effects due to prior subsidence may be evident in this swamp due to its enhanced drainage recession rates.

- **PCR1** in upland swamp CRUS1 overlies pillar extraction workings in the Bulli Seam. CRUS1 undergoes evapotranspiration as well as drainage after rainfall with overland seepage outflow to a southerly draining gully then to Cataract River. Evans and Peck (2014) concludes that water level reduction can be largely, but not fully, accounted for by evapotranspiration loss. Possible adverse effects due to prior subsidence may be evident in this swamp due to its enhanced drainage recession rates. However, as the swamp has limited humic matter with numerous shallow outcropping or subcropping sandstone outliers, it is equally possible that the swamp has little storage capacity and drains / evaporates rapidly as a result.
Graph 5: Hydrograph – Upland Swamps CCUS4 and CRUS1

- PCc3 in upland swamp CCUS3 overlies first workings in the Bulli Seam as well as LW10 in the Balgownie workings. CCUS3 undergoes evapotranspiration as well as rapid drainage after rainfall with overland seepage outflow to a northerly draining gully then to Cataract Creek. Evans and Peck (2014) assert that rapid water level lowering following rainfall suggests that water is being lost from the base of the swamp into the underlying sandstone. Possible adverse effects resulting from prior subsidence may be evident in this swamp due to its enhanced drainage recession rates. However, as the swamp is small, has essentially no humic matter with numerous shallow outcropping or subcropping sandstone outliers, it is equally possible that the swamp has little storage capacity and drains / evaporates rapidly as a result.

- PCc6 in upland swamp CCUS6 overlies pillar extraction in the Bulli Seam as well as LW8 in the Balgownie workings. CCUS6 undergoes evapotranspiration as well as rapid drainage after rainfall with overland seepage outflow to a northerly draining gully then to Cataract Creek. Evans and Peck (2014) assert that rapid water level lowering following rainfall suggests that water is being lost from the base of the swamp into the underlying sandstone. Possible adverse effects resulting from prior subsidence may be evident in this swamp due to its enhanced drainage recession rates. However, as the swamp is small, has essentially no humic matter with numerous shallow outcropping or subcropping sandstone outliers, it is equally possible that the swamp has little storage capacity and drains / evaporates rapidly as a result.
SP1 is located external to a swamp community to the west of Mount Ousley Road, and overlaps the edge of a pillar extraction area in the Bulli Seam as well as LW9 in the Balgownie workings. The piezometer, which is located down gradient of swamp CCUS6, undergoes evapotranspiration as well as rapid drainage after rainfall with overland seepage outflow to a northerly draining gully then to Cataract Creek. It is possible that adverse effects due to prior subsidence may be evident. However, as the piezometer is located in a sandy clay soil / weathered sandstone profile, with no humic matter and numerous shallow outcropping or subcropping sandstone outliers, it is interpreted that the colluvial soil profile has little storage capacity and drains / evaporates rapidly as a result.

SP2 is also located external to the west of Mount Ousley Road, and overlaps the edge of a pillar extraction area in the Bulli Seam as well as LW10 in the Balgownie workings. The piezometer, which is located down gradient of swamp CCUS3, undergoes evapotranspiration as well as rapid drainage after rainfall with overland seepage outflow to a northerly draining gully then to Cataract Creek. It is possible that adverse effects due to prior subsidence may be evident. However, as the piezometer is located in a sandy clay soil / weathered sandstone profile, with no humic matter and numerous shallow outcropping or subcropping sandstone outliers, it is interpreted that the colluvial soil profile has little storage capacity and drains / evaporates rapidly as a result.
Groundwater data from piezometers located in upland swamps within the study area indicates that there are varying water levels in these upland swamps. The monitored locations within swamps CCUS4 and CCUS5 show sustained groundwater levels for prolonged periods following rainfall, while CCUS3 and CCUS6 show little groundwater recharge following rainfall. This corresponds with the vegetation communities within these upland swamps, with CCUS4 and CCUS5 supporting areas of MU43 Tea-tree Thicket (both upland swamps) and MU44c Cyperoid Heath (CCUS4 only), which both rely on permanent to intermittent waterlogging. In contrast upland swamps CCUS2, CCUS3 and CCUS6 support MU42 Banksia Thicket (CCUS3 and CCUS6) or MU44a Sedgeland and MU44b Restioid Heath (CCUS2) which are less reliant on waterlogging. CRUS1, which supports a mix of MU42 Banksia Thicket and MU43 Tea-tree Thicket, is an anomaly. This upland swamp has shallow soils and some areas of MU43 Tea-tree Thicket are known to be located in "bowls" within the underlying geology, resulting in water accumulation in depressions in bedrock.

It is worth noting that all of the upland swamps listed above have been subject to significant tilts and strains from past mining (see Table 1 and Table 2), substantially above what has been predicted by Mine Subsidence Engineering Consultants (MSEC) to result in fracturing of bedrock in waterways (DoP 2010) and the criteria listed in OEH (2012) and DoE (2014) for assessing the risk of negative environmental consequences to upland swamps. These levels of tilts and strains are likely to have resulted in fracturing of the bedrock beneath these upland swamps from past mining. Despite this, the majority of upland swamps in the study area maintain a perched water table (Evans and Peck 2014). The degree of past impact and / or self-healing that may have occurred cannot be adequately assessed and monitoring data is not available to confirm whether this has occurred.

It is also worth noting that only two upland swamps within the study area exhibit piezometric data consistent with the hypothesised significant contribution to baseflow from upland swamps (Evans and Peck 2014).

### 4.2.3 Groundwater model

Geoterra and Groundwater Exploration Services (2014) have recently completed the groundwater modelling and associated revised groundwater assessment for the Preferred Project Report for the Underground Expansion Project (UEP). Aspects of the model that are of relevance to upland swamps are discussed below.

The model indicates that the depressurisation zone may reach the surface over the eastern and central sections of Longwall 6 and 7 and over the eastern and central sections of Longwalls 1 to 3. It should be noted that although the depressurisation zone may extend to the surface this does not mean that this will result in a "full" direct connection between the perched ephemeral water table associated with upland swamps and the mine workings. This is supported by the model predicting depressurisation over the extracted Longwalls 4
and 5; however there have not been any observable adverse change in piezometric water levels in upland swamps above Longwalls 4 and 5 (Graph 6).

The modelling indicates that although the perched, ephemeral groundwater water table associated with upland swamps could undergo a water level reduction it is not anticipated to have a significant overall effect on stream baseflow or stream water quality. However, temporary, localised effects may be observed.

4.2.4 Groundwater chemistry

The Cataract Creek, Bellambi Creek and Cataract River swamps in the study area have electrical conductivities ranging from 70 – 170 μS/cm (Graph 9), with the salinity varying in relationship to rainfall recharge that occurs prior to sampling, along with the degree of brackish seepage from the weathered Hawkesbury Sandstone.

Graph 9: Electrical conductivity – Wonga East upland swamps

The pH ranges from 3.8 – 7.3 as shown in Graph 10.

Graph 10: pH – Wonga East upland swamps
Monitoring indicates the swamp salinity is within the acceptable range for potable water; however it is generally outside the ANZECC (2000) South Eastern Australia Upland Stream criteria for pH and can be above the ANZECC (2000) 95% Species Protection Level for Freshwater Aquatic Ecosystem Guidelines for:

- Filtered copper, lead, zinc, nickel, and occasionally aluminium (where its pH exceeds 6.5, which rarely occurs).
- Total nitrogen, and total phosphorous.

4.3 Flow accumulation

Flow accumulation modelling was undertaken based on the revised longwall layout and revised subsidence predictions (SCT Consultants 2014). The methodology for undertaking flow accumulation modelling is presented in Biosis (2012b).

Flow accumulation modelling pre- and post-mining is undertaken by modelling flow pathways across a catchment using a digital elevation model (DEM) constructed from LiDAR data. Changes in surface topography are modelled by deducting predicted subsidence values (Smax) from the pre-mining DEM. Flow accumulation is then re-modelled. This is used to predict changes to surface and sub-surface flow through an upland swamp in relation to changes in ground level (tilt) and is unrelated to tilts and strains. This method directly addresses swamp impact mechanism 2 outlined at the start of Section 4, and in particular addresses dot point 2 on page 116 of DoP (2010), which states that changes in water distribution in parts of the swamp can lead to changes in swamp health or vegetation composition.

To ensure cumulative impacts are adequately assessed, flow accumulation modelling was undertaken for the UEP, and data presented herein is from this assessment. The percentage change in flow accumulation following mining is presented in Table 6, in addition to a discussion on flow accumulation. Figures showing flow accumulation modelling are presented in Appendix 1 (Figure 7 to Figure 12).

Table 6: Discussion of changes in flow accumulation pre- versus post-mining for upland swamps in Wonga East

<table>
<thead>
<tr>
<th>Swamp</th>
<th>Percentage change in flow accumulation following mining</th>
<th>Discussion of changes in flow accumulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCUS3</td>
<td>99.18</td>
<td>Modeling of pre-mining flow accumulation through CCUS3 indicates the presence of two main flow pathways through this upland swamp, largely through areas of MU42 Banksia Thicket. Tilt associated with extraction of Longwall 5 are likely to result in only negligible (0.72%) changes in overall catchment yield for this upland swamp, and a minor re-direction of flow from the western edge of CCUS3 to the centre. This change will result in only negligible impacts to this upland swamp.</td>
</tr>
<tr>
<td>CCUS4</td>
<td>95.23</td>
<td>Flow accumulation modeling pre-mining indicates the presence of two main flow pathways through this upland swamp. One minor flow path 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 MU43 Tea-tree Thicket and MU44c Cyperoid Heath. Post-mining, tilts will result in a minor (4.77%) decline in overall catchment yield.</td>
</tr>
</tbody>
</table>
## Discussion of changes in flow accumulation

<table>
<thead>
<tr>
<th>Swamp</th>
<th>Percentage change in flow accumulation following mining</th>
<th>Discussion of changes in flow accumulation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Only negligible changes in the western flow accumulation pathway are predicted to occur, with minor changes in flows through the patches of MU43 and MU44c. Tilts will result in a new flow pathway through the centre of this upland swamp, with resultant increases in water availability to patches of MU42 Banksia Thicket. A shift in the flow pathway through the eastern section of the swamp will result in a minor redistribution of water in this eastern section. This may result in minor impacts to vegetation communities reliant on permanent and intermittent waterlogging.</td>
</tr>
<tr>
<td>CCUS5</td>
<td>98.45</td>
<td>Pre-mining flow accumulation modeling 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 MU43 Tea-Tree Thicket. Substantial benching within this swamp 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. Tilts associated with Longwall 6 are likely to result in a minor (1.55%) decline in overall water availability within this swamp. There a minor redistribution of water within the centre of this upland swamp.</td>
</tr>
<tr>
<td>CCUS6</td>
<td>97.69</td>
<td>Flow pathways through CCUS6 prior to mining are dispersed, with multiple entry and exit points reflecting the disconnected nature of this upland swamp. Tilt associated with extraction of Longwall 4 and 5 may result in a minor (2.31%) decrease in flow accumulation, but is unlikely to result in any significant changes in these pathways. Minor changes to vegetation composition are predicted to occur.</td>
</tr>
<tr>
<td>CCUS23</td>
<td>97.06</td>
<td>Given the orientation of the flow pathway perpendicular to the longwall, flow accumulation modeling pre- versus post-mining indicates only a minor (2.94%) decrease in catchment yield for this upland swamp. There is unlikely to be any change in flow pathways through this swamp. Negligible changes in water availability due to flow are predicted.</td>
</tr>
<tr>
<td>CRUS1</td>
<td>100.21</td>
<td>Only the upper northern section of CRUS1 is located above Longwall 6. An assessment of pre- versus post-mining flow accumulation through the upland swamp indicates a negligible (0.21%) increase in catchment yield and negligible changes in flow pathways through this upland swamps. No changes in water availability are predicted to occur.</td>
</tr>
</tbody>
</table>

Flow accumulation modelling for upland swamps within the study area indicates that, for the majority of upland swamps, only negligible or minor changes in both cumulative flow and flow pathways are likely to occur following mining. No significant reconcentration of flows that may result in increased erosion risk, are
likely to occur. For the majority of upland swamps mining is likely to result in only minor changes in water availability.

4.4 Subsidence

Reassessment of subsidence predictions following monitoring of Longwalls 4 and 5 indicates that previous mining has resulted in the softening of the underlying rock strata, and that subsidence is occurring over a much shorter distance than has previously occurred in un-mined areas, with subsidence largely restricted to immediately above the goaf. Whilst this means that subsidence movements occur over a smaller area, it also means that tilts and strains are greater than previously predicted (SCT Operations 2014).

Maximum subsidence within the bounds of the swamp may not necessarily be a good indicator of the maximum subsidence parameters of strain and tilt given that maximum strain and tilt typically occur on the fringes of a subsided area. The maximum strain and tilt values have been estimated based on the level of subsidence within the general proximity of a swamp that would contribute to maximum strains and tilts within the swamp boundary (SCT Operations 2014).

When strains are greater than about 1-2 mm/m in tension and 2-3 mm/m in compression, perceptible fracturing of the sandstone strata below swamps may occur (SCT Operations 2014) and this may result in a decrease in the perched water table and water availability.

Upland swamps form across a range of soil moisture gradients supporting different flora species and vegetation communities (Keith et al. 2006, NSW Scientific Committee 2012, DoE 2014). The model of upland swamp response to climatic change outlined in Keith et al. (2006) describes a transition between MU43 Tea-tree Thicket to MU44c Cyperoid Heath and MU44a Sedgeland / MU44b Restioid heath / MU42 Banksia Thicket in response to changes on soil moisture. MU43 Tea-tree Thicket is likely to be reliant on semi-permanent to permanent waterlogging and MU44C Cyperoid heath on intermittent waterlogging, whilst the water table is likely to reach the root zone in other vegetation communities only following heavy rains. Similar changes in vegetation community composition within an upland swamp would be expected to occur due to changes in soil moisture resulting from fracturing of bedrock beneath an upland swamp.

Changes in soil moisture can occur in two ways; either through loss of water through fracturing of the bedrock and / or through changes in water flow through an upland swamp resulting in changes in water availability. Whilst we use the flow accumulation model to assess the second potential mechanism of change, we must use predictions for tensile and compressive strain to assess the potential for fracturing of the base of upland swamps and potential for loss of groundwater availability. In light of this, we have used these parameters to assess potential for impacts to particular vegetation communities within an upland swamp.

Subsidence predictions are presented in Table 4. This data indicates that tensile and compressive strains and tilts are of sufficient magnitude to result in fracturing of bedrock beneath upland swamps within the Wonga East area. Table 7 assesses the risk of a significant impact to these upland swamps based on vegetation communities present, and recorded response to groundwater (for upland swamps with groundwater data available).

<table>
<thead>
<tr>
<th>Swamp</th>
<th>Discussion of tilts and strains</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCUS3</td>
<td>CCUS3 supports MU42 Banksia Thicket and MU44a Sedgeland, which are not reliant on waterlogging and are thus deemed less susceptible to decreased groundwater availability. Groundwater data indicates rapid recession to basement levels following rainfall.</td>
</tr>
<tr>
<td>Swamp</td>
<td>Discussion of tilts and strains</td>
</tr>
<tr>
<td>---------</td>
<td>--------------------------------</td>
</tr>
<tr>
<td>CCUS4</td>
<td>CCUS4 supports MU43 Tea-tree Thicket and MU44c Cyperoid heath, which are reliant on permanent to semi-permanent water availability, as well as MU42 Banksia Thicket. Soils are 15 – 179 centimetre (cm) in depth and consist of humic sandy clays to minerals sands. Undergoes evapotranspiration as well as gradual drainage after rainfall. The location of water-dependent communities, including MU44C Cyperoid Heath and MU43 Tea-tree Thicket at the base of the longwall, in areas of lowest strain and tilt, are likely to mitigate impacts to some degree. An overhanging sandstone formation, approximately 7.1 m high, forms a waterfall at the base of CCUS4. This sandstone formation forms a rockbar at the downstream extent of upland swamp CCUS4. There is evidence of impacts from previous mining, including collapse of a section of this sandstone formation and some cracking of the sandstone outcrop to the west of the waterfall below CCUS4. Horizontal compression of this sandstone formation has the potential to result in rockfall or tensile cracking of this sandstone formation (SCT Operations 2014), although as the overhang will be subject to subsidence of less than 0.2 metres the risk is assessed as between 1 – 20% probability of collapse. As this sandstone formation forms a rockbar at the downstream extent of CCUS4 any fracturing is likely to result in changes in hydrology. Any rockfall that impacts on the integrity of the sandstone formation may result in significant impacts to the water holding capacity of CCUS4. There is no evidence of adverse effects due to prior subsidence in this swamp. Risk is assessed as moderate.</td>
</tr>
<tr>
<td>CCUS5</td>
<td>CCUS5 supports a mix of MU43 Tea-tree Thicket, which depends on permanent water availability, and MU42 Banksia Thicket and MU44a Sedgeland. Upper sections of CCUS5, overlying Longwall 6, consist of MU42 and MU44a. Soils in this section of CCUS5 are up to 80 cm in depth and consist of a mix of humic sandy clay and sandy clay to minerals sands. This upland swamp is unlikely to undergo significant subsidence, and is outside the 200 mm subsidence impact zone, but within the 20 mm subsidence limit. Undergoes evapotranspiration as well as gradual drainage after rainfall. There is no evidence of adverse effects due to prior subsidence in this swamp. Risk is assessed as low.</td>
</tr>
<tr>
<td>CCUS6</td>
<td>CCUS6 supports MU42 Banksia Thicket, which is not reliant on waterlogging and is thus deemed less susceptible to decreased groundwater availability. Groundwater data indicates rapid recession to basement levels rapidly following rainfall. Risk is assessed as low.</td>
</tr>
<tr>
<td>CCUS23</td>
<td>CCUS23 supports MU42 Banksia Thicket and MU44a Sedgeland. No groundwater data is available. Risk is assessed as low.</td>
</tr>
<tr>
<td>CRUS1</td>
<td>CRUS1 supports a mix of MU43 Tea-tree Thicket and MU42 Banksia Thicket. Based on shallow soil profile, MU43 Tea-tree Thicket is likely to persist in areas of water accumulation resulting from rock terracing, as evident from analysis of slope and testing of soil depths. Only a small, upper section of this upland swamp is located within the predicted subsidence impact zone. Soils in this area are between 25 and 70 cm, and consisting of mineral sands. These areas are unlikely to support significant groundwater. Vegetation in this area consists of MU42 Banksia Thicket.</td>
</tr>
</tbody>
</table>
### Swamp

<table>
<thead>
<tr>
<th>Discussion of tilts and strains</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undergoes evapotranspiration as well as gradual drainage after rainfall. Possible adverse effects due to prior subsidence may be evident in this swamp due to its enhanced drainage recession rates. However, as the swamp has limited humic matter with numerous shallow outcropping or subcropping sandstone outliers, it is equally possible that the swamp has little storage capacity and drains / evaporates rapidly as a result. Risk is assessed as low.</td>
</tr>
</tbody>
</table>

---

### 4.5 Final risk assessment

#### 4.5.1 Potential impacts

Potential impacts to upland swamps in the study area may result from the following mechanisms:

- Fracturing of bedrock beneath upland swamps, resulting in increased secondary porosity and permeability, with potential to drain into deeper sandstone strata.
- Tilting in upland swamps resulting in the re-distribution of perched water levels and surface run-off. This may result in changes in in-flow to upland swamps and / or changes in saturation of vegetation sub-communities.
- Tilting in upland swamps resulting in increased potential for development of nick points, scouring and erosion.
- Changes in baseflow discharge and from upland swamps.

Subsidence could affect upland swamps directly overlying the proposed longwalls due to either transient and/or spatial changes in secondary porosity and permeability of a swamp or its underlying weathered sandstone substrate through generation of cracks or differential displacement of the perched aquifer. If a swamp overlies an extracted panel, it may undergo temporary extensional “face line” cracking (perpendicular to the long axis of the panel) as a panel advances, followed by re-compression as the maximum subsidence occurs at any one location. In addition, where a swamp overlies a longwall, it may also undergo both longer term extensional “rib line” cracking (parallel to the long axis of the panel) along the outer edge and compression within the central portion of a panel’s subsidence trough. The more susceptible portions of a swamp to increased secondary porosity and / or permeability changes are where it undergoes “rib line” cracking. Any adverse effects, if they occur, would be related to the extent and degree of cracking that occurs in the underlying weathered sandstone, as cracking is unlikely to manifest in a swamp due to its saturated, clayey, humic, plastic nature, as well as the reliance of vegetation within the upland swamp on the perched water table (compared with surface water in-flow).

It should be noted that the headwater swamps in the study area have undergone up to an estimated 3.8 m of subsidence in the centre of Longwall 4 with up to 1.0 m of subsidence estimated for mining in the Bulli Seam, 1.0 m measured during mining in Balgownie Seam and 1.8 m is predicted to occur during mining in Wongawilli Seam. This level of subsidence would be expected to cause up to an estimated 21 mm/m of tensile strain, 41 mm/m of compressive strain, and 68 mm/m of tilt. Bulli Seam mining occurred from the late 19th Century through to about 1950. Balgownie Seam longwalls were mined between 1970 and 1982. Longwalls 4 and 5 in the Wongawilli Seam were mined in 2012 and 2013.

Where a swamp straddles a chain pillar, or is on the edge of the subsidence bowl, it could experience temporary, localised, re-distribution of perched water levels through differential subsidence of the ground. Tilting of a swamp could also potentially re-distribute surface runoff, resulting in a re-distribution of water.
flow and storage, thereby causing changes to the saturation characteristics which may alter the vegetation associations within a swamp.

Changes in flow regimes within swamps can result in changed flow paths or runoff characteristics within a swamp, with the potential for development of nick points, scouring and erosion. Dewatering and drying of swamps due to subsidence fracturing of the bedrock may increase the erosion potential of swamps. Negative environmental consequences may be caused by erosion and drying out of the swamp via channel erosion, by redistribution of water, or by water diversion through connected pathways exposed by buckling or shearing of the underlying sandstone. The swamps, however, contain sediment and organic material that may either seal or reduce water loss into the underlying fracture network. Drying, in conjunction with fire and substantial rainfall, can increase the susceptibility of swamps, particularly valley fill swamps, to erosion. However, it is often the case that no single factor can be directly implicated in enhanced erosion of upland swamps. The only swamp in the Russell Vale lease area that has undergone notable erosion is the valley fill swamp LCUS4 at Wonga West, which is outside the study area for this assessment.

Upland swamp water is stored within the shallow, perched, ephemeral groundwater system, whilst regional water is contained within the deeper Hawkesbury Sandstone aquifers. Empirical observation and field mapping (Biosis, 2013a, b) indicates that past undermining of swamps in the Wollongong Coal lease area has not generated any noticeable adverse ecological effects on swamps. It is therefore anticipated that observable reduction of swamp discharge to the study area catchments will not occur following subsidence across the subject catchment areas, although generation of potentially enhanced leakage from the base of the swamps may occur. Seepage from the swamp is currently highly ephemeral, with the volume and duration of baseflow being directly related to the degree of rainfall recharge and stream flow in the catchment.

4.5.2 Detailed risk assessment

Following assessment of a variety of risk factors, Table 8 provides an overall assessment of the potential for a significant impact to occur. This final risk assessment assesses the overall risk of a primary impact (based on the initial risk assessment) and the consequent risk of a secondary impact (based on factors such as groundwater data, reliance of vegetation communities on water availability, changes in flow accumulation and the position of water dependent communities within the upland swamp compared to areas of greatest tilt and strain).

The changes in storativity and permeability are estimated to have no observable impact above the water level variability due to climatic influences. Connective cracking to deeper strata is not predicted and, as such, it is not anticipated that the swamps could freely drain into the deeper sandstone strata. Based on observation of previously undermined swamps in the study area that have undergone similar strains to those predicted due to undermining by the previous Bulli and Balgownie workings, no observable adverse consequences are anticipated on the water holding capacity, water quality or ecosystem health of the majority of swamps, except possibly CCUS4. In addition to fracturing of the base of CCUS4, there is potential for impacts to the sandstone formation that forms a rockbar at the downstream extent of this upland swamp. Any rockfall that impacts on the integrity of this rockbar is likely to result in a significant impact to the water holding capacity of CCUS4.

All other designated upland swamps are not anticipated to undergo sufficient compressional or extensional strains to generate cracks in the underlying or adjacent sandstone, and therefore are not anticipated to undergo any adverse effects or consequences from the proposed mining.

While there is some limited potential for redistribution of perched water levels and surface water run-off in some upland swamps, significant changes in water run-off are likely to be limited to small sections of upland swamps.
Although erosion of swamps is possible where elevated tilts occur due to subsidence, it is only generally valley fill swamps which have been directly mined beneath that are susceptible to erosion and scouring. No valley fill swamps are present in the study area.

It is not anticipated that the ephemeral water levels or baseflow seepage will be significantly adversely affected. The groundwater model (Geoterra and Groundwater Exploration Services 2014) indicates that the average daily stream flow from Cataract Creek to Cataract Reservoir is 11.2 ML/d, of which 3.5 ML/d is baseflow. The model predicts a 0.013 ML/d (0.12%) loss of stream baseflow following mining. This level of change is unlikely to be detectable and unlikely to result in observable changes to flow regimes in Cataract Creek.

This final risk assessment indicates that there is a risk of a secondary impact to upland swamp CCUS4 from the proposed extraction of coal from Longwall 6.
Table 8: Final risk assessment for upland swamps in the study area

<table>
<thead>
<tr>
<th>Swamp</th>
<th>Initial risk assessment (risk of negative environmental consequences?)</th>
<th>Groundwater</th>
<th>Flow accumulation</th>
<th>Compressive tilts and strains</th>
<th>Final risk assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCUS3</td>
<td>Yes</td>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
<td>Low</td>
</tr>
<tr>
<td>CCUS4</td>
<td>Yes</td>
<td>Moderate</td>
<td>Low</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>CCUS5</td>
<td>Yes</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>CCUS6</td>
<td>Yes</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>CCUS23</td>
<td>Yes</td>
<td>N/A</td>
<td>Negligible</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>CRUS1</td>
<td>Yes</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>
The following section provides for a Significant Impact Assessment for the Coastal Upland Swamp EEC, according to the factors outlined in the *Matters of National Environmental Significance Significant Impact Guidelines 1.1* (DoE 2013).

An action is likely to have a significant impact on a critically endangered or endangered ecological community if there is a real chance or possibility that it will:

- reduce the extent of an ecological community

  No clearing of upland swamp vegetation is proposed.

  There is some potential for a reduction in the extent of upland swamps due to changes in the perched water table and transition of upland swamp vegetation communities to woodland.

  Analysis of the historic impacts to upland swamps in the study area from mining of the Bulli and Balgownie seams indicates that at least some of the upland swamps in the study area have experienced levels of subsidence considered likely to have resulted in fracturing of bedrock and an increased risk of negative environmental consequences. A previous report by Biosis (2013) concluded that data from piezometers located in some of these upland swamps show regression of groundwater consistent with a ‘fractured’ swamp (e.g. CCUS3, CCUS6 and CRUS1), whilst others do not (e.g. CCUS2, CCUS4 and CCUS5). A subsequent review undertaken by Evans & Peck (2014), on behalf of DP&E, concluded that the water retention characteristics of upland swamps had not been affected by past mining and that the majority of upland swamps in this area have maintained a perched groundwater system and do not show any evidence of cracking (see below for further information).

  It should be noted that despite upland swamps CCUS3 and CCUS6 showing signs of impacts from past mining, the vegetation in these upland swamps remains characteristic of the Coastal Upland Swamp EEC. The paucity of suitable monitoring data from past mining does not allow for a determination as to whether past mining has resulted in changes in the extent of this EEC.

  Although there is potential for a reduction in the extent of the Coastal Upland Swamp EEC this is likely to be localised in nature and occur over long time frames (i.e. decades). There is currently 4,739 ha of Coastal Upland Swamp EEC across the Woronora plateau, with 21 ha (0.44%) within the study area.

  There is a negligible likelihood of the complete loss of upland swamp vegetation within the study area. All upland swamps that intersect the predicted subsidence impact zone total 20 ha. This equates to 0.44% of the extent of the community across the Woronora plateau. Based on the risk assessment outlined above impacts are likely to be restricted to upland swamp CCUS4. This upland swamps totals 1.77 ha, equating to 0.03% of the extent of the community across the Woronora plateau.

  Upland swamps are not co-dependent and impacts to one swamp unless located on the same flow pathway which is not the case in the study area. Impacts to one upland swamp will not impact others.

  Any reduction in the extent of the community from the proposed activity is likely to be negligible when considered in a regional context.

- fragment or increase fragmentation of an ecological community, for example by clearing vegetation for roads or transmission lines

  No clearing of upland swamp vegetation is proposed.

  Although a reduction in the perched water table has the capacity to reduce the size of individual
upland swamps, given the existing fragmented nature of this EEC it is considered unlikely that further fragmentation will occur.

- **adversely affect habitat critical to the survival of an ecological community**

  DoE (2014) identifies all areas currently occupied and the associated sub-catchments as habitat critical to the survival of the Coastal Upland Swamp EEC.

  No clearing of upland swamp vegetation is proposed.

  Potential impacts to upland swamps within the study area are outlined in Section 4.5.1. Some adverse impacts are predicted to occur, particularly for upland swamp CCUS4. This may include changes in the species composition of these swamps, with an increase in species more tolerant of dry conditions and a decrease in species requiring permanent to intermittent waterlogging.

- **modify or destroy abiotic (non-living) factors (such as water, nutrients, or soil) necessary for an ecological community’s survival, including reduction of groundwater levels, or substantial alteration of surface water drainage patterns**

  The proposed action may result in a reduction in the perched water table in one upland swamp, CCUS4. Two of the vegetation communities in upland swamps CCUS4, MU43 Tea-tree Thicket and MU44c Cyperoid Heath, are reliant on this perched water table. This may result in changes to vegetation composition in this area.

  However, although this may result in impacts to two vegetation sub-communities in CCUS4, it is unlikely to result in the loss of the Coastal Upland Swamp EEC in the study area or impacts on the EEC at a regional level. This conclusion is supported by the assessment of historic impacts to upland swamps in the study area.

  Changes to the hydrology of upland swamps in the study area will be monitored as a part of the detailed upland swamp monitoring program. The management plan will specify performance measures and management actions to be undertaken should these be exceeded.

- **cause a substantial change in the species composition of an occurrence of an ecological community, including causing a decline or loss of functionally important species, for example through regular burning or flora or fauna harvesting**

  There is some potential for a change in the distribution of upland swamp vegetation communities in upland swamp CCUS4 if the base of this upland swamp is fractured and the perched water table drops. Sections of CCUS4 support MU43 Tea-Tree Thicket and MU44c Cyperoid Heath, both of which rely on permanent to intermittent water logging for maintenance. This may result in changes to vegetation composition in this area.

  If there are changes in water availability this may result in drying of the substrate in these areas which may result in the transition of these vegetation sub-communities to drier variants of the EEC (e.g. MU42 Banksia Thicket, MU44a Sedgeland or MU44b Restioid Heath).

  Vegetation composition of upland swamps will be monitored as a part of the detailed upland swamp monitoring program. The management plan will specify performance measures and management actions to be undertaken should these be exceeded.

- **cause a substantial reduction in the quality or integrity of an occurrence of an ecological community, including, but not limited to:**

  - assisting invasive species, that are harmful to the listed ecological community, to become established, or
causing regular mobilisation of fertilisers, herbicides or other chemicals or pollutants into the ecological community which kill or inhibit the growth of species in the ecological community, or

No clearing of upland swamp vegetation is proposed.

Activities associated with the proposed action are unlikely to result in increased invasion of exotic species, or release of any chemicals of pollutants in upland swamps in the study area. No water discharges are proposed. All personnel accessing the study area do so under strict environmental controls.

It is unlikely that any activities associated with the proposed action will result in a substantial reduction in the quality or integrity of this EEC.

- **interfere with the recovery of an ecological community.**

  There is currently no recovery plan for this EEC, and DoE (2014) considers that a recovery plan is not required at this time.

This assessment indicates:

- That whilst there is potential for a reduction in the extent of the EEC, any reduction resulting from the proposed action is likely to be negligible when considered in a regional context.

- The proposed action is unlikely to fragment or increase fragmentation of the EEC.

- Some adverse impacts to habitat critical to the survival of the EEC are predicted to occur, with a moderate risk of impact to upland swamp CCUS4.

- There is some potential to modify abiotic factors for individual swamps. Any changes are unlikely to result in the loss of the Coastal Upland Swamp EEC in the study area or impact on the EEC at a regional level.

- There is potential for change in the distribution of upland swamp vegetation communities, particularly in upland swamp CCUS4. However, analysis of data from past mining indicates that this will result in transition from wetter to drier sub-communities rather than loss of the EEC.

- It is unlikely that any activities associated with the proposed action will result in a substantial reduction in the quality or integrity of this EEC.

- The proposed action will not interfere with the recovery of the EEC.

Although there is potential for localised impacts to occur, significant impacts are unlikely to result from the proposed activity as impacts will be restricted to small sections of CCUS4 and CRUS1. Impacts are not likely to be significant at a regional scale, with upland swamps in the study area accounting for 0.44% of the extent of the EEC in the region.

Based on the information presented above and the assessment undertaken above we conclude that the proposed action is unlikely to result in a significant impact to the Coastal Upland Swamp EEC. Any impacts are likely to be localised and affect only a small occurrence of the EEC at a regional scale.
Figure 5: Predicted subsidence values for upland swamps in the study area

Coordinate System: GDA 1994 MGA Zone 56
Figure 6: Final risk assessment for upland swamps in the study area

Legend

Risk Assessment
- Moderate
- Low

Longwall Layout
- UEP Longwall Layout
- Previously Mined Longwalls
- Proposed Action Boundary
- Study Area
- Longwall 6 600m Buffer

Coordinate System: GDA 1994 MGA Zone 56

5. Impact Avoidance and Mitigation

This section outlines how the four step process, to avoid, minimise, mitigate and then offset any residual impacts, has been incorporated into the planning process for the current application.

5.1 Measures to mitigate impacts

The primary measure to mitigate impacts will be to undertake detailed monitoring, set performance measures in line with Conditions of Approval, and determine adaptive management measures, mitigation strategies and remediation works should performance measures be exceeded.

The existing Biodiversity Management Plan (BMP) for Longwalls 4 and 5 (Biosis 2012a), which currently outlines the above for Longwalls 4 and 5, will be updated. A monitoring plan consistent with the monitoring plan outlined in the existing BMP for Longwalls 4 and 5 (Biosis 2012a) will be adopted and expanded for Longwall 6 and included in the revised BMP. The current monitoring focuses on natural features at risk of subsidence effects, including upland swamps. The BMP includes:

- Monitoring of vegetation in upland swamps according to the Before-After Control-Impact (BACI) design where data is collected before (baseline) and after impact at control and impact sites. Data collected during baseline monitoring will be used for comparison of data collected during and after mining and data collected at impact sites will be compared to data collected at control sites (control-impact).
- Monitoring of upland swamps using shallow piezometers to gauge any changes in standing water levels and swamp groundwater quality (see Geoterra 2012b).

The BMP will be updated to include Longwalls 1 – 3 and 6 – 11. The BMP will be further updated to include a detailed upland swamp monitoring plan. The purpose of this detailed monitoring plan will be to determine, as far as possible, the historic impacts on swamps and establish a comprehensive monitoring regime for water, ecology and geotechnical elements of swamp communities.

Key elements of the monitoring plan will include:

- 3D subsidence surveys to gather detailed data on subsidence levels, particularly in upland swamps CCUS4 and CCUS5.
- Shallow piezometers to monitor changes in water levels and quality in upland swamps.
- A network of weirs to monitor base flow from upland swamps and inflows into Cataract Creek.
- Monitoring to get detailed data on climatic conditions.
- Detailed vegetation monitoring, as outlined above.

The aim of the upland swamp monitoring plan will be to determine whether subsidence associated with longwall mining results in impacts to the ecological functioning of upland swamps. The specific objectives of the upland swamp monitoring program will be to

- Assess upland swamp hydrology.
- Provide advance warning of potential breaches of subsidence predictions.
- Allow for detection of adverse impacts on upland swamp and underlying strata hydrology.
• Allow for the detection of secondary impacts, such as erosion or changes in the size or distribution of vegetation within an upland swamp, should primary impacts occur.

• Characterise the relationship between swamp/s and their role in recharging the regional groundwater systems.

• Characterise the relationship between swamp/s and their role in providing baseflow to local watercourses.

The plan will be developed in consultation with relevant stakeholders.

An adaptive management plan will be developed to use the monitoring program to detect the need for adjustment to the mining operations so that the subsidence predictions are not exceeded and subsidence impacts creating a risk of negative environmental consequences in upland swamps are minimised.

Further measures to mitigate potential small scale affects of subsidence will be considered as required.

5.2 Measures to offset residual impacts

A Biodiversity Offset Strategy would be developed if triggers, outlined in the Conditions of Approval and detailed in the Biodiversity Management Plan, are exceeded. If the Action is deemed a controlled action and threatened species and communities are considered controlling provisions due to impacts to upland swamps, a full assessment will be undertaken in accordance with the assessment approach chosen by the Minister. If necessary, an offset strategy will be developed, in line with the Commonwealth Environmental Offsets Policy (DSEWPaC 2012).
References


Appendix
Appendix 1
Figure 7: Flow accumulation pre- and post-mining, upland swamp CCUS3, Longwall 6

Legend
Vegetation Sub-Communities
- MU42, Upland Swamps: Banksia Thicket
- MU43, Upland Swamps: Tea-Tree Thicket
- MU44, Upland Swamps: Sedgeland-Heath Complex
- MU44a, Upland Swamps: Sedgeland-Heath Complex (Sedgeland)
- MU44b, Upland Swamps: Sedgeland-Heath Complex (Restioid Heath)
- MU44c, Upland Swamps: Sedgeland-Heath Complex (Cyperoid Heath)

Flow accumulation pre-mining (m²)
- 0 - 2,500
- 2,500 - 5,000
- 5,000 - 10,000
- 10,000 - 100,000
- 100,000 - 1,000,000
- 1,000,000 - 17,179,869,180

Flow accumulation post-mining (m²)
- 0 - 2,500
- 2,500 - 5,000
- 5,000 - 10,000
- 10,000 - 100,000
- 100,000 - 1,000,000
- 1,000,000 - 13,307,610
Figure 8: Flow accumulation pre- and post-mining, upland swamp CCUS4, Longwall 6

Flow accumulation post-mining (m²)
- 0 - 2,500
- 2,500 - 5,000
- 5,000 - 10,000
- 10,000 - 100,000
- 100,000 - 1,000,000
- 1,000,000 - 13,307,610

Flow accumulation pre-mining (m²)
- 0 - 2,500
- 2,500 - 5,000
- 5,000 - 10,000
- 10,000 - 100,000
- 100,000 - 1,000,000
- 1,000,000 - 13,307,610
Legend

Vegetation Sub-Communities
- MU42, Upland Swamps: Banksia Thicket
- MU43, Upland Swamps: Tea-Tree Thicket
- MU44, Upland Swamps: Sedgeland-Heath Complex
- MU44a, Upland Swamps: Sedgeland-Heath Complex (Sedgeland)
- MU44b, Upland Swamps: Sedgeland-Heath Complex (Restioth Heath)
- MU44c, Upland Swamps: Sedgeland-Heath Complex (Cyperoid Heath)

Flow accumulation pre-mining (m²)
- 0 - 2,500
- 2,500.000001 - 5,000
- 5,000.000001 - 10,000
- 10,000.00001 - 100,000
- 100,000.0001 - 1,000,000
- 1,000,000.001 - 17,179,869,180

Flow accumulation post-mining (m²)
- 0 - 2,500
- 2,500.000001 - 5,000
- 5,000.000001 - 10,000
- 10,000.00001 - 100,000
- 100,000.0001 - 1,000,000
- 1,000,000.001 - 13,307,610

Figure 9: Flow accumulation pre- and post-mining, upland swamp CCUS5, Longwall 6
Figure 10: Flow accumulation pre- and post-mining, upland swamp CCUS6, Longwall 6
Figure 11: Flow accumulation pre- and post-mining, upland swamp CCUS23, Longwall 6

Legend

Vegetation Sub-Communities

- MU42, Upland Swamps: Banksia Thicket
- MU43, Upland Swamps: Tea-Tree Thicket
- MU44, Upland Swamps: Sedgeland-Heath Complex
- MU44a, Upland Swamps: Sedgeland-Heath Complex (Sedgeland)
- MU44b, Upland Swamps: Sedgeland-Heath Complex (Restioid Heath)
- MU44c, Upland Swamps: Sedgeland-Heath Complex (Cyperoid Heath)

Flow accumulation pre-mining (m²)

- 0 - 2,500
- 2,500.000001 - 5,000
- 5,000.000001 - 10,000
- 10,000.00001 - 100,000
- 100,000.0001 - 1,000,000
- 1,000,000.001 - 17,179,869,180

Flow accumulation post-mining (m²)

- 0 - 2,500
- 2,500.000001 - 5,000
- 5,000.000001 - 10,000
- 10,000.00001 - 100,000
- 100,000.0001 - 1,000,000
- 1,000,000.001 - 13,307,610

Coordinate System: GDA 1994 MGA Zone 56

Acknowledgements: Topo (c) NSW Land and Planning Information (2011); Overview (c) State of NSW (c.2003)
Figure 12: Flow accumulation pre- and post-mining, upland swamp CRUS1, Longwall 6.