Department of Planning & Infrastructure

Gujarat Underground Expansion: Preferred Project Report

Review of Surface Water Issues

January 2014

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1 Introduction

This report provides a review of the surface water aspects of the modified Underground Expansion Project proposed by Gujarat NRE Coking Coal Ltd (NRE) as set out in the *Preferred Project Report including Response to Submissions* (PPR) (September 2013). Because the separate sections of the document deal with the same subject matter, for ease of reference they are referred to as follows:

- *Preferred Project Report (PPR);*
- *Response to Submissions (RTS)*

Features of the modified project relating to surface water management include:

- Extensive modification of the Wonga East longwall layout to minimise impacts to identified significant features;
- Limiting the extent of the Wonga Mains driveage so that it will not extend northwards under the south arm of Cataract Reservoir;
- Removal of the Wonga West longwalls from the application.
- No change to the following aspects as presented in the original *Environmental Assessment* (*EA*) (ERM, February 2013):
  - Pit Top upgrade,
  - Extraction rate of 3 million tonnes per annum (Mtpa),
  - Peak rates of coal transport.

The PPR includes:

- A *Subsidence Assessment* undertaken for the *PPR* (SCT, September 2013) that includes a review of previous mining in the Bulli and Balgownie Seams together with an estimate the subsidence likely to be associated with revised layout of the longwall panels in the Wongawilli Seam.
- Revised impact assessments (Biosis, September 2013) for significant natural features previously recorded within the study area (including upland swamps), based on the revised subsidence predictions. The assessment includes additional surveys and information that have been undertaken or has become available since the EA was submitted; and includes assessment of likely historic impacts due to previous mining of the Bulli and Balgownie Seams.

The PPR notes that:

> *"NRE is currently remodelling the potential catchment area surface water effects from the Preferred Project in accordance with advice from the DPI's independent surface water review findings. The new model will benefit from significantly improved understanding of subsidence behaviour and better stream, swamp and groundwater monitoring baseline data. This modelling process will take up to 3 months."*

Accordingly, some surface water related issues will only be resolved once the further analysis is completed. However, as noted in the *PPR*, the modified mine plan is intended to reduce surface subsidence impacts and, accordingly, any impacts on streamflow and water quality are anticipated to be smaller than those described in the *EA*. Notwithstanding, further review will be required once the remodelling has been undertaken and additional issues for inclusion in any *Catchment Surface Water Management Plan* for the project may arise.

This report provides a review and assessment of the potential surface water impacts of the modified project with particular focus on the risks to the headwater swamps in the vicinity of the modified longwall layout. The report is structured as follows:

Section 2 reviews the predicted subsidence impacts resulting from mining of the Wongawilli Seam**;**

Section 3 reviews the available information on the hydrologic status the headwater swamps taking account of the inferred subsidence attributable to previous mining of the Bulli and Balgownie Seams;

Section 4 Reviews the assessment of the risks to the headwater swamps from the predicted subsidence resulting from the proposed mining of the Wongawilli Seam based on the predicted subsidence;

Section 5 provides an assessment of the potential impacts of the modified mine plan to Cataract Creek;

Section 6 summarises and comments on the proposed upgrade works to the Pit Top area and matters covered in the response to submissions relating to the Pit Top area;

Section 7 provides comments in relation to matters to be considered in any conditions of approval and the preparation of an updated surface water assessment. These comments are limited by the fact that further groundwater modelling and surface water modelling is still to be completed.

This report should be read in conjunction with the original report relating to surface water issues, *NRE N0 1 Colliery Project: Review of Surface Water Assessments*, (Evans &Peck, June 2013), particularly in relation to detailed assessment of those aspects of the project that remain unchanged (primarily in the pit-top area). For these issues, this report only provides an overview of the matters covered in the original report or that require further comments in regard to matters raised in the *Preferred Project Report Including Response to Submissions.*

For purposes of this report the term 'project assessment area' is taken to mean the 'Assessment Area', as defined in Section 2.2.2.2 of the *PPR*, namely;

> *"The Assessment Area has been defined as an area that extends to a horizontal distance of 600m from the outside edge of any of the proposed longwall panels including LW4 and LW5."*

Much of the assessment in this report relies on the subsidence predictions contained in the *Subsidence Assessment for the NRE Preferred Project Russell Vale No 1 Colliery* (SCT, 2013 which forms Attachment B to the *Preferred Project Report*). That report only considers conventional subsidence, upsidence and valley closure. However, the *PPR* (Section 2.2.9.3) acknowledges the additional possibility of connective cracking from surface to seam but notes that this has not been observed over LW4 or LW5 and the *PPR* contends that it is considered extremely unlikely. This view is supported in the letter report by Hebblewhite (18 December 2012) which reported on further discussions between relevant experts and concludes that:

". . . the risk of inter-connective cracking is considered low in the vicinity of LW7 (or any other part of the proposed workings)."

2 Impacts of Mining

2.1 Subsidence Predictions

The *PPR*, in particular the *Subsidence Assessment* (Annexure B), provides an assessment of the estimated subsidence that occurred as a result of previous mining in the Bulli and Balgownie Seams and the predicted additional subsidence as a result of mining the Wongawilli Seam. It is not the purpose of this review to comment on the subsidence methodology and assumptions. Accordingly, it is assumed that Annexure B provides reasonable estimates of the magnitude and location of subsidence impacts.

The Bulli Seam was mined from the late nineteenth century through to the 1950's using a variety of mining systems including mechanised pillar extraction in the later stages. The Balgownie Seam was mined as one of the first longwall mining operations in Australia from 1970 through to 1982. Consequently, any gradual changes in the vegetation within the headwater swamps as a result of increased drainage resulting from subsidence impacts have had over 30 years to become apparent.

The *PPR* and Annexures contain various figures that separately show the location of the headwater swamps and the estimated subsidence contours resulting from previous and proposed mining. However, none of the figures show all of the features of relevance together:

- Location of swamps and creeks;
- Land surface contours;
- Estimated subsidence.

In order to provide a basis to better understand the spatial relationship of these features, and the surface water context surrounding the swamps, Gujarat NRE provided maps showing these features for historic and predicted subsidence. **Figure 2.1** and **Figure 2.2** are reduced size copies of the original plans that ware provide at A1 size to assist with analysis. As shown on both these figures, the modified layout has all longwalls offset by a minimum of 50 m from Cataract Creek and its third order tributaries. All other longwalls except LWs 4, 9, 10 and 11 run under at least one first or second order watercourse.

For purposes of the *EA* and *PPR* all swamps mapped have been mapped on the basis of common features of the relevant vegetation community. This has led to the swamps having highly irregular shapes that do necessarily reflect all the surface water factors that would influence the hydrologic behaviour of the swamps such as any contributing up-slope catchment area and variations in soil characteristics and depth. The likely variation in soil characteristics and depth within a single swamp (defined by the vegetation community), and the area and lateral extent of some swamps implies that each vegetation community is capable of surviving in a variety of hydrologic conditions.

Table 2.1 summarises the subsidence data for swamps most likely to be affected by mining in the Wongawilli Seam (taken as maximum tensile strain > 1 mm/m). The data has largely been drawn from the table "*Incremental Subsidence for Proposed Mining in the Wongawilli Seam*" in Appendix 1 of Annexure B to the *PPR* with the exception of the following data taken from Table 15 in Annexure A to the *PPR*:

- 'Maximum Subsidence within Swamp' (Column 2);
- 'Overburden Depth' (Column 4);
- 'Longwall Panel Width' (Column 5); and
- 'Ratio of Overburden Depth to Longwall Panel Width' (Column 6).

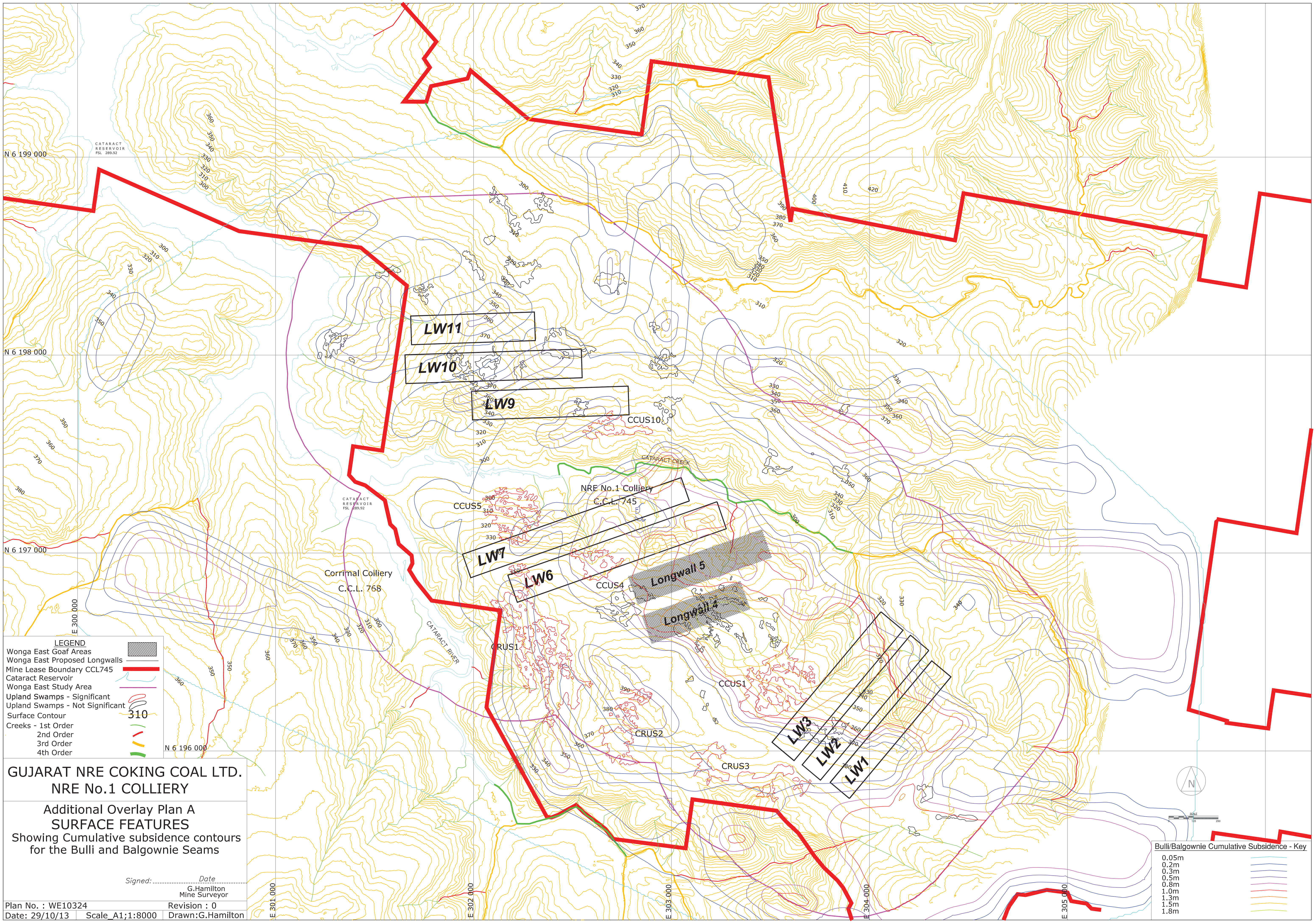
In the process of compiling the data for **Table 2.1**, a number of differences were noted in the data drawn from the two sources. In particular:

- The values of 'Adjacent Subsidence Used to Calculate Strains and Tilts' (Column 3) in Table 15 of Annexure A are inconsistent with the equivalent values quoted in Appendix 1 of Annexure B. It is assumed that this is a transcription error and that the values in Annexure B are correct.
- The 'Overburden Depth' quoted in Appendix 1 of Annexure B appear to be the overburden depth above the Wongawilli Seam whereas the values in Table 15 of Annexure A represent the minimum overburden depth above the Bulli Seam. The latter values have been adopted for **Table 2.1**.

Table 2.1: Swamps with Predicted Tensile Stress >1 mm/m

Swamp	Max Subsidence within Swamp	Adjacent Subsidence Used to Calculate Strains and Tilts	Overburden Depth	Longwall Panel Width	Ratio of Overburden Depth to Longwall Panel Width	Max Tensile Strain	Max Compressive Strain	Max Tilt
	(m)	(m)	(m)	(m)		(mm/m)	(mm/m)	(mm/m)
BCUS4	1.0	1.5	295	150	1.97	6.8	13.6	23
BCUS11	1.5	1.5	335	150	2.23	6.1	12.2	20
CCUS1	0.6	1.5	285	-	-	7.0	14.1	23
CCUS2	2.0	2.0	285	150	1.90	9.4	18.8	31
CCUS3	1.0	1.5	300	125	2.40	6.7	13.4	22
CCUS4	1.4	2.0	290	150	1.93	9.2	18.5	31
CCUS5	1.2	1.5	272	131	2.08	7.3	14.7	24
CCUS6	2.0	2.0	285	125	2.28	9.4	18.8	31
CCUS10	0.8	0.8	280	150	1.87	3.8	7.6	13
CCUS11	1.8	2.0	340	150	2.27	8.8	17.6	29
CCUS12	1.0	1.5	355	150	2.37	5.8	11.5	19
CCUS21	<0.1	2.0	280	-	-	9.5	19.0	32
CCUS23	0.2	1.5	310	125	2.48	6.5	13.0	22
CRUS1	1.4	1.5	300	150	2.00	6.7	13.4	22

Unfortunately, the data provided in the *PPR* and Annexures does not include mapping to show the location of maximum tensile stress. For subsequent assessment of the most likely location of any surface cracking (see **Section 4** below), it has been assumed that this would be most likely to occur in the region of maximum convex curvature (as inferred from the subsidence contours).

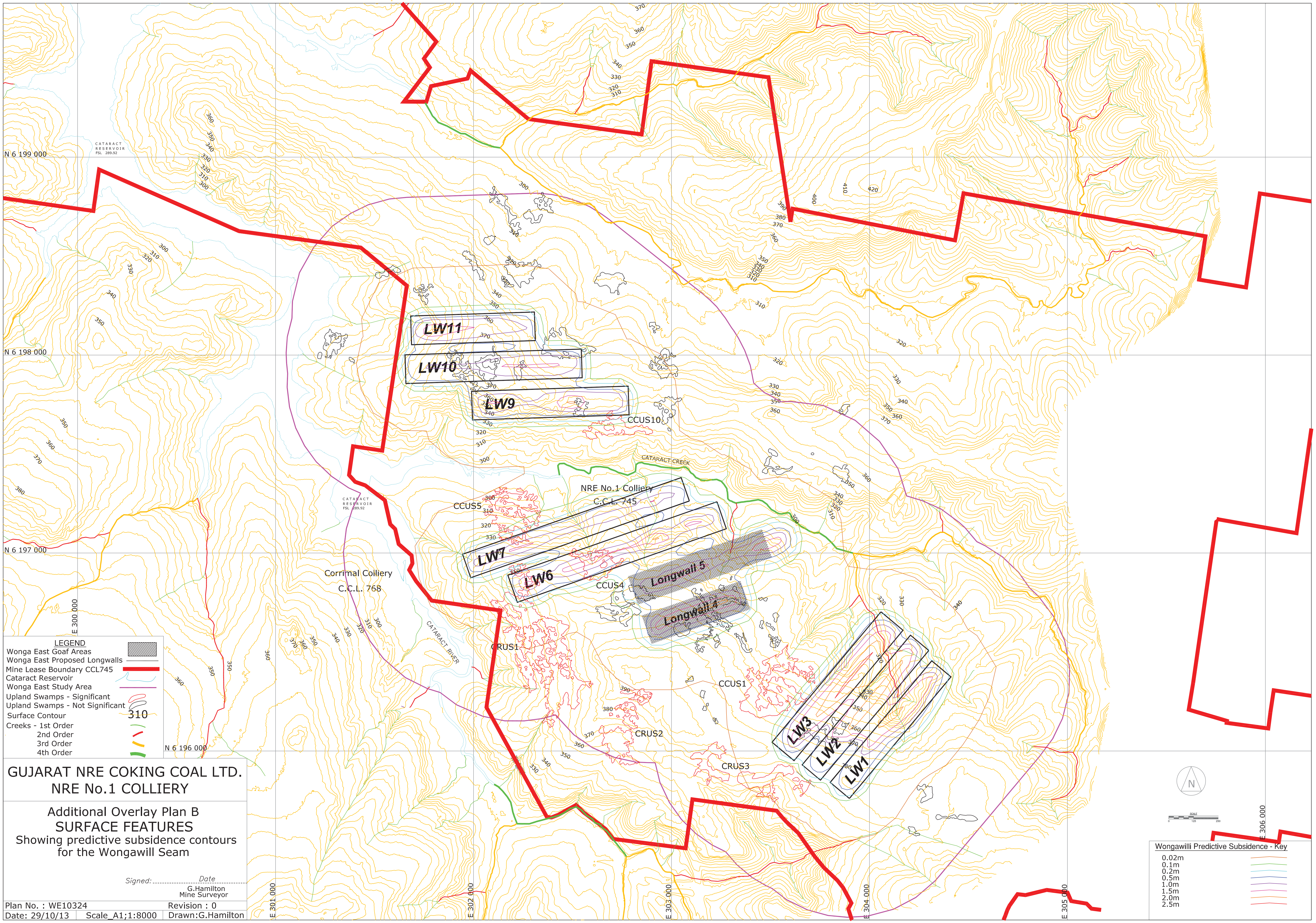


GUJARAT NRE COKING COAL LTD.
NRE No.1 COLLIERY

Additional Overlay Plan A
SURFACE FEATURES
Showing Cumulative subsidence contours
for the Bulli and Balgownie Seams

Signed:............................ Date
G.Hamilton
Mine Surveyor

Plan No. : WE10324 Revision : 0
Date: 29/10/13 Scale_A1;1:8000 Drawn:G.Hamilton



GUJARAT NRE COKING COAL LTD.
NRE No.1 COLLIERY

Additional Overlay Plan B
SURFACE FEATURES
Showing predictive subsidence contours for the Wongawill Seam

Signed:.................. Date
G.Hamilton
Mine Surveyor

Plan No. : WE10324 Revision : 0
Date: 29/10/13 Scale_A1;1:8000 Drawn:G.Hamilton

2.2 Potential Subsidence Effects

The potential effects of subsidence on headwater swamps include:

- Differential settlement leading to change in the bed level relative to any drainage outlet (if one exists), and:
  - Increased water storage capacity of the swamp if the subsidence occurs up-slope of any drainage outlet;
  - Decreased water storage capacity if the subsidence occurs at the outlet;
  - Change in flow pathways through the swamp due to changes in ground level (tilt) (as assessed by Biosis using 'flow accumulation modelling'). The *RTS* (**Section 3.1.3**) acknowledges that this analysis is primarily applicable to valley-fill swamps.)

  Notwithstanding these possible effects, because the surface slope of the headwater swamps is of the order of 10% (10 m in 100 m), subsidence of the order of a few metres is unlikely to significantly impact on the water storage characteristics or flow pathways of these swamps.

- Cracking due to tensile or compressive strains, or unconventional subsidence. The impact of any cracking will depend significantly on nature of the cracking (depth and any sub-surface shearing) and the location of any cracking with respect to the local topography:
  - Cracking towards the up-slope edge of the swamp has the potential to re-direct surface runoff from the contributing catchment;
  - Cracking within the body of the swamp or towards the down-slope boundary has the potential to drain any seasonal perched water table;
  - Cracking towards the sides of the swamp is unlikely to have a significant impact on any runoff contribution from up-slope or the balance of incident rainfall and evapotranspiration loss that leads to a seasonally varying perched water table.

In addition, as noted in the *Bulli Seam Operations PAC Report* (PAC, July 2010):

> *"Consequences of these impacts depend upon a wide variety of factors such as how much water is lost, over what period, whether "self-healing" occurs and to what degree, and whether there are severe rainfall events or fire events. Depending on these factors and their interactions, a swamp could show no evidence of change, or be severely damaged over a relatively short space of time."*

It is recognised that subsidence prediction is an imprecise science, particularly in the case of multi-seam mining. In his review of the subsidence assessments in the *PPR*, Hebblewhite (November 2013), noted that:

> *"In discussing strains and tilts, it is worth emphasising the point made by SCT that it is simply not possible to predict exact locations of maximum or peak strains, and hence potential crack locations, for example. Regions where such strains might occur can be identified, but it is never going to be possible to predict in advance the actual location of actual cracks in the rock mass."*

2.3 Connective Cracking

The *PPR* (Section 2.2.9.3) acknowledges the additional possibility of connective cracking from surface to seam but notes that this has not been observed over longwalls LW4 or LW5 and is considered extremely unlikely.

In his review of the groundwater assessment for the project, Tammetta (20/12/2013), (page 11) notes:

"The PPR states that swamps have undergone subsidence due to previous mining, and that despite this, they are reported as thriving. The height of the collapsed zone from previous mining is calculated to not have reached the surface tensile cracking zone, therefore permanent drainage from the swamp to a goaf is unlikely to have occurred. If H intersects the ground surface, permanent drainage will occur. Where H does not reach to surface, filling of only a finite surface storage (increased void ratio from surface tensile fracturing) occurs, frequently resulting in temporary water loss.

Notwithstanding the possibility of connective cracking raised by Tammetta, Hebblewhite 18/12/2013) reports on joint discussions with Tammetta and Dr Mills (of SCT):

"It is understood that Mr Tammetta's original reported results which suggested an intersection with the surface were based on using the sum of all three mined or proposed to be mined seams, i.e. Balgownie, Bulli and Wongawilli. However, further analysis by Dr Mills suggests that in the area in question above Wongawilli LW7, the Bulli Seam workings only consisted of development roadways, not extraction. As such, it is considered inappropriate to include the thickness of the Bulli Seam workings in the calculation for H. Without the Bulli Seam thickness, the calculated value of H using Tammetta's equations, does not intersect the surface. Therefore based on the above interpretation, the risk of inter-connective cracking is considered low in the vicinity of LW7 (or any other part of the proposed workings)."

Connective cracking between the surface and the mine workings would provide a pathway for water to drain from a creek or swamp. In both cases, it is possible that some reduction in water loss might occur over time as fine sediments gradually fill the surface cracks. However the occurrence and effectiveness of any sealing will be highly dependent on the size of the cracks in the sandstone and the availability of suitable sized soil particles to create a full or partial seal. While the possibility of such self-sealing has been contemplated by others (e.g. the *Bulli Seam Operations PAC Report*, quoted above), there does not appear to be any quantitative evidence of the effectiveness of this mechanism.

3 Hydrology of Headwater Swamps

3.1 Upland Swamps

Upland swamps are found on sandstone plateaux areas with rainfall in excess of about 1,200 mm. Any consideration of potential impacts of subsidence on upland swamps needs to clearly distinguish between:

- **Valley fill swamps** located either side of drainage lines. These swamps have relatively shallow down slope gradient dictated by the gradient of the drainage line and contain areas of open water. No valley fill swamps are located in the vicinity of the proposed Wonga East mining operations. Because of their topographic location, valley fill swamps are likely to receive some groundwater baseflow.
- **Headwater swamps** located on the hillside with typical gradient of the order of 10% in the Wonga East area. Some, but not all, of these swamps drain via first order streams. Because of their topographic position, headwater swamps are reliant on direct rainfall and any contribution of surface runoff from the up-slope contributing catchment. Headwater swamps exhibit seasonally varying perched water tables that are independent of the regional water table in the underlying Hawkesbury Sandstone. All swamps in the vicinity of the proposed Wonga East mining operations are headwater swamps. These swamps vary in area from 0.26 to 9.84 ha and typically extend between 100 and 430 m in the down slope direction.

3.2 Published Assessments and Reviews

Because of the wide distribution of upland swamps on the Woronora plateaux and the potential impacts of underground mining, the hydrology of upland swamps has received considerable public scrutiny, particularly in:

- *Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield: Strategic Review* (Department of Planning, July 2008);
- *Bulli Seam Operations – PAC Report* (Planning Assessment Commission, July 2010).

In addition, the Office of Water Science (Department of the Environment, Canberra) commissioned

- *Peat Swamps – Ecological Monitoring*
- *Peat Swamps – Engineering Subsidence*

These two reports are not yet in the public domain.

Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield: Strategic Review quotes various sources that indicate the dates of basal sediments vary between roughly 2,000 – 17,000 years. Fryirs et al (2012) describe the upland swamps inn the Blue Mountains as, *"accumulations of mineral sands and organic pert that started forming around 13,000 years BP and have accumulated throughout the Holocene to today"*.

As reported by Ross (2009), monitoring of headwater swamps in the Kangaloon area by SCA suggests the water table in the swamps is perched; the water table in the underlying sandstone is situated some 4 to 5 m below the swamp(s). This finding is consistent with the location of headwater swamps away from the main drainage lines.

3.3 Swamps in the Wonga East Area

Annexure A to the PPR (*NRE No. 1 Colliery – Underground Expansion Project: Preferred Project Report – Biodiversity*, Biosis, 2013) provides additional detail relating to a number of piezometers installed to measure the perched water table levels in a number of the swamps located along the ridge that separates the catchments of Cataract Creek and Cataract River. **Figure 3.1** is a reproduction of the piezometer data depicted in Graph 2 of the Biosis report (raw data provided by Gujarat NRE) together with daily rainfall data for the Bureau of Meteorology site at Darkes Forest (Station No. 068024).

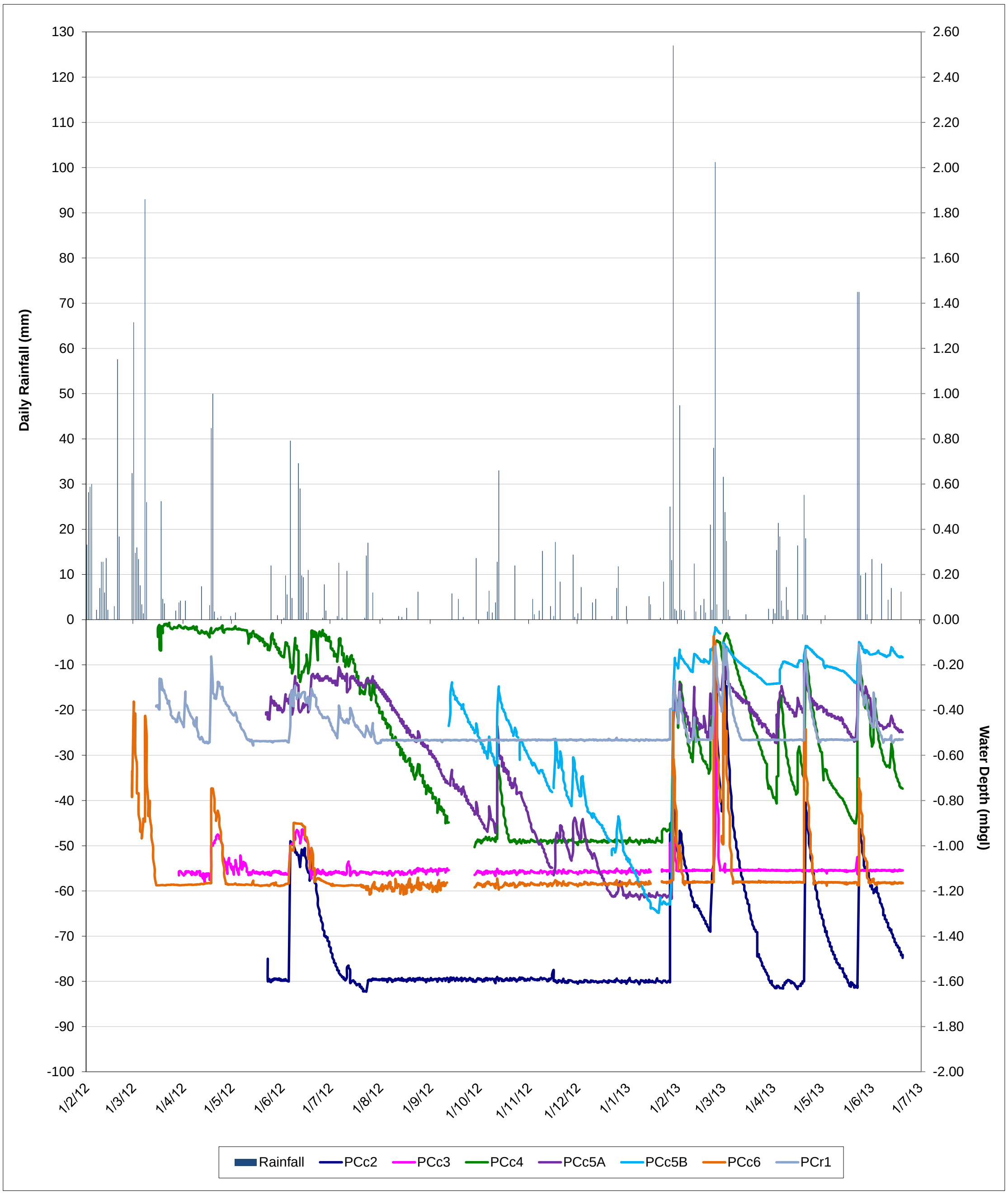


Figure 3.1:
Daily Rainfall and Swamp Piezometer Hydrographs for the Wonga East Area

For purposes of the analysis provided below, the rainfall data from Darkes Forest has been adopted for **Figure 3.1** because the data from the No 4 Site (collected by Gutarat NRE) has some missing data. As indicated on the rainfall isohetal map of the area (Figure 4.4 in *NRE No 1 Colliery Surface Water Modelling*, WRM, 2012 which forms an appendix to Annex O of the EA), the average annual rainfall at Darkes Forest is comparable to that of the Wonga East project area.

Figure 3.2 shows the vertical profiles of the piezometers taken from Figure 11 of the *Groundwater Assessment* (GeoTerra 2012). The figure shows that all piezometers were constructed to a depth below the interface between the swamp material and the weathered sandstone. **Table 3.1** summarises details of the piezometers extracted from Table 3 of the *Groundwater Assessment*.

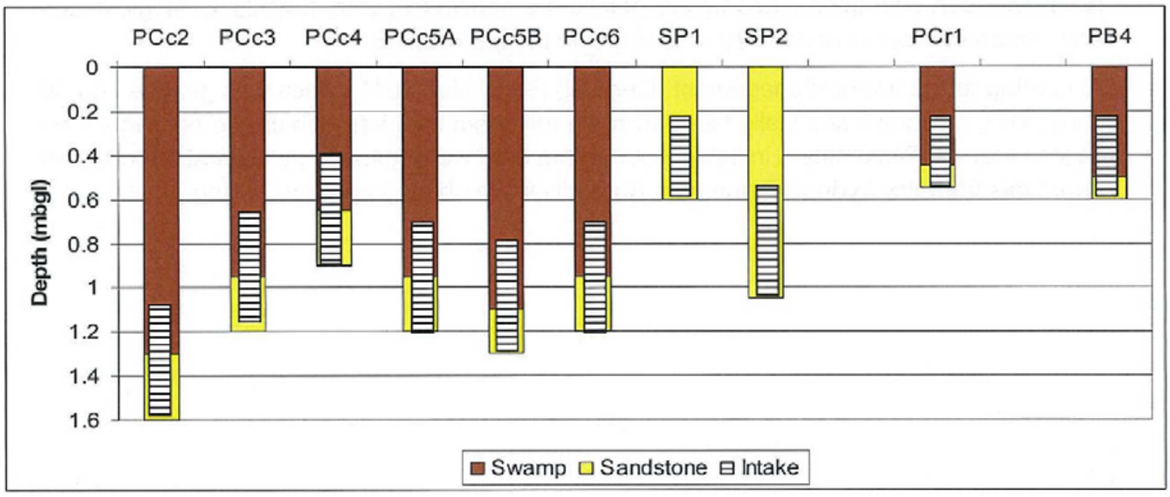


Figure 3.2:
Piezometers in the Wonga East Area

Table 3.1: Details of the Piezometers in the Wonga East Area

Piezometer	Swamp	Total Depth Below Ground (m)	Depth to Sandstone (m)	Swamp Material
PCc2	CCUS2	1.60	1.30	Humic sandy clay
PCc3	CCUS3	1.20	0.95	Sandy clay
PCc4	CCUS4	0.90	0.65	Sandy clay
PCc5A	CCUS5	1.24	0.95	Humic sandy clay
PCc5B	CCUS5	1.31	1.10	Humic sandy clay
PCc6	CCUS6	1.20	0.95	-
PCr1	CRUS1	0.55	0.45	Humic sandy clay

The assessment of the groundwater behaviour provided in the text by Biosis is limited to how rapidly the water levels fall following significant rainfall. No assessment has been provided of the hydrologic processes associated with the different behaviour.

For purposes of further detailed analysis set out below, the slope of each hydrograph has been compared to the average seasonal point potential evapotranspiration rate that would occur if water supply to vegetation was not limited (derived from the point spatial data on CD for *Climate of Australia: Evapotranspiration*, BoM 2003). The analysis also assumes an effective porosity of 50% for the soils characterised in **Table 3.1**. While values that are more precise could be adopted following field analysis, the assumed value provides a reasonable basis for an indicative analysis.

The analysis indicates that the hydrographs fall into four categories:

1) Water level reduction that can be accounted for by evapotranspiration loss. This category includes piezometers PCc5A and PCc5B, both of which are located in swamp CCUS5 in which the water level was drawn down below the interface between the swamp and the underlying weathered sandstone in January 2013. This swamp was subject to an estimated 0.6 m maximum subsidence along its south-eastern edge as a result of mining of the Bulli and Balgownie Seams (see **Figure 2.1**). While the estimated subsidence occurred to the south-east of the locations of the piezometers, the hydrographs infer that water retention characteristics of CCUS5 have not been affected by subsidence.

2) Water level reduction that can be largely, but not fully, accounted for by evapotranspiration loss. This category includes piezometers PCc4 and PCr1, located in swamps CCUS4 and CRUS1 respectively. **Figure 2.1** shows the cumulative subsidence as a result of mining of the Bulli and Balgownie Seams as 0.9 m and 0.6 m respectively. The slope of the water level drawdown after rainfall cannot be fully explained by evapotranspiration. In particular:

   - The rapid fall in water level in PCc4 following rainfall in the middle of October 2012 which led to a rise of about 0.4 m in PCc4 followed by a return to a 'base' level (assumed to be the interface between the swamp and the underlying sandstone) within about 5 days;
   - Similar rapid falls in the water level following the rainfall events in February to May 2013;
   - In the case of PCr1, the water level shows relatively muted response to rainfall in the period up to the end of July 2012. The hydrograph shows no response to the rainfall events in mid-September and mid-October 2012, suggesting that the water level recorder malfunctioned.
   - For the rainfall events between February and May 2013, the rate of the fall in the water level is significantly greater than can be accounted for any evapotranspiration.

   It is interesting to note that the recorded water level in PCc4 fell to a level of about 0.95 m below ground level in the period between November 2012 and late January 2013. As this level is below the quoted depth of the base of the piezometer, the accuracy of the level measurements is questionable.

3) Water level lowering that follows a characteristic gradual slowing in the rate that suggests drainage from a swamp to a creek, which would help sustain baseflow. This behaviour is exhibited by piezometer PCc2 in swamp CCUS2. This swamp, which is located in the vicinity of proposed longwalls LW2 and LW3, was subject to estimated maximum subsidence of 1.1 m as a result of mining in the Bulli and Balgownie Seams. While the hydrograph recession suggests drainage to a creek, the mapping (**Figure 2.1**) shows the nearest identified drainage line starting about 150 m down-slope of the swamp.

4) Rapid water level lowering following rainfall, typically falling back to a 'base' level within 5 to 10 days of rainfall, which suggests that water is being lost from the base of the swamp into the underlying sandstone. Piezometers PCc3 and PCc6 (swamps CCUS3 and CCUS6) are examples of this behaviour. Both these swamps are located over LW4 and LW5 and were subject to 1.0 m and 1.8 m maximum subsidence respectively, as a result of previous mining (see **Figure 2.1**). LW4, which runs beneath CCUS6, was extracted between 19 April and 18 September 2012. Because the site of the piezometer is about 30% of the way along the longwall, the site of piezometer itself is unlikely to have been undermined before the start of June 2012. The start of mining occurred <u>after</u> the rise and rapid fall of water level following rainfall in February and early March 2012 (which led to persistent elevated water levels at

PCcs5A in Swamp CCUS5). The fact that rapid water level lowering occurred before the influence of subsidence from longwall LW4 infers that the rapid drawdown cannot be attributed to mining of LW4. Notwithstanding the apparent rapid drainage of these 'swamps', the vegetation communities have been classified as consistent with the vegetation communities that define an upland swamp:

- CCUS3 Banksia Thicket (MU42) and Sedgeland (MU44a);
- CCUS6 Banksia Thicket (MU42).

It is interesting to note the fact that only one of the headwater swamps, out of six, exhibits behaviour consistent with the hypothesised significant contribution to baseflow from upland swamps in general. This suggests that the dominant contribution to baseflow may be valley-fill swamps rather than headwater swamps, not upland swamps in general as is commonly supposed.

The Biosis report links the different behaviour of the perched groundwater systems to differences in the vegetation:

"Groundwater data from piezometers located in upland swamps within the study area indicates that there are varying degrees of contact with groundwater resources in these upland swamps. CCUS4 and CCUS5 show significant groundwater contact for prolonged periods, CCUS2 shows some contact but recedes rapidly, 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, 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 and MU43, is an anomaly. This upland swamp has shallow soils and areas of MU43 are likely to be located in areas of terracing, resulting in water accumulation in depressions in bedrock."

The conclusions with respect to the vegetation in CCUS3 and CCUS6 suggest that the episodic perched groundwater conditions in these swamps pre-date the recent mining of longwalls LW4 and LW5. However, the rapid draw down of the water level following rainfall suggests that water is being lost through the base of these swamps, possibly as a result of cracking due to subsidence from previous mining activities. Given that the previous mining occurred 30 years ago, it is possible that the existing vegetation has had time to adapt to any change in swamp hydrology.

Biosis (Attachment A to the PPR) concludes that:

"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 13 and Table 14), substantially above what has been predicted by MSEC to result in fracturing of bedrock in waterways (DoP 2010) and the criteria listed in OEH (2012) 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. However, monitoring data is not available to confirm whether this has occurred."

Overall, it appears that the majority of the headwater swamps that have been subject to subsidence from previous mining have maintained a perched groundwater system that does not show evidence that cracking may have occurred. The exceptions are swamps CCUS3 and CCUS6. Notwithstanding, it appears that the vegetation in these swamps has similar characteristics to other swamps in the area. Therefore, any link between possible cracking of the base of a swamp and change in vegetation remains an unanswered question.

In terms of subsidence impacts on swamps, Biosis acknowledges the lack of direct linkage between subsidence and hydrologic changes leading to changes in the vegetation community (**Section 3.1.3** of the *RTS*):

> *"Biosis does not assert that subsidence associated with longwall mining does not result in impacts to upland swamps, or that changes in groundwater availability are not an impact to upland swamps. Rather, that the maintenance and persistence of upland swamps is much more complex than has been recognised, and that further research and assessment is required to understand the complex processes that maintain upland swamps, particularly in relation to changes brought about by longwall mining."*

3.4 Groundwater Interactions

The interaction between the perched groundwater in upland swamps and the deeper regional groundwater system in the Hawkesbury Sandstone is not well understood. Golder Associates, (December, 2013) offer the following comments (page 32):

> *'Water levels within these shallow perched 'swamp' systems are highly variable, subject to climatic and seasonal variations in local rainfall amounts. Post-storm surface runoff into a swamp typically occurs via indistinct drainage channels or flow paths to the swamp.*
>
> *Water levels within these shallow swamp systems are entirely separate from the deeper, regional Hawkesbury Sandstone water table. . . . . However in some areas the swamp waters might be at least temporarily hydraulically connected to the uppermost portions of the Hawkesbury Sandstone, where bedding discontinuities or low permeability zones in the sandstone promote lateral flow into or out of a swamp after high rainfall periods. Depending on the relative water levels established soon after rainfall events, ephemeral groundwater seepage from the shallow sandstone might flow to the swamps, or conversely, swamp water might migrate into the underlying shallow ephemeral sandstone aquifer (GeoTerra, 2012).'*

Whilst hydraulic connection between a swamp and a temporarily elevated water table in the sandstone is plausible, the overall contribution to the water balance of a swamp will be dependent on specific local topography and geology. Also, it must be noted that, because of their position on the landscape, it is less likely that headwater swamps would receive a significant contribution from the regional groundwater system compared to valley fill swamps which are likely to receive some 'baseflow' in a similar manner to creeks.

3.5 Monitoring and Management

The monitoring undertaken for the piezometers discussed in Section 3.3 provides an excellent basis for achieving a better understanding of the hydrology of headwater swamps. Useful additional monitoring and analysis activities would include:

- Establishment of a recording meteorologic station within the Wonga East area to measure rainfall and potential evapotranspiration;
- Establishing piezometers at the upslope end and downslope end of a minimum of two swamps in order to understand the down-slope movement of shallow groundwater;
- Adding two flow monitoring points to swamps in which pairs of piezometers (upslope and downslope) are to be installed;

- Monthly review of the water balance of each monitored swamp based on recorded rainfall, estimated evapotranspiration and recorded water levels and outflow measurement.
- Characterisation of soils within the swamps to determine:
  - the porosity - in order to provide a basis for relating piezometer water levels to rainfall and evapotranspiration;
  - the presence, or absence, of clay materials at the interface with the underlying sandstone which could mitigate water loss from the swamp to the underlying sandstone in the event that subsidence induced cracking of the sandstone occurred under a swamp.

4 Impact of Proposed Mining on Headwater Swamps

Figure 4.1 shows the location of headwater swamps with respect to the location of the proposed longwall mining in the Wongawilli Seam.

4.1 Predicted Subsidence and Impacts

Table 4.1 summarises the predicted subsidence effects on swamps in the Wonga East project area subject to more than 1 mm/m tensile stress from mining in the Wongawilli Seam (from **Table 2.1**), together with some of the factors that influence the hydrologic characteristics including:

- Area of the swamp itself;
- Effective contributing catchment area, after accounting for any up-slope swamps;
- Downslope distance from the nearest ridge;
- The down-slope gradient of the swamp; and
- The presence of a defined drainage outlet.

Table 4.1: Subsidence and Hydrologic Characteristics of Selected Wonga East Swamps

Swamp	Max Subsidence within Swamp (m)	Max Tensile Strain (mm/m)	Max Compressive Strain (mm/m)	Max Tilt (mm/m)	Swamp Area (ha)	Contributing Catchment Area (ha)	Distance from Ridge (m)	Slope (%)	Defined Drainage Outlet	Piezometer	Swamp Vegetation[1]
BCUS4	1.0	6.8	13.6	23	2.2	7.0	230	7%	-		MU42, 43
BCUS11	1.5	6.1	12.2	20	0.26	0.5	25	15%	-		MU42, 44b
CCUS1	0.6	7.0	14.1	23	4.81	11.0	200	34%	Yes		MU42, 43,44b, 44c
CCUS2	2.0	9.4	18.8	31	1.21	3.0	150	10%	-	PCc2	MU44a, 44b
CCUS3	1.0	6.7	13.4	22	0.55	7.0	200	9%	-	PCc3	MU42, 44a
CCUS4	1.4	9.2	18.5	31	1.77	6.8	200	11%	Yes	PCc4	MU42,43, 44c
CCUS5	1.2	7.3	14.7	24	3.45	4.5	180	13%	Yes	PCc5A PCc5B	MU42,43, 44a
CCUS6	2.0	9.4	18.8	31	2.05	12	300	11%	-	PCc6	MU42
CCUS10	0.8	3.8	7.6	13	1.63	5.0	160	9%	-		MU42,43, 44c
CCUS11	1.8	8.8	17.6	29	0.34	0.5	60	11%	-		MU42
CCUS12	1.0	5.8	11.5	19	1.84	0	0	6%	-		MU42
CCUS21	<0.1	9.5	19.0	32					-		MU42
CCUS23	0.2	6.5	13.0	22					-		MU42, 44a
CRUS1	1.4	6.7	13.4	22	9.84	11.0	0 - 200	9%	Yes	PCr1	MU42, 43

1. *Source: Appendix 1 of Annex Q to the EA*

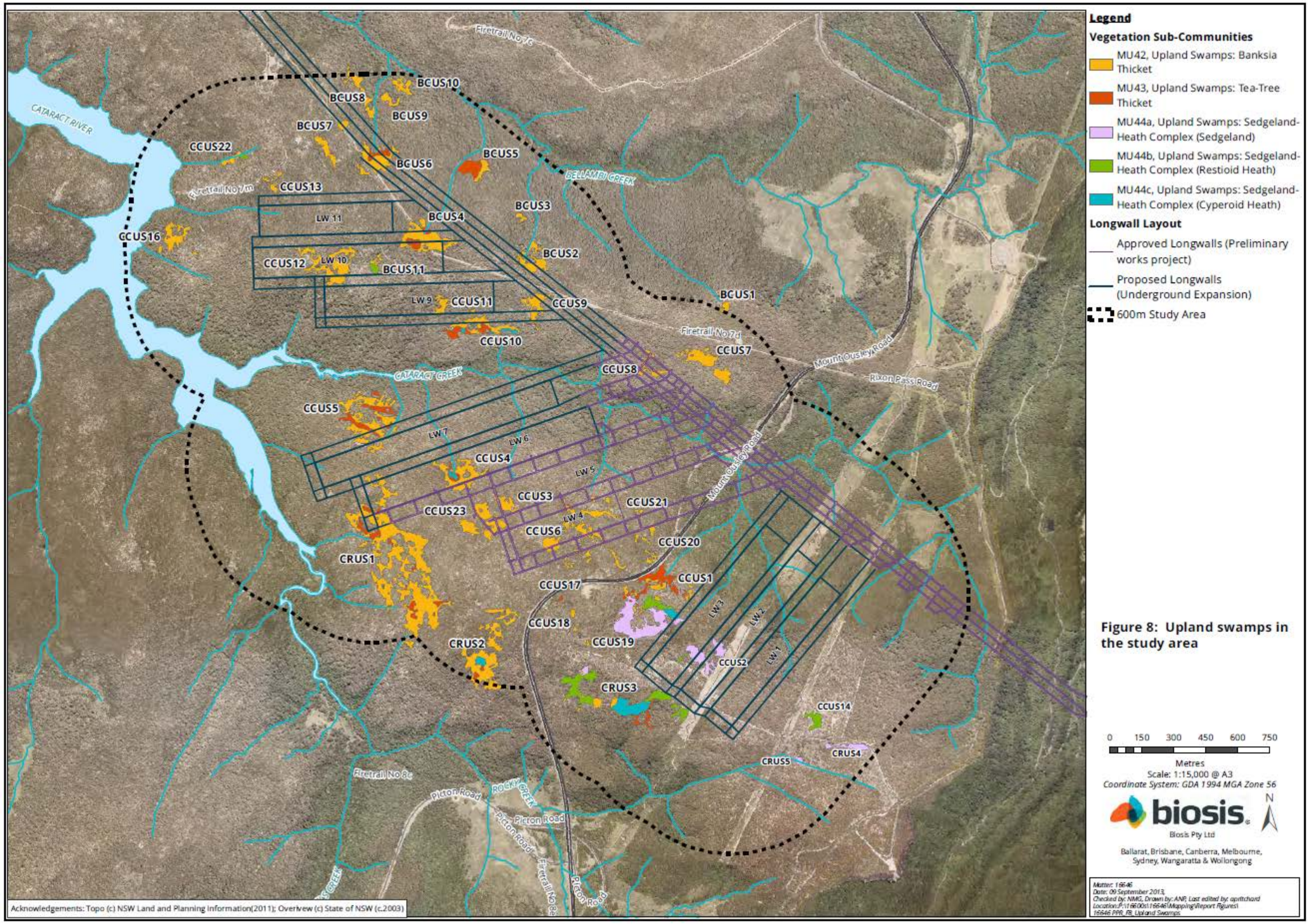


Figure 4.1:
Headwater Swamps of 'Special Significance'
(*Source: Biosis, September 2013*)

Table 4.2 (data from Annexure Q of the *EA*) summarises the various upland swamp vegetation communities and their reliance on waterlogging. The table shows that a number of the communities, while classified as 'swamps' in terms of the vegetation, have vegetation that is less reliant on waterlogging than others. This classification from a vegetation community perspective, together with the recorded behaviour of the piezometers in swamps CCUS3 and CCUS6, suggests that some vegetation communities may lack the characteristics that would classify them as swamps from a hydrologic perspective.

Table 4.2: Reliance on Waterlogging of Vegetation Communities

Classification	Vegetation	Reliance on Waterlogging
MU42	Banksia Thicket	Less reliant
MU43	Tea-tree Thicket	Permanent to intermittent
MU44a	Sedgeland	Less reliant
MU44b	Restioid Heath	Less reliant
MU44c	Cyperoid Heath	Permanent to intermittent

The previous analysis of potential subsidence risks to swamps undertaken by Biosis and documented in Annex Q of the *EA* has been updated to account for the modified mine plan described in the *PPR*. The revised analysis identified two swamps in the Wonga East area (BCUS4 and CCUS4) as being at 'moderate' risk. Biosis conclude:

- *"The revision of the mine plan has resulted in a reduction in risk for several upland swamps, including CRUS2, CRUS3 and CCUS5, and will result in low risk of impact for all upland swamps except BCUS4 and CCUS4."*
- *"The revised mine plan and revised subsidence predictions have resulted in an increase in risk to one upland swamp, CCUS4."*

For purposes of this review, a further assessment of the hydrologic risks to the swamps in the Wonga East area has been undertaken considering the topographic and hydrologic features of the swamps set out in **Table 4.1**. As noted in **Section 2**, the *PPR* and Annexure B do not include mapping to show the location of maximum tensile stress. It has therefore been assumed that the most likely location for any surface cracking would be in the area of maximum convex curvature (as inferred from the subsidence contours).

Table A1 in **Appendix A** provides details of this assessment including the risk of subsidence induced cracking and the most likely location of impacts, taking account of the topographic position of the swamp. **Table 4.3** provides a summary of those assessments, together with the risk as assessed by Biosis (based on subsidence impacts occurring anywhere within the swamp).

The analysis summarised in **Table 4.3** indicates that, notwithstanding the additional features of the individual swamps included in the assessment, the majority of the swamps have a low risk of cracking that would affect the swamp itself or intercept runoff from the contributing catchment. (In this regard, it is acknowledged that the relative contribution of surface runoff or shallow subsurface runoff – at the interface between the soil and underling weathered rock – is not understood in the context of the overall water balance of a swamp.). Two swamps that show up as having some risk (using either method of analysis) are:

- **BCUS4** which is located over the footprint of longwall LW10. The Biosis analysis provides a risk rating of 'moderate' whereas the separate analysis for this review rates it as 'minor'. The difference is not just one of semantics. The 'minor' rating was assessed on the basis that convex curvature would, occur through the middle of the swamp.

- **CCUS4** which is located over the footprint of LW6. The 'minor' rating was assessed on the basis that, while the main body of the swamp would be subject to subsidence, the greatest convex curvature would occur along the up-slope edge. While this might alter the contribution of up-slope runoff, the majority of the swamp is unlikely to be affected.

In addition, the assessment carried out for this review indicates there could also be a 'minor' risk to swamp **CCUS10** located above the footprint of longwall LW10. The 'minor' assessment for this swamp was assessed on the basis that the greatest convex curvature would occur along the up-slope edge, affecting the contribution of up-slope runoff.

4.2 Management, Monitoring and Mitigation

The *EA* (pages 385-386) identifies a range of possible mitigation techniques:

- Use of coir logs to control erosion. This is only applicable where there is a distinct flow path through the swamp and relates to conditions in valley fill swamps rather than headwater swamps.
- Water spreading to redirect flow. This is also only applicable to valley fill swamps where there is a distinct flow path.
- Sealing of observed surface cracks. Because this required cracks to be identified, it is only applicable to the margins of swamps, not the main body of the swamp.
- Injection grouting to seal cracks in the sub-surface rock. While technically possible, this option relies on the precise location and extent of any crack to be identified and is of no practical value where a crack occurs in the body of a headwater swamp.

It can be seen that none of these techniques are applicable to remediating the effects of cracking of the rock underlying a headwater swamp.

The *RTS* (page 284) acknowledges that it is not feasible to remediate bedrock fractures and changes in groundwater availability in upland swamps because the impacts from the remediation works would likely be far greater than the degree of benefit. Accordingly, in this instance, the primary management mechanism is to design a mine plan that minimises potential subsidence impacts. However, ongoing monitoring of groundwater levels at key locations in potentially affected swamps should continue in order to provide further evidence of any impacts and provide an opportunity to regularly reassess the mine plan in terms of stopping longwalls short of the current layout.

The Subsidence Assessment notes that

> *"It is considered that more work is required to determine the relationship between mining subsidence and the long term health of swamps. The extended baseline of subsidence impacts over 60-100 years in the Bulli Seam and 30-40 years in the Balgownie Seam provides a rare opportunity to study these effects. The changes that are expected from proposed mining are nominally sufficient to cause significant impacts to the rock strata and to surface and near surface water flows in the areas directly mined under, so it would be helpful to study how and if the wide range of swamps present above the site are significantly impacted by further mining."*

Table 4.3: Ecological Significance and Potential Subsidence Impacts on Wonga East Swamps

Swamp	Ecological Significance (Note 1)	Relevant Longwall	Subsidence Impacts (Note 2)	Comments	Assessed Risk	
					Biosis	This Review
BCUS4	-	LW10	Subsidence range 0.1 downslope to 1.0 upslope. Maximum convex curvature across centre of swamp	BCUS11 directly uphill, BCUS5 directly downhill. Convex curvature through centre of swamp suggests minor risk	Moderate	Minor
BCUS11	-	LW10	Whole swamp subsided 1.0 – 1.5 m. Negligible convex curvature	BCUS4 directly downhill. Whole swamp to be subsided. Minor curvature on edge of swamp suggest low risk	Low	Low
CCUS1	Significant	LW3	Subsidence range 0.1 – 0.5 m only along SE (side) edge. Negligible convex curvature	Top of minor ridge line, drains to both sides of ridge. Negligible curvature on edge of swamp suggests low risk.	Low	Low
CCUS2	-	LW2, LW3	Subsidence 0.5 – 1.0 m across majority of swamp Negligible convex curvature	Spans chain pillar between LW2 and LW3. Majority of swamp affected by subsidence. Negligible curvature suggests low risk.	Low	Low
CCUS3	-	LW4, LW5	Subsidence 0.1 - 0.2 m on NE (side) edge. Negligible convex curvature along the side edge of the swamp	CCUS4 directly downhill. Minor subsidence and negligible curvature suggest low risk of impact	Low	Low
CCUS4	Significant	LW6	Subsidence 0.1 m on upslope edge to 1.5 m in middle. Minor convex curvature along up-slope edge.	CCUS3 directly up-slope. Whole swamp to be subsided. Absence of significant curvature suggests minor risk of impact.	Moderate	Minor
CCUS5	Significant	LW7	Subsidence 0.1 – 1.0 m along upslope edge only. Max convex curvature along edge of swamp	South edge above LW7. Only minor part of up-slope section of swamp potentially affected. Negligible impact on runoff contribution to remainder of swamp	Low	Low
CCUS6	-	LW4	Subsidence range 0.1 m – 0.5 m across swamp.	Located above LW4. Whole swamp subsided. Relatively uniform subsidence suggests low risk. Swamp already exhibits rapid drainage after rainfall – unlikely to be exacerbated.	Low	Low
CCUS10	Significant	LW9	Subsidence 0.1 – 1.0 m along upslope edge. Maximum convex curvature likely along edge of LW9	Minor subsidence in body of swamp. Minor risk of reduced runoff from upslope catchment (5 ha)	Low	Minor
CCUS11	-	LW9	Whole swamp subsided 0.5 - 1.5 m. Maximum convex curvature likely along upslope edge of swamp	Whole swamp subsided. Relatively uniform subsidence suggests low risk.	Low	Low
CCUS12	-	LW10	Majority of swamp subsided about 1.0 m. Maximum convex curvature likely to only affect minor northern 'arm'	Top of a ridge, drains to all sides. Relatively uniform subsidence suggests low risk.	Low	Low
CCUS21	-	LW4	Subsidence range 0.1 m – 2.0 m across swamp.	Spans across LW4 and subject to significant variation in subsidence. Convex curvature through centre of swamp suggests minor risk	Low	Minor?
CCUS23	-	LW5	Subsidence range 0.5 m – 1.0 m across swamp.	Located above end LW5. Whole swamp subsided. Relatively uniform subsidence suggests low risk.	Low	Low
CRUS1	Significant	LW6	Subsidence 0.02 - 1.5 m in a minor northern arm of swamp along a ridge.	North edge of swamp located above LW6. Subsidence impacts confined to approx. 5% of swamp. Negligible impact on remainder.	Low	Low

Note 1. Swamps CRUS 1 and CRUS2 also assessed as 'significant' but predicted maximum tensile strains are less than 1 mm/m.

Note 2. Convex curvature (inferred from subsidence contours) is taken to be indicative of locations where cracking <u>might</u> occur.

In this regard, the *RTS* notes that:

> *"NRE are currently re-designing the monitoring plan to integrate surface water, groundwater and ecological monitoring programs to ensure a comprehensive assessment of the ecosystem function of upland swamps within the study area."*

A key element of this monitoring should be the expansion of the existing network of shallow swamp piezometers, and regular review (say monthly) to asses any abnormal behaviour that cannot be attributed to evapotranspiration or drainage to a watercourse.

A further relevant undertaking is provided in the *PPR* (page 198):

> *"Due to the disagreement over the potential impacts of subsidence with regard to subsurface water flow and stream networks that is currently prevalent in the scientific and regulatory community, primarily due to inadequate data on both sides of the argument, a network monitoring methodology is being designed, based around CCUS4 and possibly CCUS5, to capture the total water balance of representative sections of surface waterways in order to determine the effects and impacts of subsidence on stream networks from Upland Swamps to Reservoir. This approach will be designed with input from specialists and agencies to ensure the monitoring is reasonable, effective and scientifically robust."*

Overall, the proposed monitoring is likely to significantly enhance the body of knowledge relating to the hydrology of headwater swamps, their role in sustaining different vegetation communities and their role in providing baseflow to the creek system.

5 Potential Mine Impacts on Creeks

5.1 Geological Setting

The potential effects of subsidence on streamflow and pools are heavily influenced by the geology of the creek bed. The *Subsidence Assessment* (Attachment B to the *PPR*) makes the following general points in relation to the geology of Cataract Creek and its tributaries:

- Almost all the second order and higher sections of Cataract Creek that are likely to be influenced by mining flow within Bald Hill Claystone outcrop. However, despite Longwall 11 in the Balgownie Seam causing the creek bed to subside 1.4 m, there have not been any significant long-term effects on the bed of the creek or the character of the creek.
- Where valley closure is less than 200 mm, experience in Hawkesbury Sandstone channels elsewhere indicates that there has been not been total loss of surface flow.

5.2 Extent and Magnitude of Subsidence

The *Subsidence Assessment* includes an analysis of the changes in the profile of Cataract Creek as a result of predicted subsidence. **Figure 5.1** below reproduces part of Figure 25 from the subsidence assessment which shows the profile of the Southern Tributary, which crosses LW1 – LW3 and joins the main creek about 350 m downstream of LW3 as shown on **Figure 5.2**.

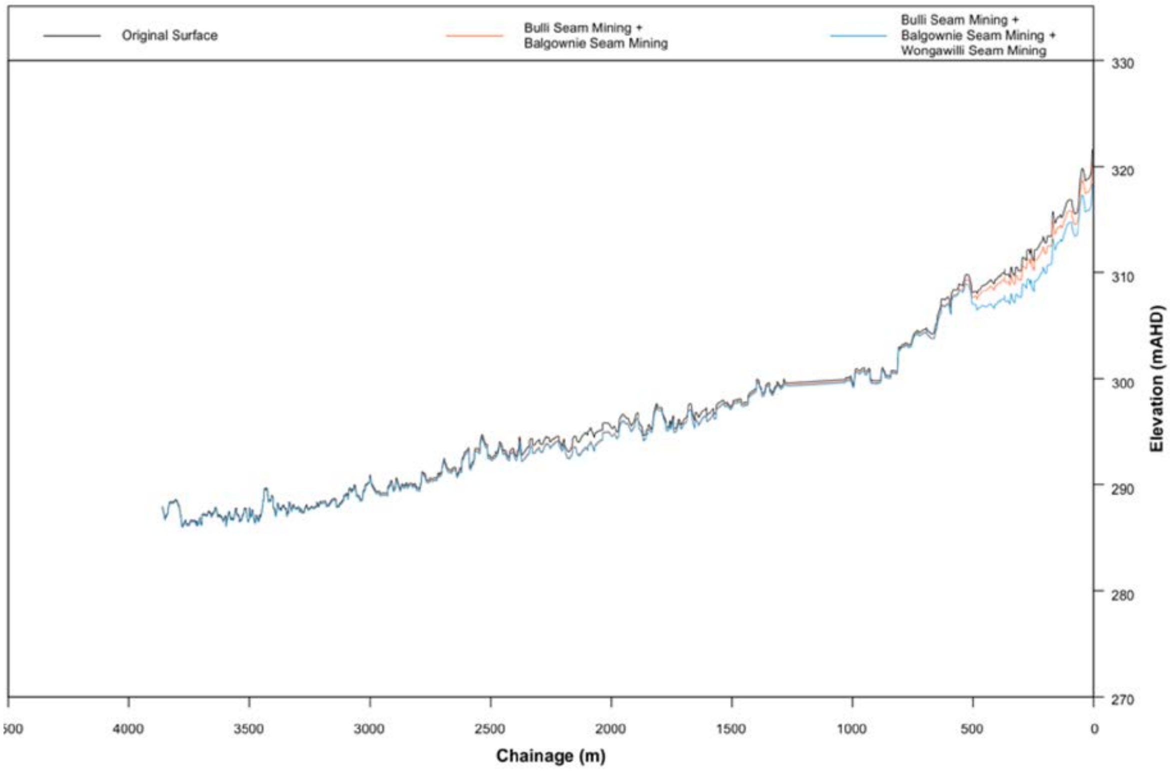


Figure 5.1:
Cataract Creek Bed Profile
Source: *Subsidence Assessment* (SCT, 2013), Figure 25

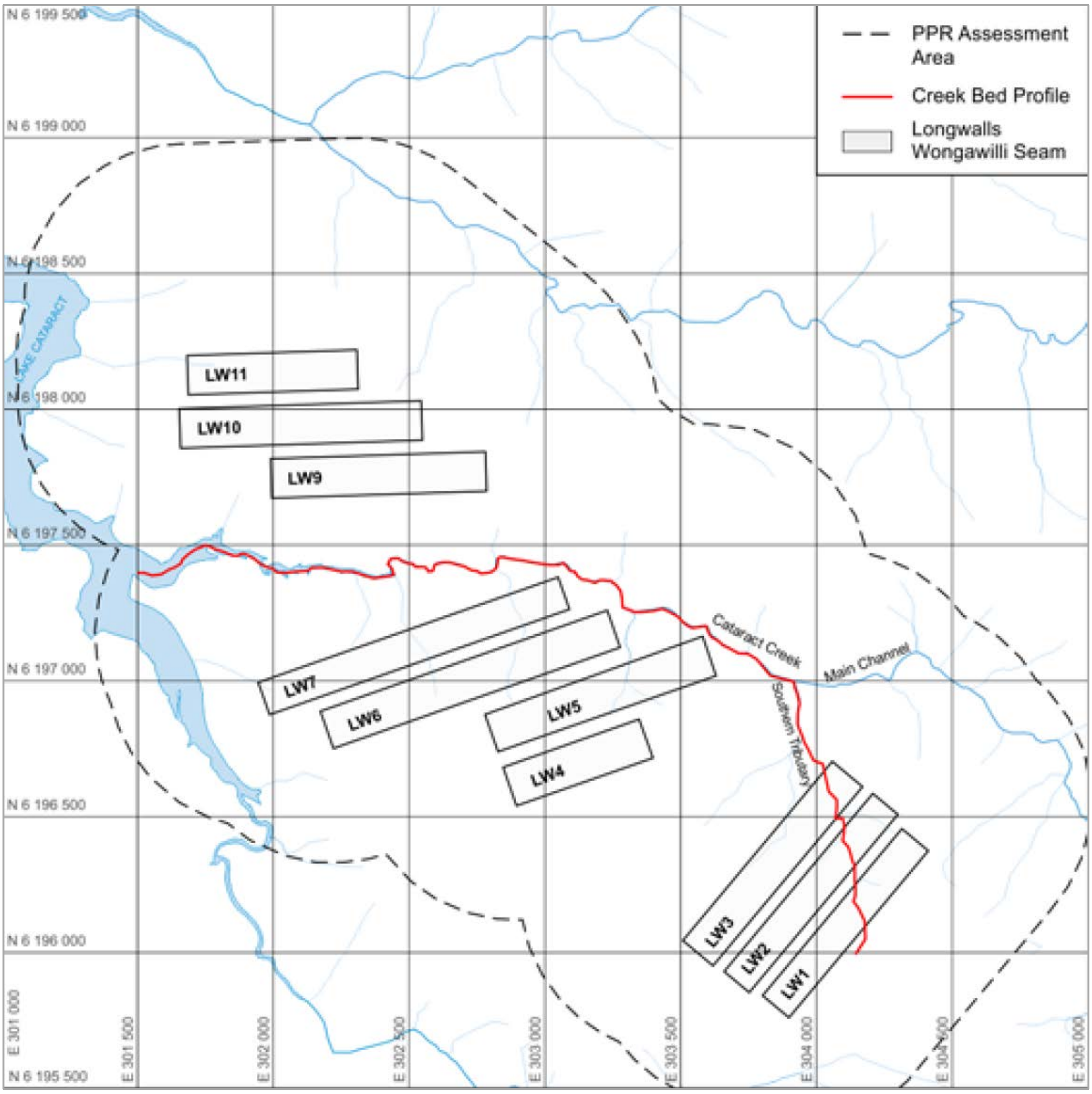


Figure 5.2:
Alignment of Cataract Creek Bed Profile
Source: *Subsidence Assessment* (SCT, 2013), Figure 25

The profile in **Figure 5.1** shows the following features of note:

- Significant vertical subsidence in the reach between Chainage 100 m and 500 m, corresponding to longwalls LW1 and LW2. Although not quoted in the *Subsidence Assessment*, it appears that maximum subsidence of up to 1.8 m may occur in this area and that the sharp end to the subsidence zone could lead to ponding in this area;
- Minor vertical subsidence is predicted upstream of about Chainage 1,650 m, which corresponds to the alignment of the south-east corner of longwall LW6. The maximum magnitude of the predicted subsidence appears to be about 0.5 m and to lead to a relatively sharp downstream 'lip' that could lead to minor additional ponding;
- A reach between about Chainage 1,880 m and 2,100 m in which up to 1.2 m vertical subsidence is predicted. These chainages align with the north-eastern end of longwall LW7.

- A reach between about Chainage 2,100 m and 2,370 m where up to 0.5 m vertical subsidence is predicted.

The *Subsidence Assessment* also notes other subsidence effects on creeks that are not shown on **Figure 5.1:**

- Vertical subsidence is predicted to mainly influence second order creeks above longwalls LW1 to LW3;
- Up to 2.6 m of vertical subsidence may occur below these second order creeks above longwall LW1.

5.3 Connective Cracking

The main potential for connective cracking appears to be at the northern corner of Longwall 7 which has been relocated as part of the revised project described in the *PPR*. This relocation has moved the northern corner of the longwall in a south-easterly direction by about 45 m. However the horizontal distance from the vertical projection of the longwall to Cataract Creek remains about 45 m.

In this regard, Tammetta (December 2013) notes that:

> ‘*Despite the absence of existing full extraction workings over a small strip of about 50 m width, there may still be a risk to the capacity of the channel of Cataract Creek to transmit surface water. There may also still be a risk of direct hydraulic connection between the creek channel and goaf, through the collapsed zone, where the channel comes to close to the panel edge. The significance of these risks cannot be quantified, but warrants consideration.*’

Whilst there remains some uncertainty regarding the potential for connective cracking, as noted in Section 2.3, the report by Hebblewhite (18/12/2013) on joint discussions with Tammetta and Dr Mills (of SCT) concludes:

> “*Therefore based on the above interpretation, the risk of inter-connective cracking is considered low in the vicinity of LW7 (or any other part of the proposed workings).*”

In addition, it should be noted that the creek ben in this vicinity is predominantly on rock and, therefore, the chance of any cracking being identified and repaired would be greater than if cracking occurred in a section of alluvial creek bed.

5.4 Impacts on the Flow in Creeks

Key aspects of the potential impacts on ponding and flow identified in the *Subsidence Assessment* include:

- Although there is potential for water to pool in second order creeks above LW1 – LW3, valley closure effects are expected to increase the potential for sub-surface flow. Accordingly pooling may only be short lived during periods of heavy rain.
- Valley closure is expected to cause perceptible cracking and surface flow diversion in the upper reaches of the southern branch of Cataract Creek, particularly where it flows across Hawkesbury Sandstone outcrop above LW1 leading to some loss of surface water and iron staining.
- Further downstream where the bed of the stream is located mainly in Bald Hill Claystone, low levels of perceptible impact are expected. Iron staining and flow diversion into the surface strata are not expected.

Section 2.2.9.3 of the *PPR* also notes that:

> "*Subsidence impacts on Upland Swamps and 1st and 2nd order tributaries are anticipated to have localised effects on the affected tributary stream flow and longevity and increased Fe, reduced DO, increased salinity and potentially increased metal concentrations in the downstream re-emergence and discharge zone.*"

In addition, the *PPR* (Section 2.2.9.3) notes that the main effect on overall stream discharge into Cataract Reservoir is expected to be attributable to any regional groundwater depressurisation effects. These effects have yet to be quantified on the basis of the remodelling of catchment groundwater impacts which is underway (as at December 2013). Some indication of the potential impacts of baseflow reduction as a result of regional groundwater depressurisation effect can be gained from the initial analysis in the *Groundwater Assessment* for the EA (data reproduced below).

Table 5.1: Modelled Cataract Creek Stream Flow Changes

	Creek Catchment Area (km^2)	Creek Flow Loss (ML/day)	Creek Flow Gain (ML/day)	Net Result (ML/day)	Change Due to Proposed Mining Compared to Current Stage (ML/day)
Current	5.2	-0.03	+0.36	0.33 (gaining)	
End of Mining Wonga East	5.2	-0.04	+0.31	0.27 (gaining)	0.06 (0.0115 $ML/km^2/day$) or 0.5% loss
End of Mining Wonga West	5.2	-0.04	+0.30	0.26 (gaining)	0.07 (0.0135 $ML/km^2/day$) or 0.6% loss

(Source: *Groundwater Assessment*, Table 10)

The data in **Table 5.1** indicates that, in the main, Cataract Creek is a 'gaining' stream but there is a small section which is a 'losing' stream. However, no details are provided to indicate where the gaining and losing sections are located.

In order to provide a basis for the assessment of potential impacts on stream ecology, the updated surface water modelling should assess the predicted loss of groundwater derived baseflow in the context of flow duration characteristics, not just average flow. The analysis should include a 'worst case' sensitivity assessment that considers the possibility of both shallow bedrock cracking (leading to loss of water in pools, but possible return flow downstream) as well as connective cracking to the mine workings. In both cases it would be useful to consider situations in which no repair work was undertaken and if repairs were undertaken in a similar manner to repairs undertaken on other creeks in the Southern Highlands. A flow duration graph showing existing and predicted flow characteristics would be desirable.

5.5 Water Quality Impacts

Sections 10.5.3 and 10.5.4 of the *Stream Assessment* provide an overview of the water quality monitoring program including locations and periods over which monitoring has occurred. The monitoring program includes:

- Bi-monthly monitoring of four sites on Cataract Creek upstream of Mount Ousley Road and one immediately downstream since August 2008;
- Bi-monthly monitoring of one site within Cataract Reservoir since August 2008;
- Progressive expansion of the monitoring on Cataract Creek to include an additional six sites on Cataract Creek and one of its tributaries since July 2010;

- Commencement of monitoring outflow from three swamps and one piezometer since March 2012.

The *Stream Assessment* provides graphs of the longitudinal profiles of median values of pH, conductivity, iron (total and filtered) and manganese (total and filtered) as well as graphs of the variability of pH and conductivity over time.

- pH shows a slight increasing trend from a median of about 5.6 at the upstream monitoring point to 6.3 upstream of Cataract Reservoir;
- Conductivity declines from a median of about 145 µS/cm at the upstream monitoring point to about 120 µS/cm just upsteram of Cataract Reservoir;

The assessment of overall water quality is summarised in the following quotations:

> *"In general, enhanced rainfall in the catchment has the effect of reducing salinity, marginally raising pH, increasing dissolved oxygen, diluting ferruginous discolouring (or deposition), diluting major metals and generally increasing nutrients, with the degree of change relating to the degree and duration of rainfall runoff dilution in the stream."*

> *"Hydrous ferruginous seeps are relatively common in Cataract Creek, although their exact inflow location has not yet been identified as ferruginous precipitation is relatively ubiquitous in the creek both upstream and downstream of the freeway.*

5.6 Monitoring and Management

5.6.1 Monitoring

The *Stream Assessment* (GeoTerra, 2012 – Annex O to the EA) describes the stream monitoring program together with proposed additional monitoring. Tables 16 and 17 in the *Stream Assessment* list the locations of the various monitoring locations but does not specify the precise monitoring activities at each site. **Table 5.2** is an attempt to consolidate the range of surface water monitoring activities based on the text and graphs in the *Stream Assessment.* The term 'observed flow' in the table is used to designate locations where visual observations of streamflow are made at the time of other monitoring, principally collection of water quality samples.

The table shows that Gujarat NRE has established a reasonably comprehensive set of monitoring sites in the Wonga East area. Notwithstanding, in response to one of the submissions regarding water quality monitoring, the *RTS* (page 315) commits as follows:

> *"The spatial and temporal distribution of water quality monitoring of streams within the project area will be detailed, including the analytes monitored and tables showing key statistics and justification of proposed triggers when the remodelling is complete."*

A further relevant undertaking is provided in the PPR (page 197):

> *"LW5 is currently mining beneath the Cataract Creek tributary CT1. NRE will continue to monitor CT1 tributary flow, water levels and water chemistry as LW5 passes beneath the tributary to clearly identify impacts that mine subsidence may have. There may be some effects on surface flow volumes but little impact on discharge into Cataract Creek. NRE is in the process of establishing monitoring points close to the mouth of CT1 and other tributaries along Cataract Creek to improve its understanding of the effects of mining on tributary discharge volumes."*

Table 5.2: Surface Water Monitoring in the Wonga East Area

Site	Location	Pool Level	Monitored Flow	Observed Flow	Water Quality
Cataract Creek					
CC1	Tributary draining east of the escarpment to the east of proposed Panel A1 LW2	✓		✓	✓
CC2	Tributary draining east of the escarpment over proposed Panel A1 LW3	✓		✓	✓
CC3	Nthn tributary junction east of freeway, between proposed Panels A1 LW3 and A2 LW4	✓	✓	✓	✓
CC4	Sthn tributary junction east of freeway, between proposed Panels A1 LW3 and A2 LW4	✓	✓	✓	✓
CC5	Start of main Cataract Ck channel west of freeway upstream of proposed panel A2 LW5	✓	✓		✓
CC6	Adjacent to proposed Longwall 5	✓	✓		
CC7	Adjacent to proposed Longwall 6, downstream of tributary CT1	✓	✓		
CC8	Over the originally proposed Longwall 8 (*now eliminated from mine plan*)	✓	✓		
CC9	Upstream of dam high water level over proposed panel A2 LW9	✓			✓
Cataract River					
CR1	Cataract River upstream of Freeway			✓	✓
CR2	Cataract River at SCA weir flow monitoring site, downstream of Freeway	✓		✓	✓
CR3	Cataract River upstream of Swamp CRUS1			✓	✓
Swamp Outflow					
Crus1c	Surface water discharge from swamp CRUS1		✓		
Crus3c	Surface water discharge from swamp CCUS3		✓		
Crus4c	Surface water discharge from swamp CCUS4		✓		
Surface Runoff					
SP1c	Surface water runoff down slope of shallow piezometers SP1		✓		

In addition, the *RTS* (page 314) notes that the available stream level data (sites CC2, CC3, CC6, CC7, CC8 in Cataract Creek and the SCA site in Cataract River) will be used to back calculate streamflow as part of the remodelling of the surface water impacts from the Preferred Project in order to assess the degree of flow loss / gains in the streams.

5.6.2 Management

In relation to monitoring if subsidence impacts on creeks, the *Subsidence Assessment* (page 59/60) proposes:

> *"A management strategy based on closure monitoring and cessation of mining if there is a likelihood of significant perceptible impacts becoming apparent is considered to be an effective method of managing the potential for subsidence impacts on Cataract Creek."*

More generally, the PPR (page 198) states:

> *"Monitoring and management are not intended to vary significantly but will be reviewed on the basis of the revised surface water model and assessment outcomes during the approvals process. A stream network monitoring program is being developed around CCUS4 and possibly CCUS5 and the Cataract Creek tributaries they feed to determine the actual impacts on surface and near surface water balances within a defined catchment area."*

As noted in the *Review of Surface Water Issues* (Evans & Peck, June 2013), baseline water quality data has been collected for range of relevant analytes. This data should provide an appropriate basis for establishing baseline water quality for purposes of identifying any water quality impacts as a result of mining. Further analysis of the water quality statistics should also be provided along with justification for any proposed water quality 'trigger' levels that differ from the default values in the ANZECC Guidelines. Provided an appropriate range of analytes has been monitored for sufficient length of time (monthly over 2 years minimum recommended in ANZECC) any proposal to establish locally specific water quality 'trigger' levels (for further investigation) would be consistent with the principles set out in the ANZECC Guidelines.

6 Pit Top Water Management

6.1 Russell Vale

The *PPR* includes all the surface facility upgrades described in the *EA* including the following relating to surface water management:

Stormwater Management:

- Improved separation and control of conveyance of water from the different catchments;
- Upgrading of about 560 m of the Southern Stormwater Channel to ensure separation of 'clean' water from the site and up-slope from 'dirty' stormwater from the coal stockpile area;
- Construction of a stormwater energy dissipater and settlement area with a low flow outflow pit to control discharge from the Southern Stormwater Channel into Bellambi Gully;
- Construction of a dry sediment basin to provide pre-treatment of stormwater from the coal stockpile area before it drains to the existing settling ponds;
- Cleaning out and reconfiguration of the existing settling ponds into a single pond.

Flooding and Channel Stability

- Channel protection works including Reno mattresses and gabion basket drop structure at various locations on major conveyance channels (as set out in Annexure B to the EA, *Water Management)*;
- Improvement works to the 'M3 Culvert' (to prevent the recurrence of the flooding event of August 1998). Options include:
  - Increasing the capacity of the pipe culvert and provision of an overland flow path that would convey water back to Bellambi Creek Gully;
  - Increase the capacity of the culvert to sufficient capacity to ensure that it does not become fully blocked and has a freeboard of 500 mm above the 100 year ARI flow conditions.

Subject to clarification or a range of issues identified in Section 4.1.2 of the *Review of Surface Water Issues* (Evans & Peck, June 2013), these proposed upgrades can be expected to significantly improve on site water management and provide appropriate mitigation against a recurrence of the August 1998 flood event.

Currently stormwater and treated mine water are both discharged to Bellambi Gully. This results in an un-naturally persistent flow regime in the gully and elevated salinity levels compared to what could be expected in a natural creek. Although not documented, the flow and water quality have probably contributed (along with urban runoff) to a severely degraded creek. No consideration has been given to the feasibility or benefit of alternative means of conveyance of the treated mine water (such as via a pipeline)

The main issue arising from the *PPR* is the proposed staging of the site rehabilitation works including those to address stormwater management and flooding issues. Table 6 of the *PPR* (copy included as **Table 6.1** below) indicates that highest priority for construction is proposed for facilities concerned with the transport of coal (2.5 years), with works associated with water management taking a further year. Some of the works related to stormwater quality control and flooding are considered to warrant higher priority, particularly:

- Improvement works to the 'M3 Culvert';
- Cleaning out and reconfiguration of the existing settling ponds into a single pond.

Table 6.1: Estimated Construction Element Times

Construction Stage	Mining Element	Estimated Construction Time
1	Truck Loading Facilities, Associated Road Works and Parking Area	30 months from approval date
2	6ML Settling Pond and Associated Drainage Works	12 months from completion of Construction Stage 1
3	Stockpiles 2 & 3	18 months from completion of Construction Stage 2

6.2 Mine Groundwater Inflow and Site Water Balance

Estimates of the groundwater inflow to the workings have been updated for the *PPR* to reflect the reduced scope of mining. Data presented in the *PPR* shows that the average inflow to the workings for 211 and 2012 was about 460 ML/year. **Figure 6.1** shows that the inflow associated with extraction from Longwalls 4 and 5 (from early 2012) was significantly higher than had been previously experienced at the mine.

Estimates of future inflows are to be prepared once further groundwater modelling has been undertaken. At that stage it would be appropriate for the site water balance to be re-visited and a range of issues identified in the *Review of Surface Water Issues*.

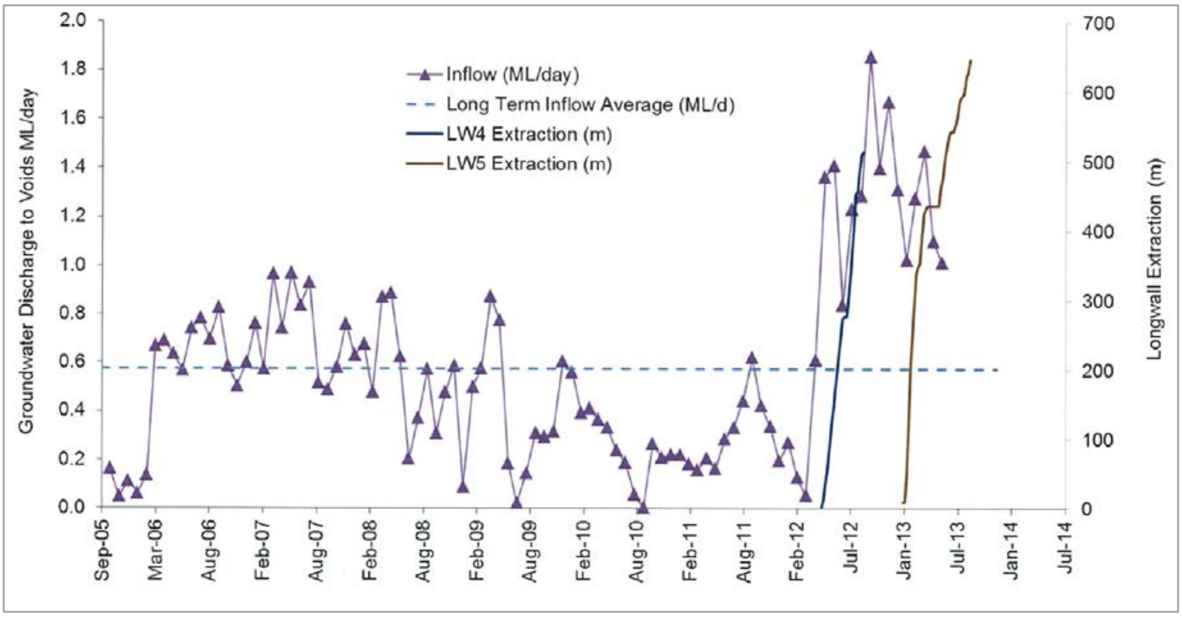


Figure 6.1:
Groundwater Discharge to NRE No. 1 Voids
Source; Figure 27, *NRE No 1 Hydrogeological Conceptual Model*

6.3 No 4 Shaft

The *Review of Surface Water Issues* questioned some aspects of the effluent irrigation system at the No 4 Shaft site. On the basis that, as part of the activities to be undertaken to implement the mining described in the *PPR*, the number of employees would remain about the same as currently (13), it is accepted that the effluent disposal system has adequate capacity.

7 Commitments and Conditions of Approval

Is Section 4 of the *PPR*, the Proponent seeks to remove all commitments set out in Table 29.1 of the EA and proposes requests the Department to consider the a range of conditions, if considered necessary, to ensure that specific environmental outcomes are met. The proposed conditions include the following of relevance to matters considered in this review.

1. A general condition in any approval requiring:
   - NRE to comply with all relevant legislation related to its operational environmental impacts.
2. Specific conditions for the Pit Top areas requiring the preparation of arrange of plans including:
   - *Construction Management Plan*/s;
   - *Surface Facilities Water Management Plan.*
3. Specific conditions for Mine Subsidence areas requiring the preparation of an:
   - *Extraction Plan*.

Presumably, any *Extraction Plan* would include a whole series of sub-plans including:

- A *Subsidence Management Plan* that included specific proposal regarding cessation of mining in the event of certain subsidence criteria being exceeded (such as valley closure of more than 200 mm).
- A *Creek Monitoring and Management Plan* (including pool levels, flow and water quality) as well as criteria for undertaking remediation of any excessive cracking in the creeks;
- A *Swamp Management Plan* that included:
  - a comprehensive program of water level and outflow monitoring;
  - on-site climate monitoring to enable water balance analysis to be undertaken for individual swaps;
  - soils investigations to define the water holding characteristics of the soils within the swamps for purposes of relating the observed water levels to a depth of water and assessing the likelihood of ‘self-sealing’.

Appendix A

Assessment of Historic and Potential Subsidence Affecting Swamps

Swamp Name	Characteristics and Subsidence Effects	Potential Impact (This Review)	PPR Assessment (Biosis)
BCUS2	BCUS2, an upland swamp with an area of approximately 0.89 ha, is located north of CCUS9 and CCUS10. BCUS2 slopes northward and has an effective catchment area of approximately 2 ha. No defined drainage outlet is visible on **Figure 2.1**. Cumulative subsidence effects due to mining of the Bulli and Balgownie Seams are approximately 0.2 m through the middle of the swamp (see **Figure 2.1**). An additional 0.02 m subsidence is predicted through the middle of the swamp due to mining of the Wongawilli Seam (see **Figure 2.2**), resulting in negligible convex curvature through or immediately adjacent to the swamp. Any cracking is likely to occur to the south-west of the swamp around the edge of LW9, which could decrease the amount of flow entering the swamp from the catchment. However, as the catchment area is very small, BCUS2 is considered to be at a low risk of negative environmental consequences.	Low risk	-
BCUS4	BCUS4, an upland swamp with an area of approximately 2.2 ha, is located directly downhill of BCUS11, which decreases the effective catchment area for the swamp. BCUS4 slopes north-east, and has an effective catchment area of approximately 7 ha. Biosis flow accumulation modelling pre-mining indicates that there is a dispersed flow through the swamp, with four exit points from the base of the swamp. These flow pathways are not visible on **Figure 2.1**. Cumulative subsidence effects due to mining of the Bulli and Balgownie Seams range between 0.2 m at the north east edge and 0.5 m at the south west edge of the swamp (see **Figure 2.1**). LW10 is to be located directly below the south edge of BCUS4. Additional subsidence ranging from 0.1 m at the north-east edge to 1 m at the southern edge is predicted due to mining of the Wongawilli Seam (see **Figure 2.2**). Convex curvature through the centre of the swamp may result in cracking at the north-east edge (downhill side) of the swamp. This is likely to alter the flow paths exiting the swamp. As such, BCUS4 is considered to be at minor risk of negative environmental consequences.	Minor risk	Moderate risk
BCUS5	BCUS5, an upland swamp with an area of approximately 0.96 ha, is located directly downhill of BCUS11 and BCUS4. BCUS5 slopes north-east and has an effective catchment area of approximately 12.5 ha. No defined drainage outlet is visible on **Figure 2.1**. Cumulative subsidence effects due to mining of the Bulli and Balgownie Seams range between 0.2 m in the middle of and 0.3 m along the south edge of the swamp (see **Figure 2.1**). No additional subsidence effects are predicted due to mining of the Wongawilli Seam (see **Figure 2.2**). As	Low risk	-

Swamp Name	Characteristics and Subsidence Effects	Potential Impact (This Review)	PPR Assessment (Biosis)
	such, convex curvature and associated cracking should be negligible, and BCUS5 is considered to be at a low risk of negative environmental consequences.		
BCUS6	BCUS6, an upland swamp with an area of approximately 1.37 ha, is located to the east of BCUS7, with a small part of CCUS12 located at the top of the hill above BCUS6. BCUS6 slopes northward, and has an effective catchment area of approximately 11 ha. No defined drainage outlet is visible on **Figure 2.1**. Cumulative subsidence due to mining of the Bulli and Balgownie Seams is approximately 0.2 m at the south-west edge of the swamp. An additional 0.02 m subsidence is predicted through the northern section of the swamp due to mining of the Wongawilli Seam, resulting in negligible convex curvature through or immediately adjacent to the swamp. Any cracking is likely to occur to the south and south-west of the swamp around the edge of LW11. As such, BCUS6 is considered to be at a low risk of negative environmental consequences.	Low risk	-
BCUS7	BCUS7, an upland swamp with an area of approximately 0.62 ha, is located to the west of BCUS6. BCUS7 slopes north-east, and has an effective catchment area of approximately 2 ha. No defined drainage outlet is visible on **Figure 2.1**. Cumulative subsidence due to mining of the Bulli and Balgownie Seams is approximately 0.2 m beyond the south-west and south-east edges of the swamp. An additional 0.02 m subsidence is predicted through the middle of the swamp due to mining of the Wongawilli Seam, resulting in negligible convex curvature through or immediately adjacent to the swamp. Any cracking is likely to occur to the south of the swamp around LW11, which could decrease the amount of flow entering the swamp from the catchment. However, as the catchment area is very small, BCUS7 is considered to be at a low risk of negative environmental consequences.	Low risk	-
BCUS11	BCUS11, an upland swamp with an area of approximately 0.26 ha, is located directly south-west (uphill) of BCUS4 and is directly east of CCUS12. BCUS11 slopes north-east and has an effective catchment area of approximately 0.5 ha. Biosis flow accumulation modelling pre-mining indicates the swamp has three flow pathways through the swamp. No defined drainage outlet is visible on **Figure 2.1**. Cumulative subsidence effects due to mining of the Bulli and Balgownie Seams range between 0.3 m and 0.5 m. LW10 is to be located directly under BCUS11. Additional subsidence ranging between 1 m to 1.5 m is predicted due to mining of the Wongawilli Seam.	Low risk	Low risk

Swamp Name	Characteristics and Subsidence Effects	Potential Impact (This Review)	PPR Assessment (Biosis)
	Minor curvature on the edge of the swamp suggests a low risk of cracking. As such, BCUS11 is considered to be at a low risk of negative environmental consequences.		
CCUS1	CCUS1 is an upland swamp of "special significance," with an area of approximately 4.81 ha. CCUS1 is located on a minor ridge line, allowing drainage to both the north-east and north-west. The effective catchment area for CCUS1 is approximately 11 ha. Biosis flow accumulation modelling pre-mining indicates the presence of two main flow pathways through this upland swamp – one exiting the swamp in the north-east section and one in the south- east section. The flow pathway exiting the swamp in the north-east section is visible on **Figure 2.1** as a first order creek, draining to Cataract Creek. Cumulative subsidence effects due to mining of the Bulli and Balgownie Seams range from 0.8 m on the south west (downhill) edge to 1.3 m in the middle of the swamp, and 1.5 m just beyond the north-east edge. Additional subsidence of 0.1 m to 0.2 m is predicted on the south-east edge of the swamp due to mining of the Wongawilli Seam. Negligible convex curvature on the edge of the swamp suggests a low risk of cracking. As such, CCUS1 is considered to be at a low risk of negative environmental consequences.	Low risk	Low risk
CCUS2	CCUS2, an upland swamp with an area of approximately 1.21 ha, is located on a minor ridge line, allowing drainage to both the north-east and north-west. The effective catchment area for CCUS2 is approximately 3 ha. Biosis flow accumulation modelling pre-mining indicates a dispersed flow of water through the swamp. No defined drainage outlet is visible on **Figure 2.1**. Cumulative subsidence effects due to mining of the Bulli and Balgownie Seams range from 0.5 m in the middle of the swamp to 1 m at the northern edge. Additional subsidence (0.5 m to 1 m) is predicted due to mining of the Wongawilli Seam, as LW2 and LW3 are to be located directly below CCUS2. The majority of the swamp will be affected by subsidence. However, convex curvature through the swamp will be negligible. Any cracking is likely to occur on the ridge line to the south of the swamp. As such, CCUS2 is considered to be at a low risk of negative environmental consequences.	Low risk	Low risk
CCUS3	CCUS3, an upland swamp with an area of approximately 0.55 ha, is located directly uphill of CCUS4. CCUS3 slopes to the north, and has an effective catchment area of approximately 4 ha. Biosis flow accumulation modelling pre-mining indicates the presence of two main flow pathways through the swamp. No defined drainage outlet is visible on **Figure 2.1**. Cumulative subsidence effects due to mining of the Bulli and Balgownie Seams range from 0.3 m to 0.8 m,	Low risk	Low risk

Swamp Name	Characteristics and Subsidence Effects	Potential Impact (This Review)	PPR Assessment (Biosis)
	south-west to north-east. The western corner of LW5 is to be located directly under the north east corner of CCUS4. Additional subsidence ranging between 0.1 m to 0.2 m is predicted through the middle of the swamp due to mining of the Wongawilli Seam. Negligible convex curvature resulting from this minor subsidence suggests a low risk of cracking. As such, CCUS3 is considered to be at a low risk of negative environmental consequences.		
CCUS4	CCUS4 is an upland swamp of "special significance," with an area of approximately 1.77 ha. CCUS4 slopes northward, and is located directly south (down slope) of CCUS3, which decreases the effective catchment area for CCUS4. The effective catchment area for CCUS4 is approximately 6.8 ha. Biosis flow accumulation modelling pre-mining indicates the presence of two main flow pathways through this upland swamp – one minor pathway passes through the eastern section of the swamp, while the main flow pathway passes through the western section of the swamp. The flow pathway exiting the swamp in the western section is visible on **Figure 2.1** as a first order creek draining to Cataract Creek. Cumulative subsidence effects due to mining of the Bulli and Balgownie Seams range from 0.5 m on the south edge, to 0.8 m in the middle of the swamp. LW6 is to be located directly underneath CCUS4. Additional subsidence ranging from 0.1 m at the southern edge to 1.5 m in the middle of the swamp is predicted due to mining of the Wongawilli Seam. Minor convex curvature along the up-slope edge is likely. This has the potential to result in minor cracking directly uphill of the southern edge of the swamp, and across the catchment area parallel to the edge of LW6. This could alter the swamp's catchment area, decreasing flows entering the swamp. However, absence of significant curvature suggests that CCUS4 is at a minor risk of negative environmental consequences.	Minor risk	Moderate risk
CCUS5	CCUS5 is an upland swamp of "special significance," with an area of approximately 3.45 ha. CCUS5 slopes northward, and is located directly downhill of a portion of CRUS1, which slightly decreases the effective catchment area of the swamp. The effective catchment area for CCUS5 is approximately 4.5 ha. Biosis flow accumulation modelling pre-mining indicates that the swamp has a dispersed flow accumulation, with numerous flow pathways, and a significant flow pathway through the eastern section of the swamp. This significant flow pathway is visible on **Figure 2.1** as a first order creek draining to Cataract Creek. Cumulative subsidence effects due to mining of the Bulli and Balgownie Seams range from 0.3 m to 0.5 m at the south east edge of the swamp. LW7 is to be located directly underneath the south end of CCUS5. Substantial additional subsidence,	Low risk	Low risk

Swamp Name	Characteristics and Subsidence Effects	Potential Impact (This Review)	PPR Assessment (Biosis)
	ranging from 0.1 m to 1 m at the southern end of the swamp, is predicted due to mining of the Wongawilli Seam. The maximum convex curvature is expected along the north-east edge of the swamp. Any cracking would be likely to only occur in a minor part of the up-slope section of the swamp, with a negligible impact on the runoff contribution to the remainder of the swamp. As such, CCUS5 is considered to be at a low risk of negative environmental consequences.		
CCUS6	CCUS6, an upland swamp with an area of approximately 2.05 ha, slopes to the north east and is located directly west of CCUS21. The effective catchment area for CCUS6 is approximately 2 ha. Biosis flow accumulation modelling pre-mining indicates a dispersed flow accumulation, with numerous flow pathways through the swamp. No defined drainage outlet is visible on **Figure 2.1**. Cumulative subsidence effects due to mining of the Bulli and Balgownie Seams range from 1 m to 1.3 m in the middle of the swamp. LW4 is to be located directly under CCUS6. Additional subsidence ranging from 0.1 m to 0.5 m in the middle of the swamp is predicted due to mining of the Wongawilli Seam. Relatively uniform subsidence is likely to result in minor convex curvature, suggesting that cracking is unlikely to occur through the swamp. As such, CCUS6 is considered to be at a low risk of negative environmental consequences.	Low risk	Low risk
CCUS9	CCUS9, an upland swamp with an area of approximately 0.76 ha, is located to the immediate north-east of CCUS10 at the top of a ridge. CCUS9 slopes south-south-west, and has an effective catchment area of approximately 1 ha. No defined drainage outlet is visible on **Figure 2.1**. Limited subsidence effects occurred in the vicinity of the swamp due to mining of the Bulli and Balgownie Seams. Subsidence of 0.02 m is predicted through the north-east edge of the swamp as a result of mining of the Wongawilli Seam, resulting in negligible convex curvature and a low risk of cracking through the swamp. Any cracking is likely to occur to the east of the swamp. As such, CCUS9 is considered to be at a low risk of negative environmental consequences.	Low risk	-
CCUS10	CCUS10 is an upland swamp of “special significance,” with an area of approximately 1.63 ha. CCUS10 slopes to the south, and is located to the immediate south-east of CCUS11 and south-west of CCUS9. The effective catchment area for CCUS10 is approximately 5 ha. Biosis flow accumulation modelling pre-mining indicates a dispersed flow accumulation across this swamp. Cumulative subsidence effects due to mining of the Bulli and Balgownie Seams range from 0.3 m to 0.5 m	Minor risk	Low risk

Swamp Name	Characteristics and Subsidence Effects	Potential Impact (This Review)	PPR Assessment (Biosis)
	on the north west edge. An additional 0.1 m to 1 m subsidence is predicted on the north-west edge of the swamp due to mining of the Wongawilli Seam, as CCUS10 is located directly south of the future location of LW9. Maximum convex curvature will occur along the edge of LW9. Any cracking is likely to occur to the north (up-hill slope) of the swamp. This could decrease the amount of flow entering the swamp from the catchment. As such, CCUS10 is considered to be at a minor risk of negative environmental consequences.		
CCUS11	CCUS11, an upland swamp with an area of approximately 0.34 ha, is located to the immediate north-west of CCUS10. CCUS11 slopes to the south, and has an effective catchment area of approximately 0.5 ha. No defined drainage outlet is visible on **Figure 2.1**. Cumulative subsidence effects due to mining of the Bulli and Balgownie Seams range between 0.3 m and 0.5 m. LW9 is to be located directly under CCUS11. Additional subsidence of 0.5 m to 1.5 m is predicted due to mining of the Wongawilli Seam. Maximum convex curvature is likely to occur along the upslope edge of the swamp. The relatively uniform subsidence of the entire swamp suggests that CCUS11 will be at a low risk of negative environmental consequences.	Low risk	Low risk
CCUS12	CCUS12, an upland swamp with an area of approximately 1.84 ha, is located at the top of a hill allowing drainage to all sides, particularly to the west and south-west. As CCUS12 is located on the top of a hill, there is a negligible effective catchment area. No defined drainage outlet is on **Figure 2.1**. Cumulative subsidence effects due to mining of the Bulli and Balgownie Seams range between 0.2 m and 0.5 m. LW10 is to be located directly under CCUS12. An additional subsidence of approximately 1 m through the middle of the swamp is predicted due to mining of the Wongawilli Seam. The relatively uniform subsidence of the entire swamp should result in negligible convex curvature. This suggests that cracking is unlikely to occur in or around the edges of the swamp. As such, CCUS12 is considered to be at a low risk of negative environmental consequences.	Low risk	Low risk
CCUS21	CCUS21, an upland swamp with an area of approximately 0.05 ha, is located on a minor ridge line, allowing drainage to both the north-east and north-west. The effective catchment area for CCUS21 is approximately 10 ha. No defined drainage outlet is visible on **Figure 2.1**. Cumulative subsidence effects due to mining of the Bulli and Balgownie Seams range from 1 m on the south west edge to 1.8 m in the middle of the swamp. LW4 is to be located directly under the north section of CCUS21. Additional subsidence ranging from	Low risk	Minor risk

Swamp Name	Characteristics and Subsidence Effects	Potential Impact (This Review)	PPR Assessment (Biosis)
	0.1 m to 2 m across the swamp is predicted due to mining of the Wongawilli Seam. Convex curvature through the centre of the swamp could cause cracking, which could cause loss of surface flows to the subsurface. Additionally, cracking may occur across the catchment area parallel to the edge of LW4. This could decrease the amount of flow entering the swamp from the catchment. As such, CCUS6 could be considered to be at a minor risk of negative environmental consequences. However, it could also be considered that cracking is most likely to occur at the south edge of the swamp. Considering the fragmented nature of CCUS21, this would have a limited effect on the rest of the swamp. In this case, CCUS6 could be considered to be at a low risk of negative environmental consequences.		
CCUS23	CCUS23 is an upland swamp with an area of approximately 1.44 ha. CCUS23 slopes to the north, and has an effective catchment area of approximately 3 ha. No defined drainage outlet is visible on **Figure 2.1**. Cumulative subsidence effects due to mining of the Bulli and Balgownie Seams range between 0.8 m and 1 m. LW5 is to be located directly under CCUS23. Additional subsidence ranging between 0.5 and across the swamp is predicted due to mining of the Wongawilli Seam. The relatively uniform subsidence is likely to result in negligible convex curvature and minor cracking. As such, CCUS23 is considered to be at a low risk of negative environmental consequences.	Low risk	Low risk
CRUS1	CRUS1 is an upland swamp of "special significance," with an area of approximately 9.84 ha. CRUS1 is located immediately east of the Cataract River. CRUS1 slopes to the west and south-west. The effective catchment area for CRUS1 is approximately 11 ha. Three significant flow pathways are visible on **Figure 2.1** with two flowing west, from the north-west section and middle (west) section of the swamp respectively, and one flowing south-west from the south-west section of the swamp. These three flow pathways drain to Cataract River as first order creeks. Cumulative subsidence effects due to mining of the Bulli and Balgownie Seams range from 0.3 m to 0.5 m. The western end of LW6 is to be located below the north section of CRUS1. Additional subsidence ranging from 0.02 m in the middle to 1.5 m at the northern edge of the swamp is predicted due to mining of the Wongawilli seam. Impacts due to subsidence and associated convex curvature are confined to approximately 5% of the swamp (northern arm), with a negligible impact on the remainder. As such, CRUS1 is considered to be at a low risk of negative environmental consequences.	Low risk	Low risk
CRUS2	CRUS2 is an upland swamp of "special significance," with an area of approximately 3.12 ha. CRUS2 slopes to the south-south-west, and has an effective catchment area of approximately 7 ha. No defined drainage	Low risk	-

Swamp Name	Characteristics and Subsidence Effects	Potential Impact (This Review)	PPR Assessment (Biosis)
	outlet is visible on **Figure 2.1**. Cumulative subsidence effects due to mining of the Bulli and Balgownie Seams range from 0.2 m in the south to 0.5 m in the northern end of the swamp. Additional subsidence of 0.02 m at the northern edge of the swamp is predicted due to mining of the Wongawilli Seam. Convex curvature is likely to be negligible through the swamp, and cracking is unlikely to occur. As such, CRUS2 is considered to be at a low risk of negative environmental consequences.		
CRUS3	CRUS3 is an upland swamp of “special significance,” with an area of approximately 3.42 ha. CRUS3 is located on a hill in a surrounded by three minor ridge lines, and slopes to the south. The effective catchment area for CRUS3 is approximately 7.5 ha. No defined drainage outlet is visible on **Figure 2.1**. Cumulative subsidence due to mining of the Bulli and Balgownie Seams is approximately 0.3 m at the south east and west edges of the swamp. Additional subsidence of 0.1 m is predicted just beyond the north-east edge of the swamp due to mining of the Wongawilli Seam. Convex curvature is likely to be negligible through the swamp, and cracking is unlikely to occur. As such, CRUS3 is considered to be at a low risk of negative environmental consequences.	Low risk	-

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