5 SUBSIDENCE

IC has commissioned Mine Subsidence Engineering Consultants to examine the current mining proposals in Area 3, to identify all the natural features and items of surface infrastructure, and to prepare subsidence predictions and impact assessments.

Subsidence avoidance, mitigation and rehabilitation principles have been adopted in the design of the longwall layout in Area 3A. **Section 2.3** outlines the development process of the longwall layout within Area 3A based on these principles. For Areas 3B and 3C, the subsidence predictions will be undertaken when the longwall layouts in these areas are finalised. Nevertheless, preliminary concept mining domains have been developed for Areas 3B and 3C. This is outlined in **Section 1.4.1**.

The full subsidence assessment is provided in **Attachment A**. The key findings of the report are provided below.

5.1 SURFACE FEATURES

The natural features and items of surface infrastructure identified within the study area include:

- Catchment Areas or Declared Special Areas.
- Wongawilli, Sandy and Donalds Castle Creeks.
- Drainage lines.
- Lake Cordeaux and Lake Avon.
- Cliffs, rock outcrops.
- Steep slopes.
- Upland swamps.
- The abandoned Maldon–Dombarton railway corridor.
- Fire trails and four wheel drive tracks.
- A 330kV transmission line and 33kV powerline.
- Exploration bores.
- Archaeological sites.
- Survey control marks.

Other significant natural features and items of surface infrastructure located outside the general study area has been identified and included in the assessment:

- The Cordeaux River,
- Cordeaux and Upper Cordeaux No. 2 Dams, and
- Exploration bores and survey control marks further a field.

5.2 MAXIMUM SUBSIDENCE PREDICTIONS

5.2.1 Area 3A

A summary of the maximum predicted incremental systematic subsidence parameters, due to the extraction of each of the proposed longwalls in Area 3A, is provided in **Table 5.1**. A summary of the maximum predicted cumulative systematic subsidence parameters, after the extraction of each proposed longwall, is provided in **Table 5.2**. A summary of the maximum predicted travelling tilts and strains, during the extraction of each proposed longwall, is provided in **Table 5.3**.

Table 5.1 - Maximum Predicted Incremental Systematic Subsidence Parameters due to the Extraction of Each Proposed Longwall in Area 3A

Longwall	Maximum Predicted Incremental Subsidence (mm)	Maximum Predicted Incremental Tilt (mm/m)	Maximum Predicted Incremental Tensile Strain (mm/m)	Maximum Predicted Incremental Compressive Strain (mm/m)
Due to LW6	1520	13	2.0	4.5
Due to LW7	1880	19	4.0	10
Due to LW8	2075	21	4.0	11
Due to LW9	2010	20	3.5	12
Due to LW10	1945	20	3.5	11

Table 5.2 - Maximum Predicted Cumulative Systematic Subsidence Parameters after the Extraction of Each Proposed Longwall in Area 3A

Longwall	Maximum Predicted Cumulative Subsidence (mm)	Maximum Predicted Cumulative Tilt (mm/m)	Maximum Predicted Cumulative Tensile Strain (mm/m)	Maximum Predicted Cumulative Compressive Strain (mm/m)
After LW6	1520	13	2.0	4.5
After LW7	1890	19	4.0	10
After LW8	2080	21	4.5	11
After LW9	2240	21	4.5	11
After LW10	2275	21	4.5	11

Table 5.3 - Maximum Predicted Travelling Subsidence Parameters during the Extraction of Each Proposed Longwall in Area 3A

Longwall	Maximum Predicted Travelling Tilt (mm/m)	Maximum Predicted Travelling Tensile Strain (mm/m)	Maximum Predicted Travelling Compressive Strain (mm/m)
During LW6	9	2.0	1.5
During LW7	12	3.0	2.5
During LW8	15	4.0	3.5
During LW9	14	4.0	3.0
During LW10	13	3.5	3.0

5.2.2 Areas 3B and 3C

The maximum predicated systematic subsidence parameters for Areas 3B and 3C will be provided when the final longwall layouts for these areas are developed and as additional exploration data is gathered to better define the extractable resource. Once the final layout is established, further SMP applications will be prepared for these areas, supported by detailed subsidence modelling of the future longwalls in these areas.

In general, the maximum predicted systematic subsidence parameters resulting from the extraction of the future longwalls in Areas 3B and 3C will depend on the final longwall layouts, in addition to the local variations in the depths of cover, extraction heights and geology in these areas. These factors and their anticipated effect for Areas 3B and 3C include:

- *Longwall Void Width and Chain Pillar Widths* – these are expected similar to those adopted in Area 3A. Hence, the maximum predicted systematic subsidence parameters for the future longwalls in Areas 3B and 3C are expected to be similar to those predicted for longwalls 6 to 10.
- *Depth of Cover* – the average depths of cover in Areas 3B and 3C are slightly greater than the average depth of cover in Area 3A. The maximum predicted systematic subsidence parameters for the future longwalls in Areas 3B and 3C are expected to be similar to, or slightly less than those predicted for longwalls 6 to 10 in Area 3A.
- *Extraction Height* - the maximum predicted systematic subsidence parameters for the future longwalls in Areas 3B and 3C are expected to be greater than those predicted for longwalls 6 to 10 if an extraction height greater than 3.9m were adopted and, conversely, are expected to be less than those predicted for longwalls 6 to 10 if an extraction height less than 3.9m were adopted.
- *Geology* - the maximum predicted systematic subsidence parameters for the future longwalls in Areas 3B and 3C are expected to be similar to those predicted for longwalls 6 to 10 in Area 3A based on the regional geology within Area 3.

5.3 IMPACT ASSESSMENT ON NATURAL FEATURES AND SURFACE INFRASTRUCTURE

Impact assessment has been undertaken for the natural features and items of surface infrastructure within the general study area. Natural features and items of surface infrastructure located outside the general study area, which may be subjected to far-field movements and may be sensitive to these movements have also been included as part of the assessment. Impacts of these items are summarised as follows:

5.3.1 Cordeaux River

5.3.1.1 Existing Environment

The Cordeaux River is located approximately 4km north of the proposed longwalls in Area 3A and the future longwalls in Areas 3B, and 470m north of the maximum footprint for Area 3C. **Figure 1.2** shows the location of the River.

5.3.1.2 Impact Assessment

Due to the distance between Cordeaux River and Areas 3A and 3B, it is unlikely for the river to be subjected to any significant systematic subsidence, valley related, or far-field horizontal movements resulting from the extraction of the proposed and future longwalls in these areas.

Future longwalls within Area 3C would need to be set back from the river to minimise any significant impacts to the river. The setback distance will be determined using the same methodology for the setback for Area 3A from Wongawilli and Sandy Creeks.

5.3.1.3 Mitigation Measures

Mitigation measures are not required for the Cordeaux River for extraction in Area 3A. Mitigation measures for Cordeaux River for Area 3C will be developed once the longwall layout for this area is finalised.

5.3.2 Wongawilli and Sandy Creeks

5.3.2.1 Existing Environment

Wongawilli and Sandy Creeks are located within Area 3 and traverse the general study area. Both Creeks generally flow in a northerly direction (**Figure 5.1**).

Wongawilli Creek drains into the Cordeaux River. The total length of the Creek within the General Study Area is 8.6km. Wongawilli Creek effectively creates a divide between Areas 3A and 3B. Wongawilli Creek is located at least 110m west of the commencing ends of the Area 3A longwalls.

Sandy Creek drains into an arm of Lake Cordeaux at a waterfall site located 250m east of Longwall 7. The total length of Sandy Creek within the general Study Area is 2km. Sandy Creek is located at least 85m east of the finishing ends of longwalls 8, 9 and 10.

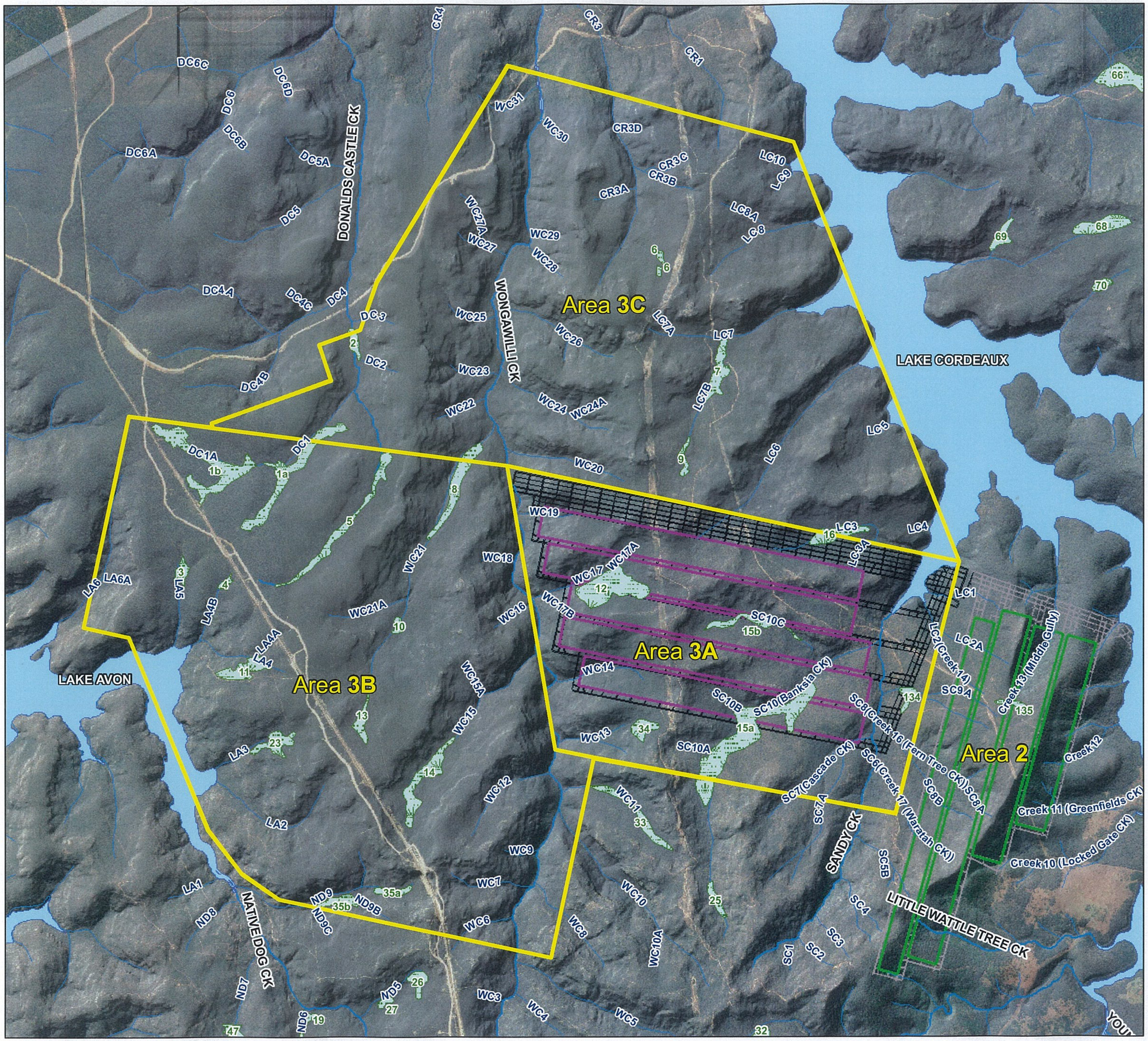
5.3.2.2 Rationale used for Assessment of Likely Impacts on Creeks

The maximum predicted total upsidence movements along Wongawilli and Sandy Creeks, resulting from the extraction of the proposed longwalls in Area 3A, are 190 mm and 125 mm, respectively. The maximum predicted total closure movements across the valleys of Wongawilli and Sandy Creeks, resulting from the extraction of the proposed longwalls in Area 3A, are 195 mm and 180 mm, respectively.

The potential for the fracturing of bedrock and, hence, the potential for surface water flow diversions along Wongawilli and Sandy Creeks, resulting from the predicted upsidence and closure movements have been assessed by comparing the predicted movements along these creeks with the back-predicted movements along a number of creeks and rivers which have been affected by mining within the Southern Coalfield. All data available to IC has been used in this analysis.

The selected case studies include the following:

- Elouera Longwalls 1 to 10 which mined adjacent to and directly beneath Wongawilli Creek (impacts observed after completion October 2001).
- Elouera Longwalls 1 to 10 which mined adjacent to and directly beneath Native Dog Creek (impacts observed during extraction November 2001).



bhpbilliton

ILLAWARRA COAL

Swamp and Watercourse Plan

DENDROBIUM AREA 3

Legend

- Approved Mine Layout
- Minor Streams
- Rivers & Creeks (LPI)
- Lakes (LPI)
- Swamps
- Proposed Area 3 Footprint
- Proposed Longwall Layout
- Existing Longwall Layout

N W E S

FIGURE 5.1

Scale 1:30,000 (at A3)

Kilometres
0 0.5 1 2

Cardno Forbes Rigby

Map Produced by Forbes Rigby Pty Ltd
Date: 13 November 2007
Coordinate System: Zone 56 MGA/GDA 94
GIS MAP REF:
107055-01_1806_EIA_Swamp_Plan.mxd

- Dendrobium Area 1 – Longwalls 1 and 2 which mined adjacent to Kembla Creek (impacts observed after completion of Longwall 1 December 2005 and completion of Longwall 2 January 2007).
- Appin Longwall 301 which mined adjacent to the Cataract River (completed April 2007, impacts observed during and after completion).
- West Cliff Longwalls 5A1 to 5A4 which mined adjacent to and directly beneath the Georges River (impacts observed during extraction of Longwall 5A1 in November 2000, and during extraction of Longwall 5A4 in September 2002) .
- West Cliff Longwalls 29 and 31 which mined adjacent to the Georges River (Longwall 29 completed in August 2004, and Longwall 31 completed in December 2006, impacts observed during extraction).
- Tahmoor Longwalls 14 to 19 which mined adjacent to and directly beneath the Bargo River (impacts observed after completion in July 2002).

Descriptions and details of each case study are provided in Appendix D of MSEC report in **Attachment A**. The case studies include a range of longwall geometries, mining details, longwall offsets from creek and river valleys and heights and shapes of creek and river valleys.

To allow comparisons between the case studies and the proposed longwalls, the back-predicted upsidence and closure movements for the case studies were determined using the ACARP Method, which is the same method that was used to predict the upsidence and closure movements for Longwalls 6 to 10 in Area 3A.

Observed valley related movements were not used in these comparisons because the mining geometries and valley geometries for the case studies are different to those for the proposed longwalls. By using the ACARP Method of prediction for valley related movements, however, the mining geometries and valley geometries for the case studies are normalised and comparisons can be made with the predictions for Longwalls 6 to 10 in Area 3A.

The back-predicted total upsidence and closure movements and the observed impacts for each case study are shown in **Figure 5.2**. Minor impacts, such as isolated fracturing, gas release and iron staining, are indicated as circles in this figure. Significant impacts, including significant fracturing and surface water flow diversions are indicated as crosses in this figure. The maximum predicted total upsidence and closure movements along Wongawilli and Sandy Creeks, resulting from the extraction of Longwalls 6 to 10 in Area 3A, are also shown in this figure for comparison.

The natural pools along Wongawilli and Sandy Creeks are controlled by the rock bars, sediment accumulations and riffles. The maximum predicted total upsidence and closure movements at the rock bars along Wongawilli and Sandy Creeks, resulting from the extraction of Longwalls 6 to 10 in Area 3A, are compared with the back-predicted movements for the case studies in **Figure 5.3**.

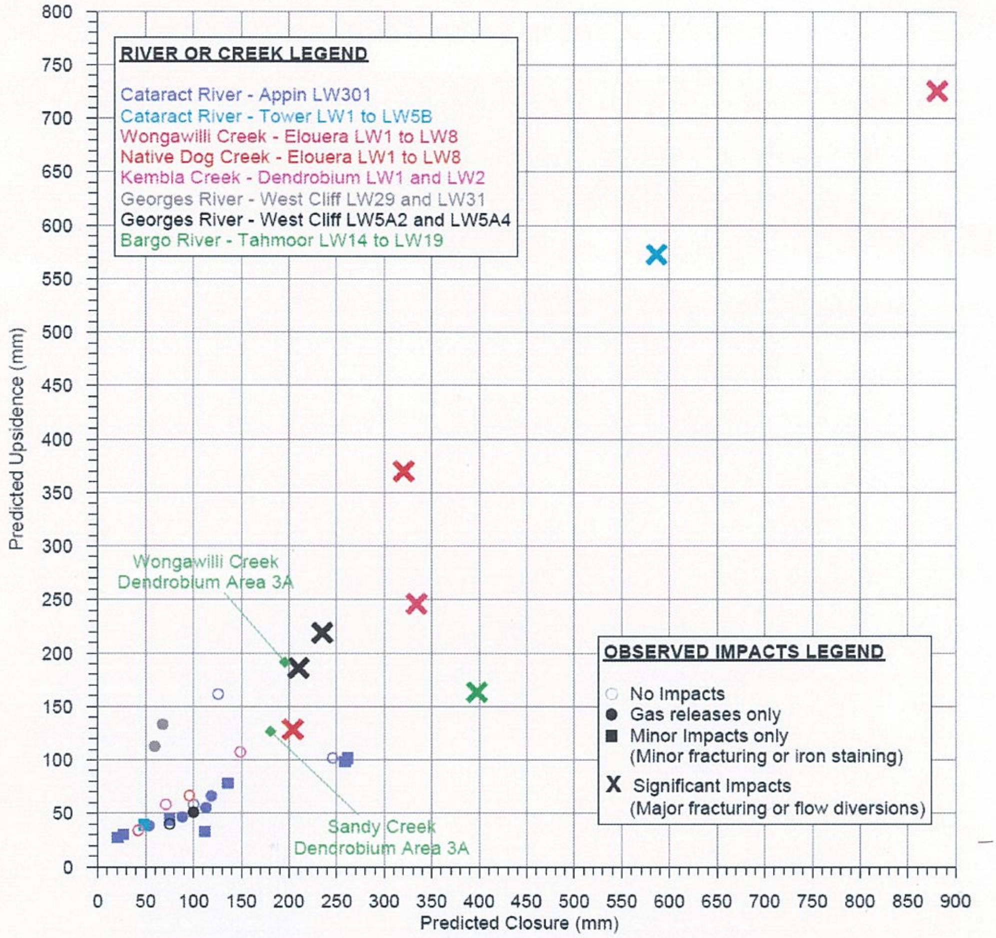


Figure 5.2 – Back-Predicted Upsidence and Closure and the Observed Impacts for the Case Studies

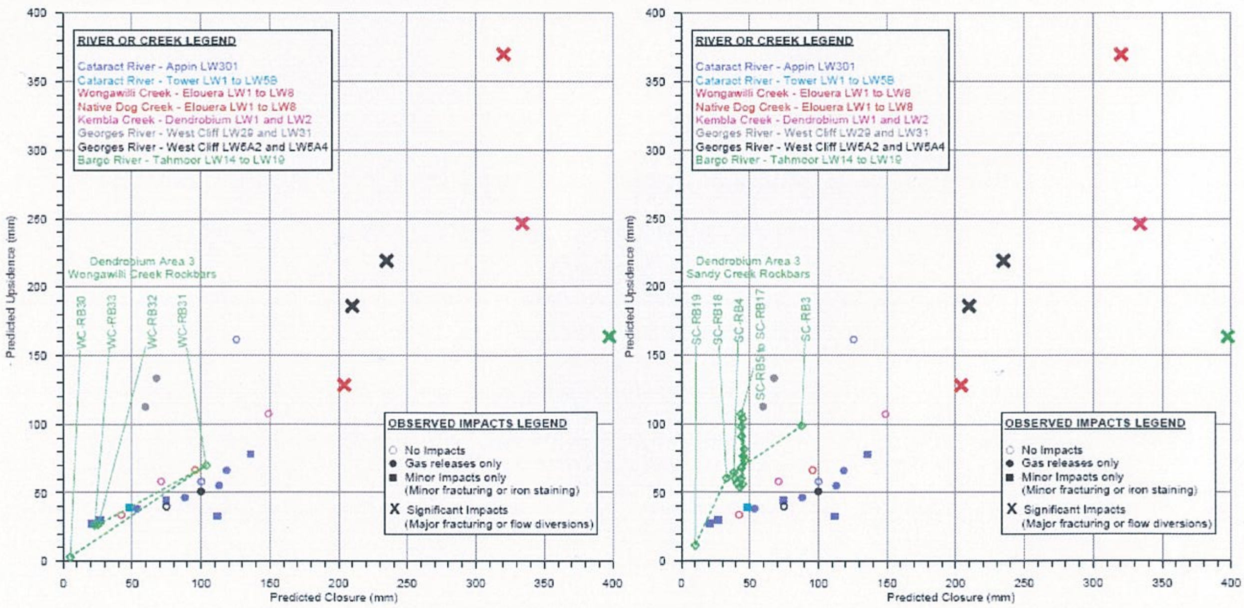


Figure 5.3 – Comparison of Predicted Upsidence and Closure at the Rock Bars along Wongawilli and Sandy Creeks with Back-Predicted Movements and Observed Impacts for the Case Studies

Where Wongawilli and Native Dog Creeks were previously mined beneath by Elouera Longwalls 1 to 10, substantial fracturing in the bedrock and rock bars occurred directly above the longwalls. Only isolated minor fractures were identified outside the extracted longwall goaf edges.

The last drained pool along Wongawilli Creek at Elouera Colliery was located 95m (to the rock bar) downstream of the main gate of Longwall 6 and the back-predicted upsidence and closure at this location were 245mm and 335mm, respectively. The first full pool along the creek was located 275m (to the rock bar) downstream of the edge of Longwall 7.

The last drained pool along Native Dog Creek at Elouera Colliery was located 75m (to the rock bar) downstream of the main gate of Longwall 7 and the back-predicted upsidence and closure at this point were 130mm and 205mm, respectively. The first full pool along the creek was located 105m (to the rock bar) downstream of the main gate of Longwall 7.

It can be seen from **Figure 5.3** that only minor impacts occurred where the back-predicted closure and upsidence for the case studies were typically less than 200mm and 125mm, respectively. It can also be seen from this figure that the commencement of significant impacts occurred where both the back-predicted closure and upsidence for the case studies were greater than 200mm and 125mm, respectively.

It should be noted that the predicted and back-predicted upsidence and closure movements made using the ACARP Method use conservative upper bound prediction curves. The observed valley related movements, therefore, are typically found to be much less than those predicted using this method. Comparisons between predicted and observed upsidence and closure movements in the valley related movements database are provided in **Figures 5.4** and **5.5**.

It has been found, in the majority of cases, that the observed valley related movements are typically between 50% and 100% of those predicted and in some cases the observed movements are less than 25% of those predicted. In rare cases, it has been found that the observed movements exceeded those predicted, which is generally the result of weak near surface geology.

While both upsidence and closure movements have been back-predicted, MSEC is of the opinion that the most relevant parameter for assessing the potential for significant impacts along the creeks is the predicted closure movements. This opinion is based on information that is currently available and is made for the following reasons:

- Closure is the measure of macro valley movements and, therefore, there is less variation in the observed closure movements between adjacent cross-sections within a valley. As a result, there is less scatter in the observed closure movement data in the empirical database, which can be seen in **Figure 5.3**.
- Upsidence is the measure of micro valley movements in the base of the valley, which can vary significantly between adjacent cross-sections due to variations in near surface geology, whether failure of the bedrock occurs and the nature of bedrock failure. As a result, there is greater scatter in the observed upsidence movement data in the empirical database, which can be seen in **Figure 5.2**.
- The observed upsidence movements in the empirical database are also influenced by the placement of survey pegs, which can miss the point of maximum upsidence within the cross-section and measurements can vary significantly between adjacent cross-sections.

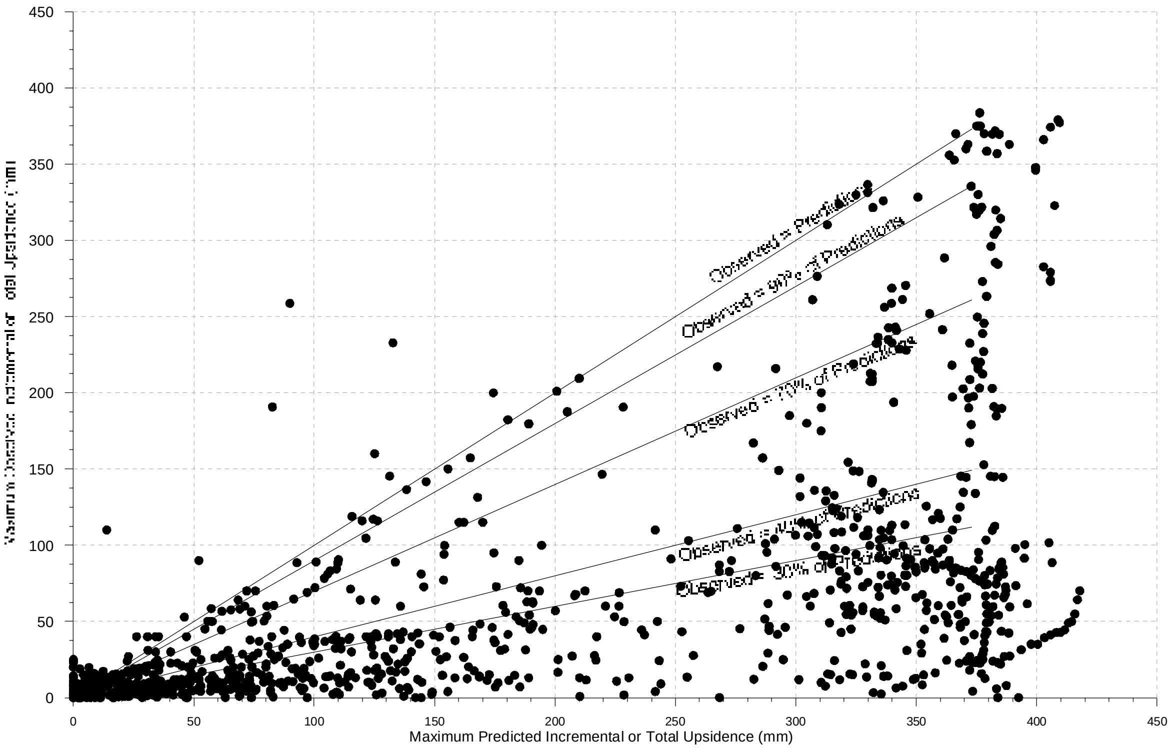


Figure 5.4 – Comparison of Predicted and Observed Upsidence Movements in Database

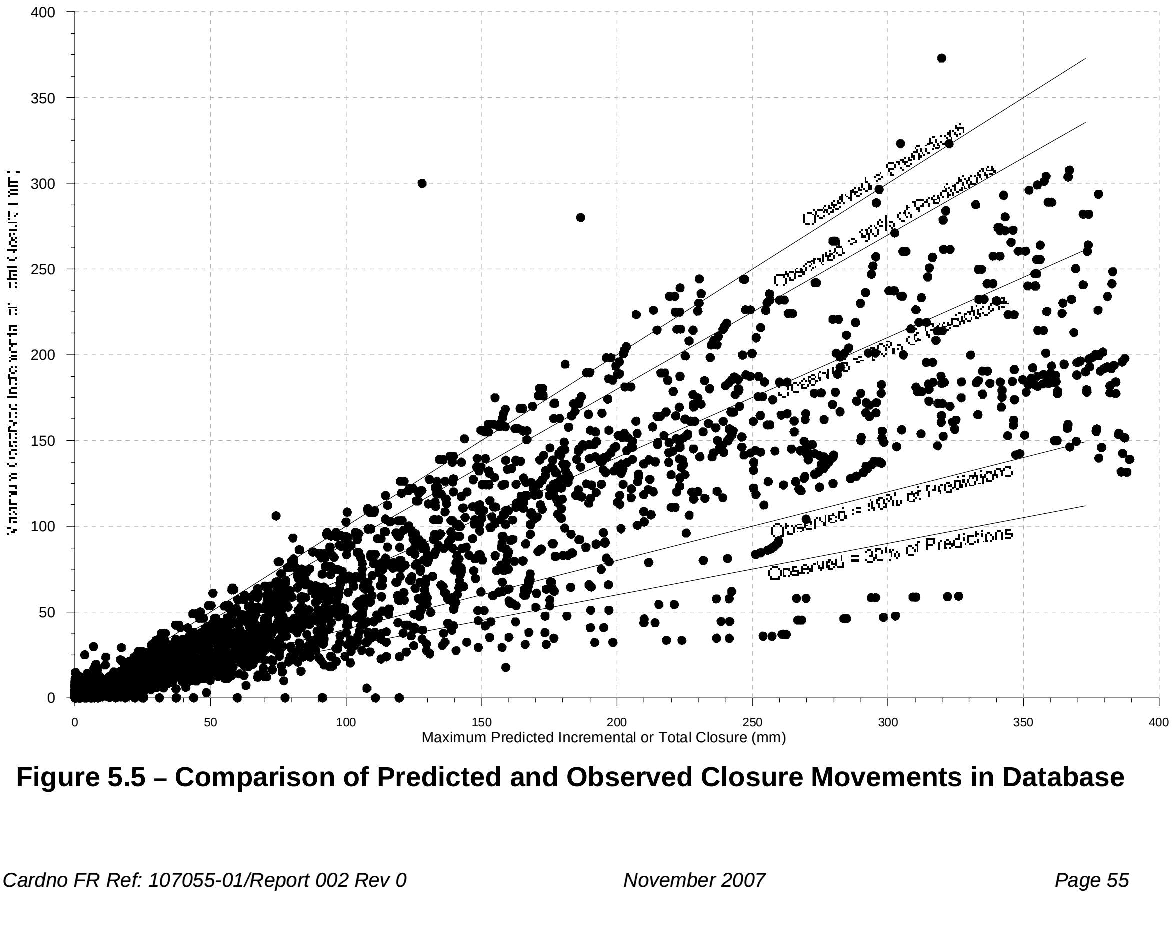


Figure 5.5 – Comparison of Predicted and Observed Closure Movements in Database

Based on the above points, the predicted closure movements are considered to be more reliable than the predicted upsidence movements. Although fracturing and dilation of underlying strata and, hence, the potential for surface water flow diversions result from upsidence movements, the correlation between closure and upsidence movements, which can be seen in **Figure 5.2**, allows us to use the predicted closure movements to assess the potential for these impacts.

It can be seen from **Figure 5.2**, that the maximum predicted closure along Wongawilli and Sandy Creeks, resulting from the extraction of proposed Longwalls 6 to 10 in Area 3A, are less than those back-predicted for all case studies which had observed significant impacts. It can also be seen from **Figure 5.3** that the maximum predicted closure at the identified rock bars along Wongawilli and Sandy Creeks are considerably less than those back-predicted for all case studies which had observed significant impacts.

The maximum predicted upsidence along Sandy Creek, resulting from the extraction of the proposed longwalls in Area 3A, is less than those back-predicted for all case studies which had observed significant impacts. The maximum predicted upsidence along Wongawilli Creek, resulting from the extraction of the proposed longwalls in Area 3A, is less than those back-predicted for all but three case studies which had observed significant impacts. However, the following should be noted for these case studies:

- The back-predicted upsidence of 130mm along Native Dog Creek was accompanied by a back-predicted closure of greater than 200mm. The impact associated with these movements was a single drained pool located at a distance of 75m from the longwalls;
- The back-predicted upsidence of 165mm along the Bargo River was accompanied by a very large back-predicted closure of 400mm; and
- The back-predicted upsidence of 185mm along the Georges River was accompanied by a back-predicted closure of greater than 200mm. The impact associated with these movements occurred at Marhnyes Hole which was directly mine beneath by the longwalls.

Predicted closure is considered to be the more reliable parameter for assessing impacts along creeks and rivers. The case studies, therefore, indicate that a maximum predicted closure of 200mm is an appropriate criteria for assessing the likelihood for significant impacts on the creeks. Similar case studies have also been assessed for creeks and rivers located over previously extracted longwalls at other Collieries within the Southern Coalfield and similar findings have been found.

It should be noted that the case studies occurred during a time of severe drought and the surface water and groundwater levels around the creeks and rivers are likely to have been at lower levels and, hence, the rate of surface water diversion would have been much greater than during normal periods. In this regard, the selected threshold for surface water diversions is considered to be conservative and represents significant protection against flow diversions, even in drought periods.

5.3.2.3 Predictions for Wongawilli Creek

The predicted profiles of incremental and cumulative subsidence, upsidence and closure along Wongawilli Creek, after the extraction of each proposed longwall in Area 3A is summarised in **Table 5.4**.

Table 5.4 – Maximum Predicted Cumulative Subsidence, Upsidence and Closure at Wongawilli Creek Resulting from the Extraction of Longwalls 6 to 10

Longwall	Maximum Predicted Cumulative Subsidence (mm)	Maximum Predicted Cumulative Upsidence (mm)	Maximum Predicted Cumulative Closure (mm)
After LW6	< 20	110	90
After LW7	< 20	145	160
After LW8	< 20	145	175
After LW9	< 20	165	180
After LW10	< 20	190	195

The maximum predicted cumulative net vertical movements and the subsequent changes in grade along the alignment of Wongawilli Creek, after the extraction of each proposed longwall in Area 3A, is summarised in **Table 5.5**.

Table 5.5 – Maximum Predicted Cumulative Net Vertical Movements and Changes in Grade along the Alignment of Wongawilli Creek Resulting from the Extraction of Longwalls 6 to 10

Location	Maximum Predicted Cumulative Subsidence plus Upsidence (mm)		Maximum Predicted Cumulative Tilt due to Subsidence plus Upsidence (mm/m)	
	Net Subsidence (+ve)	Net Uplift (-ve)	Increase in Gradient (+ve)	Decrease in Gradient (-ve)
After LW6	< +20	-105	+1	-1
After LW7	< +20	-140	+1	-1
After LW8	< +20	-140	+1	-1
After LW9	< +20	-155	+1	-1.5
After LW10	< +20	-185	+1	-1.5

The maximum predicted total systematic subsidence and valley related movements at each of these features along Wongawilli Creek, resulting from the extraction of the proposed longwalls in Area 3A, is summarised in **Table 5.6**.

Table 5.6 – Maximum Predicted Total Systematic and Valley Related Movements at the Rockbars and Riffles along Wongawilli Creek Resulting from the Extraction of Longwalls 6 to 10

Feature	Location	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Upsidence (mm)	Maximum Predicted Total Closure (mm)
Rock Bars	WC-RB30	< 20	< 20	< 20
	WC-RB31	< 20	70	105
	WC-RB32	< 20	25	25
	WC-RB33	< 20	25	25
Riffles	WC-RF8	< 20	< 20	< 20
	WC-RF9	< 20	75	120
	WC-RF10	< 20	120	145
	WC-RF11	< 20	100	160
	WC-RF12	< 20	125	175

It should be noted that at the rockbars in Wongawilli Creek that may be susceptible to subsidence related impacts, the predicted levels of subsidence are very low and of a magnitude that is unlikely to cause rock bar cracking leading to pool drainage or water loss. The riffle sections of the creek are generally unconsolidated sediments that are not prone to cracking.

5.3.2.4 Predictions for Sandy Creek

A summary of the maximum predicted values of cumulative subsidence, upsidence and closure at the creek, after the extraction of each proposed longwall, is provided in **Table 5.7**.

Table 5.7 – Maximum Predicted Cumulative Subsidence, Upsidence and Closure at Sandy Creek Resulting from the Extraction of Longwalls 6 to 10

Longwall	Maximum Predicted Cumulative Subsidence (mm)	Maximum Predicted Cumulative Upsidence (mm)	Maximum Predicted Cumulative Closure (mm)
After LW6	< 20	45	50
After LW7	< 20	75	110
After LW8	25	105	155
After LW9	25	120	170
After LW10	35	125	180

A summary of the maximum predicted cumulative net vertical movements and the subsequent changes in grade along the alignment of the creek, after the extraction of each proposed longwall, are provided in **Table 5.8**.

Table 5.8 – Maximum Predicted Cumulative Net Vertical Movements and Changes in Grade along the Alignment of Sandy Creek Resulting from the Extraction of Longwalls 6 to 10

Location	Maximum Predicted Cumulative Subsidence plus Upsidence (mm)		Maximum Predicted Cumulative Tilt due to Subsidence plus Upsidence (mm/m)	
	Net Subsidence (+ve)	Net Uplift (-ve)	Increase in Gradient (+ve)	Decrease in Gradient (-ve)
After LW6	< 20	-45	+0.5	-0.5
After LW7	< 20	-75	+0.5	-1.5
After LW8	< 20	-105	+0.5	-2
After LW9	< 20	-120	+1	-2.5
After LW10	< 20	-125	+1	-2.5

A summary of the maximum predicted systematic and valley related movements at the waterfall, rock bars, and riffles resulting from the extraction of the proposed longwalls, is provided in **Table 5.9**.

Table 5.9 – Maximum Predicted Systematic and Valley Related Movements at the Waterfall, Rock Bars, and Riffles along Sandy Creek Resulting from the Extraction of Longwalls 6 to 10

Location	Label	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Upsidence (mm)	Maximum Predicted Total Closure (mm)
Waterfall	DM23	< 20	125	175
Rock Bars in Lake Cordeaux	SC-RB1 and SC-RB2	< 20	100	170
Rock Bars along Sandy Creek	SC-RB3 to SC-RB19	30	105	90
Riffles along Sandy Creek	SC-RF1 to SC-RF8	30	70	45

It should be noted that at the rockbars in Sandy Creek that may be susceptible to subsidence related impacts, the predicted levels of subsidence are very low and of a magnitude that is unlikely to cause rock bar cracking leading to pool drainage or water loss. The riffle sections of the creek are generally unconsolidated sediments that are not prone to cracking. Longwalls 6 & 7 have been moved at least 250 m away from the waterfall to ensure that valley related movements are less than the threshold likely to cause significant impact.

5.3.2.5 Impact Assessment

Using the predicted systematic and valley related movements, impact assessments on Wongawilli and Sandy Creeks have been carried out and the findings are summarised as follows:

- *Potential for Increased Levels of Ponding, Flooding and Scouring*

  The maximum predicted increasing tilts along the Wongawilli and Sandy Creeks, due to net vertical movements resulting from proposed Longwalls 6 to 10 in Area 3A, are both 1mm/m (ie: 0.1%), or a change in grade of 1 in 1000. The maximum predicted decreasing tilts along Wongawilli and Sandy Creeks, due to net vertical movements resulting from proposed Longwalls 6 to 10 in Area 3A, are 1.5mm/m (ie: 0.15%) and 2.5mm/m (ie: 0.25%), respectively, or changes in grade of 1 in 665 and 1 in 400, respectively.

  Although the creeks have relatively shallow natural gradients, it is unlikely that there would be any significant increases in the levels of ponding, flooding, or scouring of the creek banks, as the maximum predicted changes in grade along the creeks are very small, being less than or equal to 0.25%, or 1 in 400. It is possible, however, that there could be some very localised increased levels of ponding or flooding where the maximum predicted tilts coincide with existing pools, steps or cascades along the creeks, however, any changes are not expected to result in significant impacts.

- *Potential for Fracturing of Bedrock and Surface Water Flow Diversions*

  The potential for fracturing of sandstone has been assessed by considering the previous longwall mining experiences in the Southern Coalfield. The comparisons show that:

  - The fracturing of sandstone due to systematic subsidence movements has generally not been observed in the Southern Coalfield where the systematic tensile and compressive strains are less than 0.5mm/m and 2mm/m, respectively. The maximum predicted systematic tensile and compressive strains at the creeks for the proposed longwalls in Area 3A are 0.3mm/m and 0.1mm/m respectively. It is unlikely, therefore, that the maximum predicted systematic strains at Wongawilli and Sandy Creeks would result in any significant fracturing in the sandstone bedrock or result in any significant surface water diversions.

- The future longwalls in Areas 3B and 3C will be set back from the Wongawilli Creek such that the maximum predicted total systematic strains along the creek, resulting from the extraction of all proposed and future longwalls in Areas 3A, 3B and 3C, are such that it is unlikely that there would be any significant impacts on the creek, such as significant water flow diversion or loss of pool water.

The potential for the fracturing of bedrock and, hence, the potential for surface water flow diversions along Wongawilli and Sandy Creeks, resulting from upsidence and closure movements has been assessed by comparing the predicted movements along these creeks with the back-predicted movements along a number of creeks and rivers which have been impacted by mining within the Southern Coalfield. The comparisons show that:

- The maximum predicted closure along Wongawilli and Sandy Creeks resulting from the extraction of longwalls 6 to 10 in Area 3A are considerably less than those back-predicted for all case studies which had observed significant impacts.
- The case studies indicate that a maximum predicted closure of 200mm can be used as an appropriate threshold for significant impact on Wongawilli and Sandy Creeks.
- The proposed longwalls in Area 3A are not located directly beneath Wongawilli and Sandy Creeks and the future longwalls in Areas 3B and 3C will not mine beneath these creeks. The maximum predicted total closure movements along these creeks resulting from the extraction in Area 3A are less than 200mm and the maximum predicted total closure movements at the rock bars along the creeks are considerably less than 200mm.

It has been assessed that it is unlikely that significant fracturing or surface water flow diversion will occur along Wongawilli or Sandy Creeks as a result of the extraction of the proposed longwalls in Area 3A.

It should be noted, however, that it is still possible that minor fracturing in the beds of Wongawilli and Sandy Creeks could occur as a result of the extraction of the proposed and future longwalls in Area 3. Based on previously observed fractures in the beds of creeks and rivers adjacent to longwall mining in the Southern Coalfield, it is possible that minor fractures could occur in Wongawilli and Sandy Creeks, up to 400m from the proposed and future longwalls. Any fracturing that does occur in the beds of these creeks would be expected to be isolated and of a minor nature and not result in any significant surface water flow diversions.

- *Potential on the Waterfall*

  The waterfall site, where Sandy Creek flows into an arm of Lake Cordeaux, is located 250m east of proposed longwall 7 in Area 3A. The waterfall is a 25m high concave cliff face having a maximum overhang in the order of 20m.

  Previous experience in the Southern Coalfield indicates that:

  - Very few rockfalls have occurred outside of extracted longwall goaf areas, and only in extremely rare cases have rockfalls occurred more than half the depth of cover from extracted longwall goaf edges.
  - All rockfalls observed in Area 1 at Dendrobium Mine occurred directly above the extracted longwalls, and no rock falls were observed outside of the extracted longwall goaf areas.

It is unlikely, therefore, that the extraction of the proposed and future longwalls in Area 3 would result in rockfalls at the waterfall, as the site is located more than half a depth of cover from the proposed and future longwalls.

Loss of surface water flow at the waterfall is unlikely as it has been assessed that surface water flow diversions along Sandy Creek is unlikely to occur as a result of the extraction of the proposed and future longwalls in Area 3.

- *The Potential Impacts on Water Quality*

  Mine subsidence can potentially impact on the quality of water in the creeks due to leaching of minerals from freshly fractured bedrock. Such impacts tend to be temporary, localised and associated with low flow conditions. The potential impacts of mine subsidence on water quality in the creeks are assessed in **Section 6**.

- *The Potential Impacts on Flora and Fauna*

  Mine subsidence can potentially impact on flora and fauna within creeks. The potential impact of mine subsidence on flora and fauna are provided in **Sections 8 and 9**.

5.3.2.6 Mitigation Measures

Wongawilli and Sandy Creeks will be monitored during the extraction of the proposed and future longwalls in Areas 3A, 3B and 3C. The longwall layouts have been prepared to avoid significant impacts to these waterways, however management strategies will also be developed for the creeks, in consultation with the SCA, such that any impacts can be identified and remediated accordingly. With these strategies in place, it is unlikely that there would be any significant impact on the creeks resulting from the extraction of the proposed and future longwalls in Area 3. Details of the remediation measures and ground monitoring are provided in the SMP for Area 3A.

5.3.3 Donalds Castle Creek

5.3.3.1 Existing Environment

Donalds Castle Creek is located 1.4km west of the commencing end of Longwall 6, at its closest point to the proposed longwalls in Area 3A. The upper reaches of Donalds Castle Creek are located in the northern part of Area 3B and in the western part of Area 3C (refer **Figure 5.1**)

The future longwalls in Areas 3B and 3C could potentially mine directly beneath Donalds Castle Creek. Given that the future longwalls in Areas 3B and 3C will have similar void widths, chain pillar widths and extraction heights to those in Area 3A, the maximum predicted systematic subsidence parameters resulting from the extraction of the future longwalls in these areas are expected to be similar to those predicted for longwalls 6 to 10 in Area 3A.

5.3.3.2 Impact Assessment

The impact assessments for Donalds Castle Creek have been based on the maximum predicted systematic subsidence parameters for longwalls 6-10 in Area 3A. A refined impact assessment based on the final longwall layouts in Areas 3B and 3C will be provided as part of the application for SMP Approval for the future longwalls in these areas.

If the future longwalls in Areas 3B and 3C were to mine directly beneath the creek, the impacts are likely to include:

- The maximum predicted systematic tilt for the future longwalls in Areas 3B and 3C is approximately 21mm/m (ie, 2.1%), or a change in grade of 1 in 50. The natural gradient of Donalds Castle Creek within the Study Area varies between a minimum of 10mm/m and a maximum of 150mm/m, with an average natural gradient of 30mm/m. Increased levels of ponding would occur upstream of the longwall chain pillars and increased levels of scouring of the banks could occur downstream of the longwall chain pillars. The increased levels of ponding and scouring of the banks would be expected to be of a minor nature, however, as the maximum predicted change in grade is only 2%.
- The maximum predicted systematic tensile and compressive strains for the future longwalls in Area 3B and 3C are approximately 4.5mm/m and 11mm/m, respectively. Fracturing of exposed bedrock has been observed in the Southern Coalfield in the past where the predicted systematic tensile and compressive strains have been greater than 0.5mm/m and 2mm/m, respectively.
- It would be expected that the maximum predicted valley related movements would be of sufficient magnitude to result in fracturing, buckling and dilation of the topmost bedrock along the creek, which could result in surface water flow diversions. The impacts on the creek would be expected to be similar to that observed where the Elouera Colliery longwalls mined directly beneath Wongawilli and Native Dog Creeks.

5.3.3.3 Mitigation Measures

Mitigation measures for Donalds Castle Creek are not required for Area 3A due to the insignificant impact.

Detailed subsidence modelling and a refined impact assessment for the creek will be undertaken as part of the application for SMP Approval for the future longwalls in Areas 3B and 3C. Management strategies will be developed, in consultation with the SCA, based on the final longwall layouts and the refined impact assessments.

5.3.4 Drainage Lines

5.3.4.1 Existing Environment

The drainage lines are located across Area 3 (refer **Figure 5.1**) and will experience the full range of predicted systematic subsidence and valley related movements in this area. The potential impact is greatest where the drainage lines are located directly above the proposed and future longwalls and, in these cases; the impacts are expected to be similar to Drainage Lines WC17(A) and SC10.

5.3.4.2 Impact Assessment

Specific subsidence predictions have been made for two drainage lines, being WC17(A) and SC10, which illustrate the variations in the predicted subsidence parameters above the proposed longwalls in Area 3A. A summary of the maximum predicted values of total subsidence, upsidence and closure movements at WC17A and SC10, after the extraction of the proposed longwalls in Area 3A, is provided in **Table 5.10**.

Table 5.10 – Maximum Predicted Total Subsidence, Upsidence and Closure Movements at WC17A and SC10 Resulting from the Extraction of Longwalls 6 to 10 in Area 3A

Location	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Upsidence (mm)	Maximum Predicted Total Closure (mm)
WC17/17A	1900	520	450
Banksia Creek	2260	320	250

A summary of the maximum predicted systematic tilt, systematic tensile and systematic compressive strains along WC17A and SC10, at anytime during or after the extraction of the proposed longwalls in Area 3A, is provided in **Table 5.11**.

Table 5.11 – Maximum Predicted Systematic Tilt, Tensile Strain and Compressive Strain at WC17(A) and Banksia Creek Resulting from the Extraction of Longwalls 6 to 10 in Area 3A

Location	Maximum Predicted Systematic Tilt (mm/m)	Maximum Predicted Systematic Tensile Strain (mm/m)	Maximum Predicted Systematic Compressive Strain (mm/m)
WC17/17A	10	3.2	3.8
Banksia Creek	18	4.5	9.4

Based on the predictions, the likely impacts of these drainage lines are summarised as follows:

- The predicted systematic tilts along WC17(A) are small when compared to the existing natural grades and are unlikely to result in any significant increase in the levels of ponding, flooding and scouring along the draining line.
- The predicted systematic tilts along SC10 are a similar order of magnitude to the existing natural grades and could therefore result in increased levels of ponding and flooding adjacent to the longwall tailgates and increased levels of scouring adjacent to the longwall maingates.
- It is unlikely that these drainage lines would be subjected to any significant subsidence, upsidence or closure movements resulting from the extraction of the future longwalls in Areas 3B and 3C.
- Where the drainage lines have alluvial beds it is expected that any ponding, which occurs in these areas as a result of the extraction of the proposed longwalls, would erode during subsequent rain events, especially during times of high flow. It would be expected over time, after a sufficient volume of water has flowed, that the gradients along the alluvial sections of the drainage lines would approach those which existed

before mining. The level and extent of increased ponding in these areas along the drainage lines would, therefore, be expected to decrease with time.

- The maximum predicted valley related upsidence and closure movements along the drainage lines are also likely to result in elevated compressive strains in the bases of the drainage lines of greater than 10mm/m. Compressive strains greater than 2mm/m may be of sufficient magnitude to result in the topmost bedrock buckling and fracturing, which can induce surface cracking in the beds of the drainage lines.
- Tensile strains greater than 0.5mm/m may be of sufficient magnitude to result in cracking in the beds of the drainage lines.
- Surface cracking in areas of alluvial beds along the drainage lines are likely to be filled with the alluvial materials during subsequent flow events. Fracturing of exposed bedrock along the drainage lines could result in some diversion of surface water flows into the dilated strata beneath them and the draining of any pools which existing within the drainage lines. It is unlikely that there would be any net loss of water from the catchment, however, as the depth of dilation in rivers and creeks has generally been observed to be less than 15m in the past and, therefore, any diverted surface water is likely to re-emerge into the catchment further downstream.
- The drainage lines are ephemeral and so water typically flows during and for periods of time after each rain event. In times of heavy rainfall, the majority of the runoff would flow over the beds and would not be diverted into the dilated strata below. In times of low flow, however, some of the water could be diverted into the dilated strata below the beds and this could affect the quality and quantity of the water flowing into the creeks. It is unlikely, however, that this would result in any significant impact on the overall quantity and quality of water harvested from the catchment.

5.3.4.3 Mitigation Measures

Remediation measures will be implemented for the drainage lines, as required, after mining has been completed and where necessary, any fracturing and dilation of the bedrock could be sealed by various methods, including grouting. Remedial measured will be developed and implemented in consultation with the SCA. With these measures in place, it is unlikely that there would be any significant impact on the drainage lines resulting from the extraction of the proposed and future longwalls. Details of the remediation measures and ground monitoring plan are provided in the SMP for Area 3A.

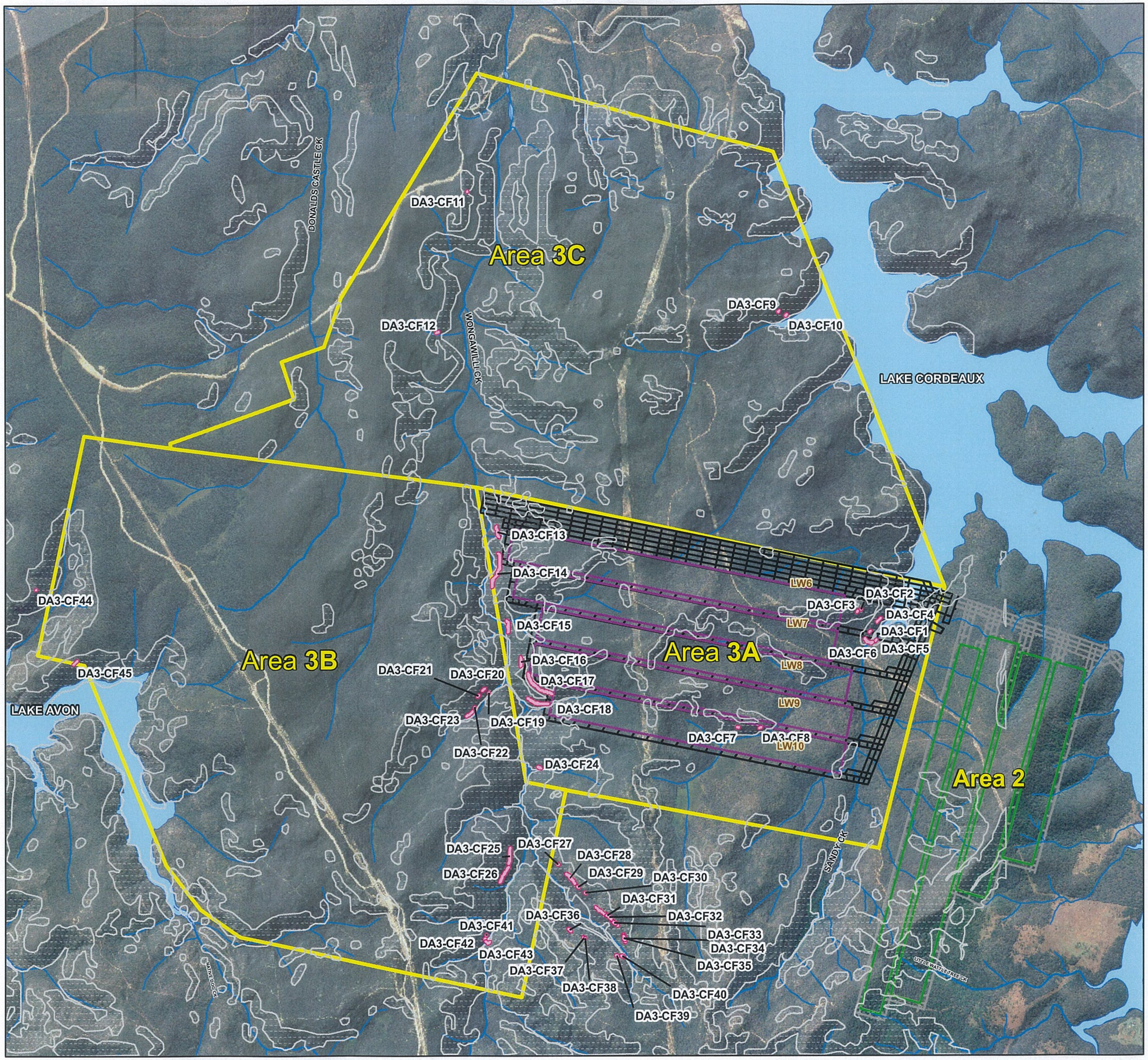
5.3.5 Ground Water Resources

Shallow aquifers associated with the drainage lines and upland swamps, and deep aquifers have been identified within the Study Area. Assessment on the subsidence induced impacts is provided in **Section 7**.

5.3.6 Cliffs

5.3.6.1 Existing Environment

The locations of the cliffs within the Study Area are shown in **Figure 5.6**.



bhpbilliton
ILLAWARRA COAL

Cliffs and Steep Slopes

DENDROBIUM AREA 3

Legend

- Minor Streams
- Rivers & Creeks (LPI)
- Lakes (LPI)
- Steep Slopes
- Cliffs (IC)
- Proposed Area 3 Footprint (IC)
- Proposed Longwall Layout
- Existing Longwall Layout

N
W E
S

FIGURE 5.6

Scale 1:30,000 (at A3)

Kilometres
0 0.5 1 2

Cardno Forbes Rigby

Map Produced by Cardno Forbes Rigby Pty Ltd
Date: 13 November 2007
Coordinate System: Zone 56 MGA/GDA 94
GIS MAP REF:
107055_01_1831_Cliffs_Steep_Slopes.mxd

5.3.6.2 Impact Assessment

A summary of the maximum predicted values of systematic subsidence, tilt and strain at the cliffs within the Area 3A, at any time during or after the extraction of the proposed longwalls, is provided in **Table 5.12**. The values provided in **Table 5.12** are the maximum predicted parameters which occur within a 20m radius of the perimeters of the cliffs.

Table 5.12 – Maximum Predicted Systematic Subsidence, Tilt and Strain at the Cliffs Resulting from the Extraction of Longwalls 6 to 10

Location	Maximum Predicted Subsidence (mm)	Maximum Predicted Cumulative or Travelling Tilt (mm/m)	Maximum Predicted Cumulative or Travelling Tensile Strain (mm/m)	Maximum Predicted Cumulative or Travelling Compressive Strain (mm/m)
DA3-CF2	25	0.4	< 0.1	< 0.1
DA3-CF3	40	0.7	0.1	< 0.1
DA3-CF6	< 20	< 0.1	< 0.1	< 0.1
DA3-CF7	1670	11	2.5	2.0
DA3-CF8	1315	11	2.5	1.6
DA3-CF13	45	0.8	0.2	< 0.1
DA3-CF14	60	1.0	0.2	< 0.1
DA3-CF15	< 20	0.2	< 0.1	< 0.1
DA3-CF16	70	1.1	0.2	0.2
DA3-CF17	240	3.5	1.4	0.3
DA3-CF18	160	2.7	0.7	0.4

The impacts on cliffs in Area 3A are summarised as follows:

- The maximum predicted systematic subsidence parameters at the cliffs in Area 3A occur at Cliffs DA3-CF7 and DA3-CF8 which are directly mined beneath by longwall 10. The cliffs in Areas 3B and 3C, away from Wongawilli Creek, could be subject to the maximum predicted systematic tilt in these areas, which have been taken as 21mm/m or a change in grade of 1 in 50.
- It is unlikely that the maximum predicted tilt will be of sufficient magnitude to directly result in topping type failures along these cliffs.
- It is possible that if the maximum predicted systematic strains are of sufficient magnitude, existing sections of rock could fracture along existing bedding planes or joints and become unstable, resulting in a sliding or toppling type failures along the cliffs.
- It is likely that the maximum predicted systematic strain at cliffs DA3-CF7 and DA3-CF8 and the cliffs which are directly mined beneath in Areas 3B and 3C are of sufficient magnitude to result in the fracturing of sandstone and hence the potential for rockfalls.
- The extent of disturbance at the cliffs which are directly mined beneath by the proposed and future longwalls in Area 3 is expected to be similar to that observed in Area 1. Previous experience in the Southern Coalfield indicates that very few rockfalls have occurred outside longwall goaf areas, and none of these have occurred outside the Dendrobium goaf area. The experience in Area 1 shows that all rockfalls were located directly above Longwall 1. The remaining cliffs within Area 3A are located outside of goaf areas of the proposed longwalls.

The cliffs in Areas 3B and 3C are typically located along the alignment of Wongawilli Creek. As the future longwalls in Areas 3B and 3C will be offset from Wongawilli Creek such that no significant impacts are predicted to occur to the creek. It is unlikely, therefore, that the future longwalls in Areas 3B and 3C would be extracted directly beneath the majority of the cliffs along the alignment of Wongawilli Creek.

It is expected, therefore, that the cliffs along the alignment of Wongawilli Creek in Areas 3B and 3C would be subjected to systematic subsidence movements similar to the cliffs in Area 3A which are not directly mined beneath (ie: cliffs excluding DA3-CF7 and DA3-CF8).

The remaining cliffs in Areas 3B and 3C could be directly mined beneath by the future longwalls and, therefore, could be subjected to the full range of predicted systematic subsidence movements. The maximum predicted systematic subsidence parameters resulting from the extraction of the future longwalls in Areas 3B and 3C will depend on the final longwall layouts in these areas.

Based on the future longwalls in Areas 3B and 3C having similar void widths, chain pillar widths and extraction heights to those in Area 3A, the maximum predicted systematic subsidence parameters resulting from the extraction of the future longwalls in these areas are expected to be similar to those predicted for Longwalls 6 to 10.

The impact assessments for the cliffs along the alignment of Wongawilli Creek within Areas 3B and 3C are expected to be similar to the impact assessments for the cliffs in Area 3A which are not directly mined beneath. The impact assessments for the remaining cliffs in Areas 3B and 3C are expected to be similar to the impact assessments for Cliffs DA3-CF7 and DA3-CF8, and similar to the impact assessments for the rock outcrops, which is described in **Section 5.3.7**.

5.3.6.3 Mitigation Measures

Any persons who enter the Study Area will be made aware of the potential for rockfalls as a result of the extraction of the proposed and future longwalls in Areas 3A, 3B and 3C. The condition of the cliffs at high risk will be monitored throughout the mining period until such time that the mine subsidence movements have ceased.

Appropriate management strategies will be put in place to ensure the safety of people that may be within the vicinity of the rock outcrops during and after the mining period.

5.3.7 The Rock Outcrops

5.3.7.1 Existing Environment

MSEC defines rock outcrops as typically discontinuous and having a maximum continuous height of less than 5m. They are not represented on figures as they are scattered densely across the landscape.

5.3.7.2 Impact Assessment

The maximum predicted cumulative subsidence at the rock outcrops resulting from the extraction of longwalls 6 to 10 is 2,275mm.

The maximum predicted systematic tilt at the rock outcrops, at any time during or after the extraction of the proposed and future longwalls, is 21mm/m (ie: 2.1%), or a change in grade of 1 in 50. Tilt does not directly result in differential movements and, hence, rock falls are more likely to occur as a result of systematic strain and curvatures.

The maximum predicted systematic tensile and compressive strains at the rock outcrops, at any time during or after the extraction of the proposed and future longwalls, are 4.5mm/m and 11mm/m, respectively. The minimum radii of curvatures associated with the maximum predicted tensile and compressive strains are 3.3km and 1.4km, respectively.

The fracturing of sandstone has been observed in the Southern Coalfield where the systematic tensile and compressive strains have been greater than 0.5mm/m and 2mm/m, respectively. It is likely, therefore, that the predicted maximum systematic strains are of sufficient magnitude to result in the fracturing of sandstone and, hence, result in a potential for rockfalls.

Previous experience in the Southern Coalfield indicates that the percentage of rock outcrops that are likely to be impacted by mining is small. Rockfalls are more likely to occur where rock outcrops are continuous, massive, overhanging and marginally stable. It is expected, therefore, that the extent of disturbance at the rock outcrops above the proposed longwalls 6 to 10 in Area 3A and above the future longwalls in Areas 3B and 3C would be less than that observed along the ridgeline in Area 1.

Detail impact assessment on the rock outcrops is provided in the Landscape Impact Assessment in **Attachment C**.

5.3.7.3 Mitigation Measures

Any persons who enter the Study Area will be made aware of the potential for rockfalls as a result of the extraction of the proposed and future longwalls in Area 3. The conditions of the rock outcrops will be monitored throughout the mining period until such time that the mine subsidence movements have ceased.

Appropriate management strategies will be put in place to ensure the safety of peope that may be within the vicinity of the rock outcrops during and after the mining period.

5.3.8 Steep Slopes

5.3.8.1 Existing Environment

The locations of the steep slopes within the Study Area are shown in **Figure 5.6**. For the purposes of this report, steep slopes have been defined as areas of land having a gradient between 1 in 3 (ie, 33%, or 18 to the horizontal) and 2 in 1 (ie, 200%, or 63 to the horizontal).

5.3.8.2 Impact Assessment

The maximum predicted cumulative subsidence at the steep slopes resulting from the extraction of longwalls 6 to 10 is 2,275 mm.

The maximum predicted systematic tilt at the steep slopes, resulting from the extraction of the proposed longwalls, is 21mm/m (ie: 0.2%), or a change in grade of 1 in 50. The steep slopes are more likely to be impacted by the systematic strains, rather than tilt, as the maximum predicted tilt is small when compared to the existing surface gradients of the steep slopes.

The maximum predicted systematic tensile and compressive strains at the steep slopes, resulting from the extraction of the proposed longwalls, are 4.5mm/m and 11mm/m, respectively. The minimum radii of curvatures associated with the maximum predicted tensile and compressive strains are 3.3km and 1.4km, respectively.

The predicted maximum systematic tensile strain at the steep slopes is likely to be of sufficient magnitude to result in surface cracking. The predicted maximum compressive strain at the steep slopes is likely to be of sufficient magnitude to result in the buckling of underlying strata, which could in turn result in surface cracking, where the depths of the overlying soils are shallow.

It is also possible that the predicted maximum systematic strains would result in downhill slumping along the steep slopes, resulting in tension cracks at the tops of the slopes and compressive ridges at the bottoms of the slopes. It is unlikely that mine subsidence would result in any large-scale slope failure, since such failures have not been observed as the result of longwall mining in the Southern Coalfield. This includes the extraction of longwalls 1 and 2 in Dendrobium Area 1 and longwall 3 in Area 2.

The natural grades of the steep slopes in Area 3A are generally less than the natural grades of the steep slopes in Areas 1 and 2. In addition to this the depths of cover across Area 3 are generally greater than the depths of cover in Areas 1 and 2. It is likely, therefore, that the maximum size and extent of surface cracking at the steep slopes within Area 3 will be less than that observed during the extraction of Longwalls 1 and 2 in Area 1 and during the extraction of Longwall 3 in Area 2 at the mine.

In the event of significant surface cracking, erosion channels could potentially develop within the drainage lines as a result of concentrated water flow. In this case, it is recommended that appropriate remediation and/or monitoring measures are undertaken, including infilling of surface cracks with soil or other suitable materials, or by locally regrading and re-compacting the surface, where it is appropriate to do so and the proposed remedial measures to not themselves cause significant environmental impacts. Similarly, where cracking restricts the passage of vehicles along roads and tracks that are required to be open to access, it is recommended that these cracks be filled with soil or other suitable materials.

Detail impact assessment on the steep slopes is provided in the Landscape Impact Assessment in **Attachment C**.

5.3.8.3 Mitigation Measures

The steep slopes will be monitored throughout the mining period and until any necessary rehabilitation measures are completed. Any significant surface cracking which could result in increased erosion or restrict access to areas will be remediated by infilling with soil or other suitable materials, or by locally regrading and compacting the surface. Management strategies will be developed, in consultation with the SCA, to ensure that these measures are implemented. Details of the remediation measures and ground monitoring are provided in the SMP for Area 3A.

5.3.9 Upland Swamps

5.3.9.1 Predictions for Upland Swamps

The locations of the swamps in Area 3 are shown in **Figure 5.1**. A summary of the maximum predicted values of systematic subsidence, tilt and strain at the swamps for proposed Longwalls 6 to 10 in Area 3A, at any time during or after the extraction of each proposed longwall, is provided in **Table 5.13**.

Table 5.13 – Maximum Predicted Systematic Subsidence, Tilt and Strain at the Swamps Resulting from the Extraction of Longwalls 6 to 10 in Area 3A

Swamp	Longwall	Maximum Predicted Cumulative Subsidence (mm)	Maximum Predicted Cumulative or Travelling Tilt (mm/m)	Maximum Predicted Cumulative or Travelling Tensile Strain (mm/m)	Maximum Predicted Cumulative or Travelling Compressive Strain (mm/m)
Swamp 12	After LW6	120	1.5	0.3	0.1
	After LW7	1730	17	2.9	7.1
	After LW8	1885	15	3.6	7.1
	After LW9	1900	17	4.0	7.1
	After LW10	1900	17	4.0	7.1
Swamp 15a	After LW6	< 20	< 0.1	< 0.1	< 0.1
	After LW7	< 20	< 0.1	< 0.1	< 0.1
	After LW8	< 20	0.4	0.1	< 0.1
	After LW9	2020	20	3.8	11
	After LW10	2275	21	3.8	11
Swamp 15b	After LW6	< 20	< 0.1	0.2	< 0.1
	After LW7	410	7.1	2.1	0.4
	After LW8	1920	15	4.5	7.1
	After LW9	2115	15	4.5	7.1
	After LW10	2115	15	4.5	7.1
Swamp 16	After LW6	70	1.0	0.3	0.1
	After LW7	70	1.1	0.3	0.1
	After LW8	70	1.1	0.3	0.1
	After LW9	70	1.1	0.3	0.1
	After LW10	70	1.1	0.3	0.1
Swamp 34	After LW6	< 20	< 0.1	< 0.1	< 0.1
	After LW7	< 20	< 0.1	< 0.1	< 0.1
	After LW8	< 20	< 0.1	< 0.1	< 0.1
	After LW9	< 20	< 0.1	< 0.1	< 0.1
	After LW10	40	0.5	0.1	< 0.1

The values provided in the above table are the maximum predicted parameters within a 20m radius of the perimeter of each swamp. The predicted tilts and strains are the maximum values which occur during, or after the extraction of each proposed longwall, whichever is the greater.

Swamps 12, 15a, 15b and 16 are located within or partially within the valleys of drainage lines and could, therefore, be subjected to upsidence and closure movements as a result of the extraction of the proposed longwalls. Swamp 34 is located on the side of a valley and is unlikely, therefore, to be subjected to any significant upsidence or compressive strains due to closure movements. A summary of the maximum predicted total upsidence and closure movements at the swamps, after the extraction of the proposed longwalls, is provided in **Table 5.14**.

Table 5.14 – Maximum Predicted Total Upsidence and Closure at the Swamps Resulting from the Extraction of Longwalls 6 to 10

Swamp	Maximum Predicted Total Upsidence (mm)	Maximum Predicted Total Closure (mm)
Swamp 12	415	335
Swamp 15a	290	200
Swamp 15b	345	265
Swamp 16	30	30

An equivalent valley depth factor of 0.7 has been adopted for the swamps. The maximum predicted upsidence movements occur at the bases of the valleys in which the swamps have formed. The maximum predicted closure movements occur between the steepest sides of the valleys and, therefore, the total closure movements across the extents of the swamps are less than the values provided in **Table 5.14**.

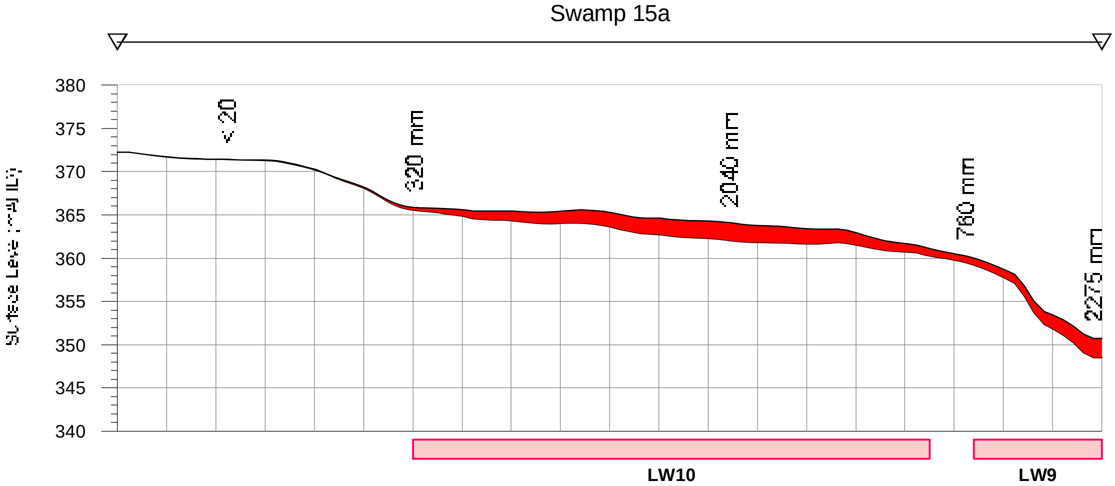
Swamps are located within Areas 3B and 3C and are likely, therefore, to be subjected to the full range of predicted systematic subsidence movements in these areas. The maximum predicted systematic subsidence parameters resulting from the extraction of the future longwalls in Areas 3B and 3C will depend on the final longwall layouts in these areas.

Based on the future longwalls in Areas 3B and 3C having similar void widths, chain pillar widths and extraction heights to those in Area 3A, the maximum predicted systematic subsidence parameters resulting from the extraction of the future longwalls in these areas are expected to be similar to those predicted for Longwalls 6 to 10.

The range of predicted systematic and valley related movements for the swamps in Areas 3B and 3C are, therefore, expected to be similar to the range of predicted movements for the swamps in Area 3A, which are summarised in **Table 5.13** and **Table 5.14**. A refined impact assessment based on the final longwall layouts in Areas 3B and 3C will be provided as part of the application for SMP Approval for the future longwalls in these areas.

5.3.9.2 Impact Assessment

The maximum predicted total subsidence at the swamps is 2275mm, which occurs at Swamp 15a after the extraction of proposed Longwall 10. The minimum predicted total subsidence at Swamp 15a is less than 20mm, which occurs south of the Longwall 10 and, therefore, the maximum predicted differential total subsidence across the extent of this swamp is 2275mm. The differential total subsidence across the extent of Swamp 15a is illustrated in **Figure 5.7**.



Source: MSEC 2007

Figure 5.7 – Cross-Section through Swamp 15a Showing the Profile of Total Predicted Subsidence

The maximum predicted differential total subsidence at Swamp 15a above the centre of Longwall 10, relative to the total subsidence above the longwall goaf edges, is 1500mm. The maximum predicted differential total subsidence at Swamp 15a above the centre of Longwall 9, relative to the total subsidence above the chain pillar is 1515mm.

Similarly, the maximum predicted differential total subsidence at Swamps 12 and 15b above the centres of the longwalls, relative to the total subsidence above the longwall goaf edges, are 1625mm and 1350mm, respectively.

The maximum predicted total systematic tilt at the swamps, resulting from the differential subsidence within the swamps, is 21 mm/m (ie: 2.1%), or a change in grade of 1 in 50, which occurs at Swamp 15a adjacent to the main gate of Longwall 10. The natural grade within the swamp varies from less than 5mm/m to greater than 500mm/m, with an average natural grade of approximately 50mm/m at the location of maximum predicted tilt.

The maximum predicted total systematic tilts at Swamps 12 and 15b, resulting from the differential subsidence within the swamps, are 17mm/m (ie: 1.7%) and 15mm/m (ie: 1.5%), respectively, or changes in grade of 1 in 60 and 1 in 65, respectively, which both occur adjacent to the chain pillar between Longwalls 7 and 8. The natural grades of the surface within these swamps vary from less than 5mm/m to greater than 200mm/m.

The predicted differential total subsidence and total tilt within Swamps 12, 15a and 15b may result in increased water levels above the centre lines of the longwalls, and decreased water levels above the chain pillars and longwall goaf edges. It is possible that the changes in water level within the swamps could impact on the distribution of local vegetation within the swamps. Generally, however, the surfaces of the swamps are free draining, and it is not anticipated that significant changes in water levels would occur as a result of differential subsidence or tilt.

The maximum predicted systematic tensile and compressive strains at the swamps in Area 3A, at any time during or after the extraction of the proposed longwalls, are 4.5mm/m and 11mm/m, respectively, which occur at Swamps 15b and 15a, respectively. The minimum radii of curvatures associated with the maximum predicted systematic tensile and compressive strains are 3.3km and 1.4km, respectively.

Tensile strains greater than 0.5mm/m may be of sufficient magnitude to result in fracturing in the topmost bedrock. Compressive strains greater than 2mm/m may be of sufficient magnitude to result in the topmost bedrock fracturing, buckling and dilating. It is expected, therefore, that fracturing, buckling and dilation of the topmost bedrock would occur at the pre-existing natural joints and bedding planes beneath Swamps 12, 15a and 15b as a result of the extraction of the proposed longwalls.

The maximum predicted total upsidence at the swamps is 415mm, which occurs at the base of the drainage line along the northern edge of Swamp 12. The maximum predicted total closure at the swamps is 335mm, which occurs across the valley in which Swamp 12 has formed. The maximum predicted upsidence and closure movements at Swamps 12, 15a and 15b are likely to result in compressive strains of sufficient magnitude to dilate and buckle the topmost bedrock at the bases of the valleys in which these swamps have formed.

Studies of upland swamps indicate that the swamps are very resilient sediment storage features in the landscape. Two fundamental types of upland swamps have been identified:

1. "Valley Infill" swamps lie along well defined drainage lines and are susceptible to scouring of the sandy substrates. Swamps 15a and 15b are valley infill swamps which lie within the valleys of Drainage Lines SC10 and SC10C, respectively, and
2. "Headwater" swamps lie within relatively low sloped areas of weathered Hawkesbury Sandstone in which confined hillslope aquifers exist. Swamps 12 and 34 are headwater swamps.

In both types of swamps, significant quantities of sediment are found above the bedrock which is highly fractured and weathered naturally. It is unlikely, therefore, that any additional fracturing in the bedrock, as a result of mine subsidence, would have a significant impact on the sediments, aquifers and, hence, the swamps. It should also be noted, that the reported incidence of impacts on upland swamps within the Metropolitan Catchment Area, due to longwall mining, has been low relative to the extent of mining under swamps in this area. Where impacts have been observed, these impacts have generally been associated with natural events or non-mining disturbances. A detailed discussion on upland swamps, the susceptibility of these swamps to impact, is provided in **Section 6.5**.

Further assessment has been undertaken for landscape impacts on swamps resulting from the extraction of Area 3A **(Attachment C)**. The landscape impacts are summarised below.

The analysis of mining induced subsidence on swamps and minor watercourses determined:

- Swamps in Area 3 are currently in a stable condition and have not shown any obvious surface disturbance over at least the last four decades.
- Analysis of predicted pre and post-mining contours in Area 3A showed no detectable difference in the sub-catchment sizes as a result of the mine subsidence.
- Although there may be a *higher potential* for scour where gradient increases occur, these changes are unlikely to result in increased scour events due to the minimal increases on shear strengths over different flow events, the occurrence of bedrock as a control in some cases, and the lack of defined concentrated flow paths in other cases.
- Any mining induced gradient change will be less than the average grade of the swamp/watercourse and is insignificant in comparison to the natural grade variations observed in these swamps.

- In many cases slope does not have a significant effect on sub-catchment surface flow velocities. Catchment area and surface roughness are the significant factors.
- Where minor gradient decreases occur, water has the potential to pool in the swamp/watercourse. The impact of increased pooling is likely to be minor and is not expected to result in any significant flow on impacts other than perhaps a redistribution of vegetation in the immediate area due to increased moisture.
- Monitoring by IC and EarthTech indicates none of the swamps in Area 3A have any notable existing points of disturbance where scour may be expected to be initiated.
- In Area 3A, Swamp 15a is considered the swamp at most risk of any potential mine induced subsidence impacts. This is due to its large catchment area, considerable length, orientation over the subsidence perimeter and longwalls 9 & 10, in addition to it's relatively flat grades over significant sections.

In summary, the landscape related impacts from the proposed mining are assessed as being minor and not significant. In addition to this assessment, other specialist studies have been undertaken in relation to the subsidence induced cracking of bedrock below and around swamps and any hydrologic, water quality, or ecological impacts that may occur due to these effects. The results of these assessments are available in **Section 6.5.**

5.3.9.3 Mitigation Measures

The swamps will be monitored during the extraction of the proposed and future longwalls in Area 3. Management strategies will be developed, in consultation with the SCA. With appropriate management strategies in place, it is unlikely that there would be a significant impact on the swamps resulting from the proposed mining.

5.3.10 The Abandoned Maldon-Dombarton Railway Corridor

5.3.10.1 Existing Environment

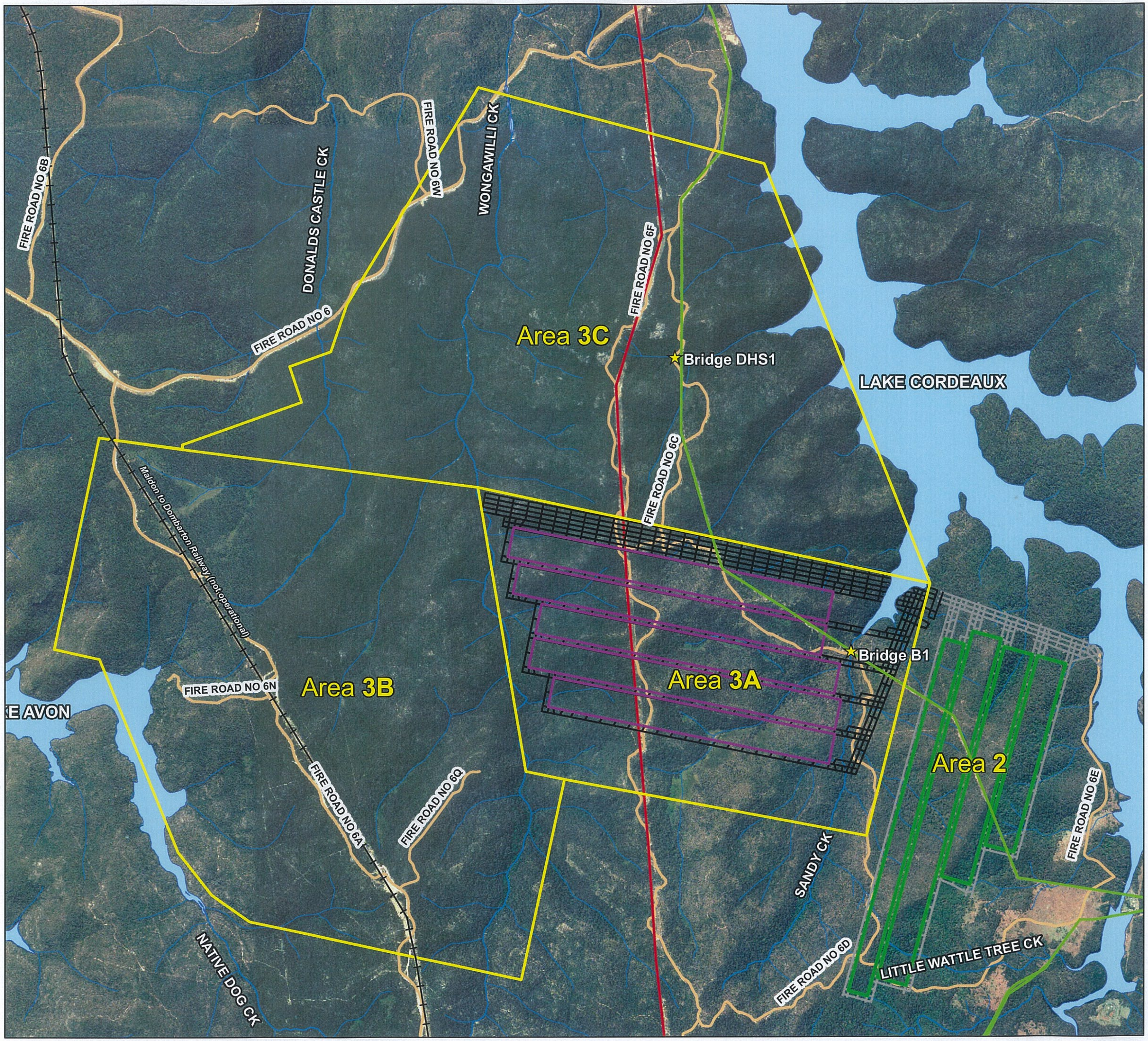
The abandoned Maldon–Dombarton Railway Corridor crosses Area 3B, the location of which is shown in **Figure 5.8**. At the time of abandoning the work, the major earthworks had been completed, but no tracks or associated equipment had been installed.

5.3.10.2 Impact Assessment

The corridor is located at a distance of 1.9km from proposed Longwalls 6 to 10 in Area 3A, at its closest point. It is unlikely, therefore, that the corridor would be subjected to any significant systematic subsidence, valley related, or far-field horizontal movements resulting from the extraction of these longwalls.

The corridor crosses Area 3B and is likely, therefore, to be subjected to the full range of predicted systematic subsidence movements in this area. The maximum predicted systematic subsidence parameters resulting from the extraction of the future longwalls in Area 3B will depend on the final longwall layouts in this area.

Based on the future longwalls in Area 3B having similar void widths, chain pillar widths and extraction heights to those in Area 3A, the maximum predicted systematic subsidence parameters resulting from the extraction of the future longwalls in this area are expected to be similar to those predicted for Longwalls 6 to 10. A refined impact assessment based on the final longwall layout in Area 3B will be provided as part of the application for SMP Approval for the future longwalls in this area.



bhpbilliton
ILLAWARRA COAL

Infrastructure Plan

DENDROBIUM AREA 3

LEGEND

- Bridge
- Railways
- 33Kv Powerlines
- 330Kv Powerlines
- Fire Roads
- Minor Streams
- Rivers & Creeks (LPI)
- Lakes (LPI)
- Proposed Area 3 Footprint
- Proposed Longwall Layout
- Existing Longwall Layout

N
W E
S

FIGURE 5.8

Scale 1:30,000 (at A3)

Kilometres
0 0.5 1 2

Cardno Forbes Rigby

Map Produced by Cardno Forbes Rigby
Date: 13 November 2007
Coordinate System: Zone 56 MGA/GDA 94
GIS MAP REF:
107055_01_1805_EIA_infrastructure_plan.mxd

It is likely that the rock cuttings would be impacted by the future longwalls in Area 3B, including the fracturing and mobilisation of joints in the rock faces and minor rock falls, similar to that observed where the Elouera Longwalls 10 and 11 mined directly beneath the corridor.

It is expected that any fracturing and rock falls along the rock cuttings, resulting from the extraction of future longwalls in Area 3B, would be of a similar nature to that observed as a result of the extraction of Elouera Longwalls 10 and 11.

5.3.10.3 Mitigation Measures

Any persons entering the Study Area will be made aware of the potential for rockfalls along the corridor resulting from the extraction of the future longwalls in Area 3B. The conditions of the rock faces will be monitored throughout the mining period until such time that the mine subsidence movements have ceased, as may be required. Management strategies will be developed, in consultation with the SCA, to ensure that these measures are implemented. Details of the remediation measures and ground monitoring plan will be provided in the SMP of Area 3B.

5.3.11 Fire Trails and Four Wheel Drive Tracks

5.3.11.1 Existing Environment

Figure 5.8 shows the locations of the Fire Trails and the Four Wheel Drive Tracks in Area 3.

5.3.11.2 Impact Assessment

The fire trails and four wheel drive tracks are located across Area 3A and are likely, therefore, to be subjected to the full range of predicted systematic subsidence movements in this area. A summary of the maximum predicted values of systematic subsidence, tilt and strain at the fire trails and four wheel drive tracks, at any time during or after the extraction of Longwalls 6 to 10 in Area 3A, is provided in **Table 5.15**.

Table 5.15 - Maximum Predicted Systematic Subsidence, Tilt and Strain at the Fire Trails and Four Wheel Drive Tracks Resulting from the Extraction of Longwalls 6 to 10 in Area 3A

Location	Maximum Predicted Cumulative Subsidence (mm)	Maximum Predicted Cumulative or Travelling Tilt (mm/m)	Maximum Predicted Cumulative or Travelling Tensile Strain (mm/m)	Maximum Predicted Cumulative or Travelling Compressive Strain (mm/m)
Fire Trails and Four Wheel Drive Tracks	2275	21	4.5	11

The fire trails and four wheel drive tracks are located across Areas 3B and 3C and are likely, therefore, to be subjected to the full range of predicted systematic subsidence movements in these areas. The maximum predicted systematic subsidence parameters resulting from the extraction of the future longwalls in Areas 3B and 3C will depend on the final longwall layouts in these areas.

Based on the future longwalls in Areas 3B and 3C having similar void widths, chain pillar widths and extraction heights to those in Area 3A, the maximum predicted systematic subsidence parameters resulting from the extraction of the future longwalls in these areas are expected to be similar to those predicted for Longwalls 6 to 10. A refined impact assessment based on the final longwall layouts in Areas 3B and 3C will be provided as part of the application for SMP Approval for the future longwalls in these areas.

The maximum predicted systematic tilt along the fire trails, at any time during or after the extraction of the proposed longwalls, is 15mm/m (ie: 1.5%), or a change in grade of 1 in 65, which occurs along Fire Road 6F above the maingate of Longwall 10. It is unlikely that the predicted tilts would result in any significant changes in the surface water drainage along the trails, as the predicted maximum changes in grades are an order of magnitude smaller than the existing gradients along the trails, which are as high as 200mm/m in the steepest sections.

The maximum predicted systematic tensile and compressive strains at the trails, at any time during or after the extraction of the proposed longwalls, are 2.6mm/m and 5.5mm/m, respectively, which both occur along Fire Road 6F. The minimum radii of curvatures associated with the maximum predicted systematic tensile and compressive strains are 5.8km and 2.7km, respectively.

Tensile strains greater than 0.5mm/m may be of sufficient magnitude to result in cracking in the unsealed surfaces of the trails. Compressive strains greater than 2 mm/m may be of sufficient magnitude to result in the underlying strata to buckle and fracture, which could induce cracking in the unsealed surfaces of the trails.

5.3.11.3 Mitigation Measures

The roads will be repaired using normal road maintenance techniques, by regrading and re-compacting the unsealed road surfaces, or by filling cracks with soil or other suitable material.

The fire trails and four wheel drive tracks will be visually monitored as the proposed and future longwalls mine beneath them, so that any impacts can be identified and rectified accordingly. Management strategies will be developed for the fire trails and four wheel drive tracks in consultation with the SCA.

Details of the remediation measures and ground monitoring plan are provided in the SMP for Area 3A.

5.3.12 Bridges

5.3.12.1 Existing Environment

There are two bridges within the study area. Bridge B1 is located where Fire Road 6C crosses Sandy Creek and is at a distance of 140 m northeast of the commencing end of Longwall 8, at its closest point to the proposed longwalls in Area 3. Bridge DHS1 is located 1.7km north of proposed longwalls 6 to 10 in Area 3A and over 2km north-east of the future longwalls in Area 3B. Their locations are shown in **Figure 5.8**.

5.3.12.2 Impact Assessment

Impact assessment for B1 and DHS1 has been undertaken and is summarised as follows:

- The maximum predicted total subsidence at bridge B1 resulting from the extraction of the proposed longwalls in Area 3A is less than 20mm. It is unlikely to result in any systematic subsidence impacts on the bridge.
- Bridge B1 is located at a distance of approximately 3000m and 700m from Areas 3B and 3C at their closest points. It is unlikely that the bridge will be subject to any significant systematic subsidence, valley related or far-field horizontal movements as a result of the future longwalls in these areas.
- Bridge B1 could be subject to valley related movements resulting from the extraction of longwalls to 10 in Area 3A. The maximum predicted values of total upsidence and closure at the bridge, resulting from the extraction of Longwalls 6 to 10, are 60mm and 40mm, respectively.
- The upsidence movement could be transferred into the bridge B1 structure via the central support and the closest movement could be transferred into the bridge B1 via the end supports. The maximum predicted upsidence of 60mm could induce a hogging curvature into the bridge having a radius of approximately 1.9km. The maximum predicted closure of 40mm could induce a compressive strain in the bridge having a magnitude of approximately 1.3mm/m, if fully transferred into the structure.
- Bridge B1 is a double span steel truss structure which has a flexible nature and is unlikely to be impacted by the maximum predicted valley related movements.
- Bridge DHS1 is located 1.7km north of the proposed longwalls in Area 3A and over 2km north east of the future longwalls in Area 3B. It is unlikely that the bridge would be subject to any significant systematic subsidence, valley related or far-field horizontal movements resulting from the extraction of the proposed and future longwalls in these areas.
- The maximum predicted systematic subsidence and valley related movement at Bridge DHS1, resulting from the extraction of the future longwalls in Area 3C will depend on the final longwall layout in this area.
- The ends of Bridge DHS1 rest on the banks of a gully and it is therefore unlikely that the systematic strains or the valley related upsidence and closure movements would be fully transferred into the timber bearers. The timber bridge is flexible and is likely to accommodate the maximum predicted systematic tensile and compressive strains of 4.5mm/m and 11mm/m respectively.
- The maximum predicted upsidence occurs in the base of the gully and is unlikely, therefore, to result in any impact on the bridge DHS1 which spans the gully. The maximum predicted closure at the bridge is expected to be less than 50mm, due to the small valley height of the gully, and is unlikely, therefore, to result in impact on the bridge.

5.3.12.3 Mitigation Measures

Bridge B1 will be monitored during the extraction of longwalls 6 to 10 and necessary remediation measures can be undertaken as required. This will be addressed in the SMP for Area 3A.

5.3.13 330kV Transmission Line

5.3.13.1 Existing Environment

The 330 kV transmission line crosses directly above proposed Longwalls 6 to 10 in Area 3A and then continues northward across Area 3C. **Figure 5.8** shows the location of the 330kV transmission line.

5.3.13.2 Impact Assessment

A summary of the maximum predicted values of cumulative subsidence, tilt along, tilt across, and strain at the transmission line, after the extraction of each proposed longwall in Area 3A, is provided in **Table 5.16**.

Table 5.16 – Maximum Predicted Cumulative Systematic Subsidence, Tilt Along, Tilt Across, and Strain at the 330 kV Transmission Line Resulting from the Extraction of Longwalls 6 to 10

Longwall	Maximum Predicted Cumulative Subsidence (mm)	Maximum Predicted Cumulative Tilt Along Alignment (mm/m)	Maximum Predicted Cumulative Tilt Across Alignment (mm/m)	Maximum Predicted Cumulative Tensile Strain (mm/m)	Maximum Predicted Cumulative Compressive Strain (mm/m)
After LW6	1165	7.5	2.2	0.9	2.0
After LW7	1490	13	3.9	2.1	5.0
After LW8	1670	12	3.6	2.0	4.0
After LW9	1690	14	3.8	2.3	5.2
After LW10	1790	16	4.3	2.6	6.5

The transmission line will also be subjected to travelling tilts and strains as the extraction face of each longwall passes beneath it. A summary of the maximum predicted travelling tilts and strains at the transmission line, during the extraction of each proposed longwall, is provided in **Table 5.17**.

Table 5.17 – Maximum Predicted Travelling Tilts and Stains at the 330 kV Transmission Line during the Extraction of Longwalls 6 to 10

Longwall	Maximum Predicted Travelling Tilt (mm/m)	Maximum Predicted Travelling Tensile Strain (mm/m)	Maximum Predicted Travelling Compressive Strain (mm/m)
During LW6	5.8	1.2	0.9
During LW7	7.2	1.5	1.2
During LW8	6.8	1.4	1.1
During LW9	7.6	1.6	1.2
During LW10	8.9	2.0	1.6

There is one tension tower within the SMP Area, being Tower 44, which is located 40m north of the tailgate of Longwall 6. A summary of the maxmum predicted values of total systematic subsidence, tilt along, tilt across, and strain at the tension tower, after the extraction of the proposed longwalls, is provided in **Table 5.18**. The values provided in **Table 5.18** are the maximum predicted parameters within a 20 m radius of the centre of the tower.

Table 5.18 – Maximum Predicted Total Systematic Subsidence, Tilt Along, Tilt Across, and Strain at Tension Tower 44 Resulting from the Extraction of Longwalls 6 to 10

Location	Maximum Predicted Subsidence (mm)	Maximum Predicted Cumulative Tilt Along Alignment (mm/m)	Maximum Predicted Cumulative Tilt Across Alignment (mm/m)	Maximum Predicted Cumulative Tensile Strain (mm/m)	Maximum Predicted Cumulative Compressive Strain (mm/m)
Tower 44	350	4.6	1.3	0.9	<0.1

The transmission line crosses Area 3C and is likely, therefore, to be subjected to the full range of predicted systematic subsidence movements in this area. The maximum predicted systematic subsidence parameters resulting from the extraction of the future longwalls in Area 3C will depend on the final longwall layout in this area.

Based on the future longwalls in Area 3C having similar void widths, chain pillar widths and extraction heights to those in Area 3A, the maximum predicted systematic subsidence parameters resulting from the extraction of the future longwalls in this area are expected to be similar to those predicted for Longwalls 6 to 10.

The cables along the 330kV transmission line are not affected by ground strains, as they are supported by the towers above ground level. The cables are, however, affected by the changes in bay lengths, (ie: the distances between the towers at the level of the cables) which result from mining induced differential subsidence, horizontal ground movements and lateral movements at the tops of the towers due to tilting of the towers. The stability of the towers are affected by the mining induced tilts and ground strains at the location of each tower and by changes in the catenary profiles of the cables.

The maximum predicted systematic tilt anywhere along the alignment of the transmission line in Area 3A is 16mm/m (ie: 1.6%), or a change in gradient of 1 in 65, which occurs adjacent to the maingate of Longwall 10. There are no towers located in the vicinity of the maximum predicted tilt.

The maximum predicted systematic tilt within 20m of the tower locations in Area 3A is 6 mm/m which occurs at Tower 43 and is orientated along the alignment of the transmission line. The associated predicted systematic horizontal movement at the base of this tower is 90mm. Based on a tower height of 50m, the maximum predicted systematic tilt and maximum predicted systematic horizontal movement at Tower 43 results in a maximum predicted horizontal movement of 400mm at the top of the tower, which is orientated along the alignment of the transmission line.

The predicted horizontal movements at the tops of the towers are expected to result in changes in the catenary profiles of the aerial cables, which in turn results in differential horizontal loads on the towers. If the towers are unable to support the differential cable loads, it may be necessary to install cable sheaves which could facilitate the predicted movements at the tops of the towers.

The maximum predicted systematic tilt within 20m of tension Tower 44 is 4.6mm/m (ie: 0.5%), or a change in gradient of 1 in 215. The associated predicted systematic horizontal movement at the base of this tower is 70mm. Based on a tower height of 50m, the maximum predicted systematic tilt and maximum predicted systematic horizontal movement results in a maximum predicted horizontal movement of 300mm at the top of the tower, which is orientated along the alignment of the transmission line. Cable sheaves cannot be installed on tension towers and, therefore, it may be necessary to adjust the cable catenaries either side of Tower 44, prior to the extraction of Longwall 6.

The maximum predicted systematic tensile and compressive strains anywhere along the alignment of the transmission line are 2.6mm/m and 6.5mm/m, respectively, which occur above Longwalls 9 and 10, respectively. There are no towers located in the vicinities of the maximum predicted systematic tensile and compressive strains.

The maximum predicted systematic tensile and compressive strains at the tower locations in Area 3A are 1.5mm/m and less than 0.1mm/m, respectively. The minimum radii of curvatures associated with the maximum predicted systematic tensile and compressive strains are 10km and greater than 150km, respectively.

The maximum predicted systematic strains are likely to result in increased stresses within the tower members which could be of sufficient magnitude to result in the structure becoming overstressed. It may be necessary to strengthen some of the tower bases within the Study Area, which may include the installation of cruciform bases or additional structural members.

5.3.13.3 Mitigation Measures

The predicted movements at the 330kV transmission line will be provided to TransGrid so that a detailed structural analysis can be undertaken. The transmission line will be inspected by a suitably qualified person prior to mining to assess the existing condition. Suitable preventive measures will be undertaken, based on the findings from the detailed structural analysis and the site inspection, such that the transmission line is maintained in a safe and serviceable condition throughout the mining period. With the implementation of these management strategies, it is unlikely that there would be a significant impact on the transmission line resulting form the proposed mining.

3D survey marks will be established around each of the towers within the Study Area so that the subsidence movements can be monitored. Management strategies will be developed for the 330kV transmission line in consultation with TransGrid. Details of the remediation measures and ground monitoring plan are provided in the SMP for Area 3A.

5.3.14 33kV Powerline

5.3.14.1 Existing Environment

The 33kV powerlline crosses directly above Logwalls 6 and 7 in Area 3A and then continues northwards across Area 3C. The location of the powerline within the study area is shown in **Figure 5.8**.

5.3.14.2 Impact Assessment

A summary of the maximum predicted values of cumulative systematic subsidence, tilt along, and tilt across the alignment of the powerline, after the extraction of the proposed longwalls in Area 3A is provided in **Table 5.19**.

Table 5.19 – Maximum Predicted Cumulative Systematic Subsidence, Tilt Along and Tilt Across the 33 kV Powerline Resulting from the Extraction of Longwalls 6 to 10

Longwall	Maximum Predicted Cumulative Subsidence (mm)	Maximum Predicted Cumulative Tilt Along Alignment (mm/m)	Maximum Predicted Cumulative Tilt Across Alignment (mm/m)
After LW6	1415	4.4	11
After LW7	1530	7.2	10
After LW8	1530	7.3	11
After LW9	1530	7.3	11
After LW10	1530	7.3	11

The powerline will also be subjected to travelling tilts as the extraction faces of Longwalls 6 and 7 pass beneath it. A summary of the maximum predicted travelling tilts, during the extraction of each proposed longwall, is provided in **Table 5.20**.

Table 5.20 – Maximum Predicted Travelling Tilts at the 33 kV Powerline during the Extraction of Longwalls 6 and 7

Longwall	Maximum Predicted Travelling Tilt (mm/m)
During LW6	7.8
During LW7	4.5

The 33 kV powerline crosses Sandy Creek to the east of Longwall 7. The maximum predicted values of total upsidence and closure at the creek crossing, resulting from the extraction of the proposed longwalls, are 60 mm and 40 mm, respectively.

There is one tension pole within Area 3A, identified as Pole 33T1, which is located adjacent to the tailgate of Longwall 6 (refer **Figure 5.8**). The maximum predicted values of total systematic subsidence, tilt along, and tilt across the tension pole, after the extraction of the proposed longwalls in Area 3A, are 455mm, 4.6mm/m, and 6.2mm/m, respectively. These values represent the maximum predicted parameters within a 20 m radius of the pole.

The cables along the 33kV powerline are not affected by ground strains, as they are supported by the poles above ground level. The cables are, however, affected by the changes in the bay lengths, ie, the distances between the poles at the height of the cables, which result from mining induced differential subsidence, horizontal ground movements and lateral movements at the tops of the poles caused by tilting of the poles. The stability of the poles is also affected by the tilting of the poles and the changes in the catenary profiles of the cables.

The maximum predicted total systematic subsidence along the powerline is 1530mm, which occurs above Longwall 6, after the extraction of Longwall 7. Based on a typical bay length of 50 m between power poles, the maximum predicted total differential subsidence between the poles is 340mm, which equates to a change in bay length of less than 5mm, or less than 0.1% of the original bay length.

The maximum predicted systematic tilt at the powerline is 11mm/m (ie: 1.1%), or a change in gradient of 1 in 90, which occurs adjacent to the finishing end of Longwall 7. High tilts at the locations of the power poles could adversely impact on the cable catenaries or could result in stability problems in any tension poles that are supported by guy ropes. Overhead powerlines can typically tolerate tilts of up to 20mm/m at the poles, without any significant impacts on the cables or poles.

It is unlikely, therefore, that the maximum predicted systematic tilt would result in any significant impacts on the powerline. It is possible, however, that the predicted tilts could result in significant impacts on the powerline if the poles have high existing tilts.

The maximum predicted total upsidence at the Sandy Creek crossing is 60mm, which occurs in the base of the creek. The magnitude of upsidence is predicted to be less than 20mm at the locations of the poles and is unlikely, therefore, to have any significant impact on the powerline. The maximum predicted total closure at the Sandy Creek crossing is 40mm. Based on a typical bay length of 50 m, the maximum predicted closure represents a change in bay length of less than 0.1% and is unlikely, therefore, to have any significant impact on the powerline.

5.3.14.3 Mitigation Measures

The powerline will be inspected by a suitably qualified person prior to mining, to determine the existing condition, and whether any preventive measures are required. The powerline will be visually monitored as the proposed longwalls mine beneath it.

Management strategies will be developed for the 33kV powerline in consultation with Integral Energy. Details of the remediation measures and ground monitoring plan are provided in the SMP for Area 3A.

5.3.15 Lake Cordeaux and Lake Avon

5.3.15.1 Existing Environment

Lake Cordeaux is located east of the proposed Area 3A (**Figure 1.2**).

5.3.15.2 Impact Assessment

A summary of the maximum predicted values of cumulative subsidence, upsidence and closure at Lake Cordeaux, after the extraction of each proposed longwall in Area 3A, is provided in **Table 5.21**.

Table 5.21 – Maximum Predicted Cumulative Subsidence, Upsidence and Closure at Lake Cordeaux Resulting from the Extraction of Longwalls 6 to 10

Longwall	Maximum Predicted Cumulative Subsidence (mm)	Maximum Predicted Cumulative Upsidence (mm)	Maximum Predicted Cumulative Closure (mm)
After LW6	< 20	20	50
After LW7	< 20	70	110
After LW8	< 20	100	155
After LW9	< 20	115	170
After LW10	< 20	120	180

Lake Avon is located 3km to the west of the proposed longwalls in Area 3A, at its nearest point, when the lake is filled to its maximum storage level. It is unlikely, therefore, that Lake Avon would be subjected to any significant systematic, valley related, or far-field horizontal movements resulting from the extraction of proposed Longwalls 6 to 10 in Area 3A.

The maximum predicted total systematic subsidence at Lake Cordeaux and Lake Avon, resulting from the extraction of proposed Longwalls 6 to 10 in Area 3A, are both less than 20mm and are unlikely, therefore, to result in any significant systematic subsidence impacts on the lakes.

The maximum predicted total upsidence and closure at Lake Cordeaux, resulting from the extraction of the proposed Longwalls 6 to 10 in Area 3A, are 120mm and 180mm, respectively, which occur where the lake is closest to the proposed longwalls. The maximum predicted upsidence and closure movements at Lake Avon, resulting from the extraction of the proposed Longwalls 6 to 10 in Area 3A, are below the thresholds where significant impacts are likely to occur.

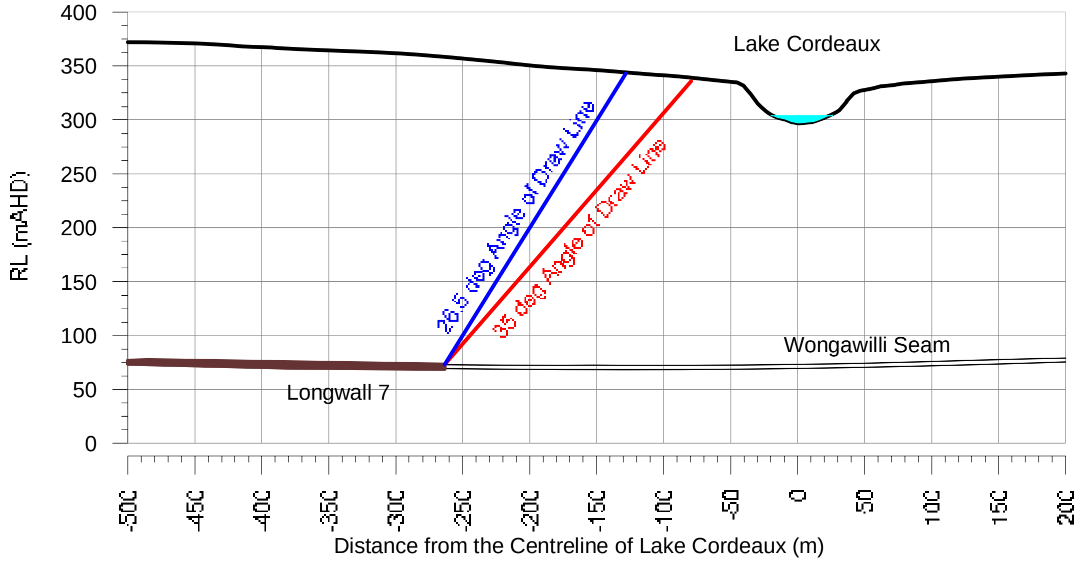
The perimeter of Lake Cordeaux is located at a distance of 250m from Longwall 7, at its closest point to the proposed longwalls in Area 3A. Minor isolated cracking has been observed within creek and river valleys at these magnitudes of predicted movements, at distances of up to 400m from extracted longwalls.

It is possible; therefore, that minor isolated cracking could occur in the bed of Lake Cordeaux as a result of the extraction of the proposed longwalls in Area 3A. It is also possible that minor isolated cracking could occur in the beds of Lake Avon and Lake Cordeaux as a result of the extraction of the future longwalls in Areas 3B and 3C, where the future longwalls are within 400m of the lakes.

It is unlikely that any minor isolated cracking that occurs in the beds of the lakes would result in any loss of water, as the depth of cracking resulting from valley related movements have typically been observed to be less than 15m in the past. Any minor isolated cracking in the beds of the lakes is also likely to be filled by the alluvial materials within the lakes.

Fracturing of bedrock submerged beneath the lakes stored waters or within the impounded areas is unlikely to have a significant impact on the lakes, as the fractures would be quickly filled with water and alluvial materials and not result in any water loss from the system. Furthermore, there is unlikely to be an impact on water quality in the lakes as a result of fracturing in the bedrock, as there would be no flow paths through these fractures

A cross-section through Lake Cordeaux and Longwall 7, where the lake is located closest to the proposed longwalls in Area 3A, is shown in **Figure 5.9**. It can be seen from **Figure 5.9** that the maximum storage water level in the lake is located outside the 35 degree angle of draw line from the proposed longwalls in Area 3A.



Source: MSEC 2007

Figure 5.9 – Cross-Section through the Proposed Longwalls and Lake Cordeaux at its Closest Point

It is also likely that the future longwalls in Areas 3B and 3C would be located outside the 35 degree angle of draw lines from Lake Cordeaux and Lake Avon.

Directly above the proposed and future longwalls in Area 3, there is likely to be a significant increase in the conductivity of subsurface water in the strata within the collapsed zone and, to a lesser extent, within the fractured zone. These zones are located well inside the 26½ degree angle of draw lines from the goaf edges of the longwalls.

Outside the collapsed and fractured zones, there is unlikely to be a significant increase in the conductivity of subsurface water in the strata. It is unlikely, therefore, that there would be any loss of water from Lake Cordeaux or Lake Avon resulting from the proposed mining. A detailed assessment of the potential impact of the proposed mining on the conductivity of subsurface water is provided in **Section 7**.

5.3.15.3 Mitigation Measures

The future longwalls in Areas 3B and 3C would be set back from the lakes such that the maximum predicted total closure at the lakes would be less than 200mm. The observed monitoring data obtained during the extraction of Longwalls 6 to 10 in Area 3A, could be used to further refine the methodology and, hence, the suitable set back distances from the lakes. Details of the remediation measures and ground monitoring plan are provided in the SMP for Area 3A.

5.3.16 Cordeaux Dam and Upper Cordeaux No. 2 Dam

5.3.16.1 Existing Environment

Cordeaux Dam and Upper Cordeaux No. 2 Dam are located 4.4km north and 2.6km south-east of the proposed Longwalls 6 to 10 in Area 3A, at their closest points. It is unlikely, therefore, that the dams would be subjected to any significant systematic or valley related movements resulting from the extraction of these proposed longwalls.

Cordeaux Dam is located 980m north of the maximum footprint for Area 3C and the Upper Cordeaux No. 2 Dam is located more than 3.5km south-east of the maximum footprints for Area 3B and 3C. It is unlikely, therefore, that the dams would be subjected to any significant systematic or valley related movements resulting from the extraction of the future longwalls in these areas.

5.3.16.2 Impact Assessment

The dams could be subjected to very small far-field horizontal movements as a result of the extraction of the proposed longwalls. These movements have, in the past, been observed more than 1km from longwall extractions, however, these movements tend to be bodily movements associated with very low levels of strain.

The observed horizontal movements at the Upper Cordeaux No. 2 Dam wall resulting from the extraction of Longwalls 1 and 2 at the mine were less than 2mm, which was within survey tolerance. The far-field horizontal movements at this dam resulting from the extraction of the proposed longwalls in Area 3A are expected to be less than those observed for Longwalls 1 and 2. The reason for this is that the proposed and future longwalls are located at a minimum distance of 2.5km from the dam wall, whereas Longwalls 1 and 2 are located at a distance of less than 1.5km. In addition to this, Longwalls 3 to 5A in Area 2 are located between the proposed longwalls in Area 3A and the dam wall, which are likely to reduce the horizontal in situ stresses in the strata in this area and, hence, the potential for further far-field horizontal movements.

Cordeaux Dam Wall is located at a distance of greater than 4km north Areas 3A and 3B and is unlikely, therefore, to be subjected to any significant far-field horizontal movements resulting from the extraction of the proposed and future longwalls in these areas. The dam wall could, however, be subjected to small far-field horizontal movements resulting from the extraction of the future longwalls in Area 3C.

A refined impact assessment for far-field horizontal movements at this dam wall, resulting from the extraction of the future longwalls in Area 3C, will be provided as part of the application for SMP Approval for the future longwalls in this area. It should also be noted, that this assessment will be based on monitoring data obtained during the extraction of the proposed and future longwalls in Areas 3A and 3B and can be further refined as the future longwall in Area 3C are mined closer towards to dam wall.

5.3.16.3 Mitigation Measures

The Cordeaux Dam and Upper Cordeaux No. 2 Dam walls will be monitored during the extraction of the proposed and future longwalls in Areas 3A, 3B and 3C. Management strategies are being developed in consultation with the SCA. Details of the remediation measures and ground monitoring are provided in the SMP for Area 3A.

5.3.17 Exploration Bore Holes

5.3.17.1 Predictions

The exploration bore holes are located across Area 3A and are likely, therefore, to be subjected to the full range of predicted systematic subsidence movements. A summary of the maximum predicted values of systematic subsidence, tilt and strain at the bores, at any time during or after the extraction of Longwalls 6 to 10 in Area 3A, is provided in **Table 5.22**.

Table 5.22 – Maximum Predicted Total Systematic Subsidence, Tilt Along, Tilt Across and Strain at Tension Tower 44 Resulting from the Extraction of Longwalls 6 to 10

Location	Maximum Predicted Cumulative Subsidence (mm)	Maximum Predicted Cumulative or Travelling Tilt (mm/m)	Maximum Predicted Cumulative or Travelling Tensile Strain (mm/m)	Maximum Predicted Cumulative or Travelling Compressive Strain (mm/m)
Exploration Bore Holes	2275	21	4.5	11

The exploration bore holes are located across Areas 3B and 3C and are likely, therefore, to be subjected to the full range of predicted systematic subsidence movements in these areas. The maximum predicted systematic subsidence parameters resulting from the extraction of the future longwalls in Areas 3B and 3C will depend on the final longwall layouts in these areas.

Based on the future longwalls in Areas 3B and 3C having similar void widths, chain pillar widths and extraction heights to those in Area 3A, the maximum predicted systematic subsidence parameters resulting from the extraction of the future longwalls in these areas are expected to be similar to those predicted for Longwalls 6 to 10.

5.3.17.2 Impact Assessment

Exploration bore holes can be impacted by mine subsidence due to the ground curvatures, which result in cracking, opening of joints and spalling of strata in the walls of the bore holes, or by the differential horizontal movements in the strata layers at different horizons in the bore holes.

The maximum predicted systematic tensile and compressive strains in the study area are 4.5mm/m and 11mm/m, respectively, and the associated minimum radii of curvatures are 3.3km and 1.4km, respectively. The predicted maximum strains and curvatures are of sufficient magnitudes to result in the fracturing of sandstone and, hence, the potential for spalling within the bore holes.

The maximum predicted systematic tilt in the Study Area is 21mm/m and the associated maximum predicted systematic horizontal movement at the surface is approximately 300mm. The differential horizontal movements between the surface and seam, which result from mining, are distributed over the strata layers at different horizons within the bore holes.

The exploration bore holes are owned by IC and most contain piezometers or geophones. Differential horizontal movements are likely to result in the shearing of the cables which connect the instrumentation with the surface. The differential movements between the strata layers could also result in fracturing and spalling of the strata within the bore holes, which could potentially result in the loss of water from aquifers, or the transmission of water or gas between strata at different horizons within the bore holes.

The majority of the exploration bore holes within the Area 3A are grouted and capped and are unlikely, therefore, to result in an increased conductivity of water and gas any greater than the surrounding strata, as a result of the extraction of the proposed longwalls in Area 3A.

Similarly, the exploration bore holes which have been grouted and capped within the remainder of the Study Area are also unlikely to result in an increased conductivity of water and gas any greater than the surrounding strata, as a result of the extraction of the future longwalls in Areas 3B and 3C.

5.3.17.3 Mitigation Measures

The open exploration bore holes within Areas 3A, 3B and 3C will be grouted and capped prior to mining within each area to minimise conductivity of water and gas between different strata horizons within the bore holes.

5.3.18 Archaeological Sites

5.3.18.1 Predictions

A number of archaeological sites have been identified within the Study Area. A summary of the maximum predicted values of systematic subsidence, tilt and strain at the archaeological sites, at any time during or after the extraction of the proposed longwalls in Area 3A, is provided in **Table 5.23**.

Table 5.23 – Maximum Predicted Systematic Subsidence, Tilt and Strain at the Archaeological Sites Resulting from the Extraction of Longwalls 6 to 10 in Area 3A

Archaeological Site	Maximum Predicted Cumulative Subsidence (mm)	Maximum Predicted Cumulative or Travelling Tilt (mm/m)	Maximum Predicted Cumulative or Travelling Tensile Strain (mm/m)	Maximum Predicted Cumulative or Travelling Compressive Strain (mm/m)
52-2-0458	220	2.9	0.6	0.2
52-2-1646	150	3.9	0.8	0.3
52-2-1647	< 20	0.1	< 0.1	< 0.1
52-2-2043	< 20	0.1	< 0.1	< 0.1
52-2-3052	75	1.0	0.2	0.1
52-5-0273	1485	5.7	1.6	1.3
52-5-0274	235	4.6	1.9	1.5
52-5-0277	1540	7.4	1.8	3.6
52-5-0278	1540	7.6	1.8	3.6
DM13	1615	15	2.5	2.0
DM14	1400	10	1.4	2.5
DM15	1265	15	2.8	2.1
DM20	1660	6.0	1.4	1.1
DM23	<20	< 0.1	< 0.1	< 0.1

The values provided in the above table are the maximum predicted parameters within a 20m radius of each site. The predicted tilts and strains are the maximum values which occur during, or after the extraction of each proposed longwall, whichever is the greater.

The maximum predicted systematic subsidence parameters at the remainder of the archaeological sites in the Area 3A south of the SMP Area, are negligible and are unlikely, therefore, to result in any systematic subsidence impacts on these sites.

Archaeological sites are located across Areas 3B and 3C and discussed in Section 10. The maximum predicted systematic subsidence parameters resulting from the extraction of the future longwalls in Areas 3B and 3C will depend on the final longwall layouts in these areas.

Based on the future longwalls in Areas 3B and 3C having similar void widths, chain pillar widths and extraction heights to those in Area 3A, the maximum predicted systematic subsidence parameters resulting from the extraction of the future longwalls in these areas are expected to be similar to those predicted for Longwalls 6 to 10.

5.3.18.2 Impact Assessment

Impacts on these sites as a result of the proposed longwall mining are examined Archaeological and Cultural Heritage assessment and provided in **Section 10** (see **Attachment G**).

5.3.19 Survey Control Marks

5.3.19.1 Predictions

There are three survey control marks located within Area 3A, being S0704, S1106 and S1343. A summary of the maximum predicted values of total systematic subsidence and horizontal movement at these survey control marks, after the extraction of the proposed longwalls in Area 3A, is provided in **Table 5.24**.

Table 5.24 – Maximum Predicted Total Systematic Subsidence, Tilt and Horizontal Movement at the Survey Control Marks Resulting from the Extraction of Longwalls 6 to 10 in Area 3A

Survey Mark	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Horizontal Movement (mm)
S0704	80	< 20
S1106	< 20	< 20
S1343	345	70

The values provided in **Table 5.24** are the maximum predicted parameters within a 20m radius of each mark.

The survey control marks are located across Areas 3B and 3C and are likely, therefore, to be subjected to the full range of predicted systematic subsidence movements in these areas. The maximum predicted systematic subsidence parameters resulting from the extraction of the future longwalls in Areas 3B and 3C will depend on the final longwall layouts in these areas.

Based on the future longwalls in Areas 3B and 3C having similar void widths, chain pillar widths and extraction heights to those in Area 3A, the maximum predicted systematic subsidence parameters resulting from the extraction of the future longwalls in these areas are expected to be similar to those predicted for Longwalls 6 to 10.

There are also a number of other survey control marks that are located in the vicinity of the Study Area which are likely to experience either small amounts of subsidence or small far-field horizontal movements as the proposed and future longwalls in Area 3 are mined. It is possible that other survey control marks outside the immediate area could also be affected by far-field horizontal movements, up to 3km outside the Study Area.

5.3.19.2 Impact Assessment

It will be necessary on the completion of the proposed longwalls, when the ground has stabilised, to re-establish any marks required for future use. Consultation between IC and the Department of Lands will be required throughout the mining period to ensure that these survey marks are reinstated at an appropriate time, as required.

5.3.19.3 Mitigation Measures

Management strategies will be developed, in consultation with the Department of Lands, such that the survey control marks can be re-established, as required, at the appropriate time.

5.4 REMEDIATION MEASURES

The impacts of subsidence will be monitored as mining occurs so that any unacceptable impacts can be addressed and so that appropriate remediation measures can be implemented. IC will liaise closely with the SCA, the DSC, and all other regulatory authorities and owners of infrastructure to ensure that the impacts of subsidence are managed to an acceptable standard. The following items will be considered within the overall management strategy:

- Wongawilli, Sandy and Donalds Castle Creeks.
- Drainage Lines.
- Lake Cordeaux and Lake Avon.
- Cliffs and rock outcrops.
- Steep slopes.
- Swamps.
- Fire trails and four wheel drive tracks.
- TransGrid 330kV transmission line.
- Integral Energy 33kV powerline.
- Cordeaux Dam and Upper Cordeaux No. 2 Dam.
- Archaeological sites.
- Survey control marks.

5.4.1 Ground Monitoring

A ground monitoring program has been developed to:

- Provide general information on the magnitude and extent of subsidence over the longwalls.
- Compare actual ground movements with predicted ground movements.
- Monitor ground movements at or near surface infrastructure at greater risk.
- Provide an indication of any non-systematic movements within the subsidence zone, however, given the low density of surface features above the longwalls, the risk of adverse impacts by non-systematic movements, ie: anomalies, is very low. If the density was high, the purpose would be to provide early detection.
- Satisfy the objectives of the subsidence management strategies.
- Satisfy the objectives of agreed management plans between IC and infrastructure owners.
- Meet the expectations of the community with regard to monitoring subsidence.

Details of the program are provided in the SMP for Area 3A.

6 SURFACE WATER QUALITY AND HYDROLOGY

Area 3 lies within the Metropolitan Special Catchment Area, which is a special declared area controlled by the Sydney Catchment Authority (SCA). The water storages in the Metropolitan Special Area provide the sole supply for the Macarthur and Illawarra regions and the townships of Campbelltown, Camden, Bargo, Picton, Thirlmere, Tahmoor, The Oaks, Buxton and Oakdale, and provide approximately 20% of the supply to the Sydney Metropolitan Area, via the Prospect Reservoir. The Metropolitan Catchment Area has been defined as an area of environmental sensitivity.

DoP and SCA have requested a general surface water-related hydrologic and water quality Environmental Assessment for all major creeks, their tributaries, swamps and shallow aquifers in Area 3. It is also necessary to consider and assess downstream and 'far field' effects within Lake Cordeaux and Lake Avon, in accord with the requirement to treat the Metropolitan Catchment Area as an area of environmental sensitivity.

IC has commissioned Ecoengineers to undertake the surface hydrology and water quality impact assessment for the proposed Area 3 modification. The assessment is based upon past experience by Ecoengineers in the investigation and assessment of water quality and hydrologic effects induced by mining in the Illawarra Region, particularly in relation to Elouera Mine which is to the immediate southwest of Dendrobium Area 3 and from previous specific water quality, geomorphological and ecological studies conducted in Dendrobium Areas 1 and 2 and their adjacent environs.

The full report is provided in **Attachment B** and its key findings are summarised below.

6.1 SURFACE HYDROLOGY ASSESSMENT

The hydrologic impacts of mining longwalls directly under Native Dog Creek and upper Wongawilli Creek in the vicinity of Area 3 have been studied since 2001. IC has a general understanding of the surface and shallow groundwater hydrologic systems in this area.

It is now known that there is no recognised deep aquifer in the bulk of the Hawkesbury Sandstone within Dendrobium Area 3. Surface and near-surface groundwater hydrologic systems are believed to be separated from any longwall mine workings by a number of well recognised aquicluding claystone units as well as relatively tight sandstones in this area, as detailed in section 7.

Hydrologic studies of Native Dog and Donald's Castle Creeks reported in Ecoengineers (2006) have shown that baseflows of the draining streams, which may be expected to be most affected by mine subsidence-related effects, are generally supplied by semi-confined hillslope aquifers contained in weathered sandstone slopes, soil catenas and swamps. These hillslope aquifers do not appear to be connected to any aquifers associated with main channel creek lines or deep water-bearing strata. Refer **Attachment B** for details on the Hydrologic studies undertaken and their results.

The studies also suggested that there was no evidence that the overall Native Dog Creek catchment (located just south of Dendrobium Area 3B) suffered any significant net loss of water to deep (unrecoverable) storages due to longwall mining by Elouera Mine, despite instances of creek bed fracturing in this Creek and in upper Wongawilli Creek.

Longwalls in Area 3 will be set back from major creeks such as Sandy Creek and Wongawilli Creek to a distance that has been, and will be guided in future, by priori subsidence modelling, to avoid significant cracking and surface water loss in these creek beds. Due to the set back distance of Area 3 longwalls it is not expected that any significant fracturing and sub-bed flow diversions will occur in Sandy Creek or Wongawilli Creek or that there will be detectable losses of outflows from these catchments.

6.2 SUBSIDENCE INDUCED EROSION ISSUES

Ground movements caused by mine subsidence may increase erosion and loss of soil materials through rock falls, or fissure opening in cohesive surface soils. Minor rock falls and surface soil cracking occurred as the result of mining Dendrobium Areas 1 and 2.

Monitoring and inspection by IC and its consultants for Elouera Mine shows there has been no evidence of sustained subsidence-induced erosion of the valley slopes of upper Wongawilli Creek and its tributaries during the past seven year monitoring period, even during the recent high rainfall period of the first 6 months of 2007.

Cliff lines associated with Wongawilli Creek are no larger than those that have been previously mined under in Dendrobium Areas 1 and 2. Slopes are no steeper or more extensive than those that have been previously mined under in Areas 1 and 2 and soil landscape types are similar to those previously encountered in upper Wongawilli Creek.

Based on that experience no significant erosive effects on water quality from the mining of Area 3 are expected.

6.3 STREAM BED FRACTURING EFFECTS

Subsidence caused by longwall mining beneath creeks and riverbeds can produce a complex suite of physico-chemical effects. Hydrological measurements, visual observations and water quality monitoring over recent years in the Southern Coalfield indicate the principal effects are:

1. Compressive and tensile failure fracturing of bedrock leading to increased permeability and storage, possibly reduced surface flows over the mined under stretch of the watercourse, especially at the low end of the flow rate regime and more rapid draining of defined pools in no and low flow situations.
2. Diversion of stream flows through the fractured bedrock leading to loss of surface flows and potential loss of catchment yield if a connection to a deep storage was established.
3. Oxidative dissolution of accessory marcasite within freshly fractured bedrock water pathways, leading to release of sulfuric acid and iron, manganese, nickel and zinc and re-emergence of more acidic water of lower pH, lower redox potential, lower dissolved oxygen concentrations and high concentrations of the above metals from immediately downstream.
4. Leaching of aluminium from kaolinite by acidic water flowing through the fracture network.

It has been demonstrated that, subject to predictive modelling, if adequate set backs from the sides or ends of longwalls from major watercourses are provided, the above-described hydrologic and geochemical effects can be avoided or minimised. Recent examples of such reductions in impact include Longwalls 301 and 302 of Appin Area 3 adjacent to Cataract River and West Cliff Area 5 Longwalls 29 and 31 adjacent to Georges River.

Dendrobium Area 3A Longwalls 6 to 10 will not mine under Wongawilli or Sandy Creeks by distances in the range from 130 – 370 m for Wongawilli Creek and 90 – 225 m for Sandy Creek. The rationale for this is described in detail in the report by Mine Subsidence Engineering Consultants (**Attachment A**). We understand this mine planning approach will also be employed for future mining in Areas 3B and 3C. On this basis we conclude it is unlikely that the mining of Area 3 will lead to significant Creek main channel bed fracturing and subsequent sub-bed diversion hydrologic and geochemical effects in Sandy Creek and Wongawilli Creek.

MSEC (2007) predicts that maximum tensile strains greater than 0.5mm/m may be of sufficient magnitude to result in cracking in the beds of (say) tributary creeks. They also predict compressive strains greater than 2mm/m may be of sufficient magnitude to result in the topmost bedrock buckling and fracturing, which can induce surface cracking in the beds of the drainage lines.

There is some evidence that these predictions are relatively conservative. This is based on local experience over Longwalls 1 and 2 in Dendrobium Area 1 where, out of 6 main tributaries with Maximum Predicted Systematic Tilts, Maximum Predicted Tensile Strains and Maximum Predicted Compressive Strains along their channels of the order of 20, 4.0 and 9.0 mm/m respectively, only one (designated No. 22) exhibited fracturing. Geochemical studies also indicated the fracturing impact was minor and of limited duration. We infer from this that, while fracturing in Banksia Creek (SC10) possibly has higher probability; the probability of a similar effect in Creek WC17/17A may be no more than about 15%.

Most of the baseflow in the lower Creek SC10 tributary of Sandy Creek (Banksia Creek) derives from Swamps 15A and 15B, which lie along relatively weakly incised tributaries. Field studies show that baseflows in Sandy Creek derive from outflows from significant hillslope aquifers on both the western (Area 3A) and eastern (Area 2) sides of the Creek and a broad un-mined southern area in Upper Sandy Creek. Mining under the SC10 (Banksia Creek) and SC7 (Cascade Creek) tributaries of Sandy Creek is likely to result in only marginal changes in several water quality parameters near their points of discharge into Lower Sandy Creek. Due to these broad scale sources of baseflow, downstream water quality impact is predicted to be insignificant.

Minor fracturing is also possible on the longer, more incised, high gradient tributaries of Wongawilli Creek in Area 3B e.g. creeks designated WC15 and WC21, and possibly in Area 3C in the well incised creeks designated LC6 and LC7 which drain to Lake Cordeaux. It is considered any such fracturing is unlikely to cause significant downstream water quality impacts.

6.4 FERRUGINOUS SPRINGS

Induction of ferruginous springs as a consequence of upland subsidence has been identified over the last three years as a longwall mining-related effect in the Southern Coalfield in subcatchments of the Nepean, Cataract and Georges River, most notably by being:

- The large, and long-lived 'SW2 Spring' (Appin Area 3) in Cataract River just west of Back Gully Creek; and
- The moderately large and long lived 'Pool 11 Spring' (West Cliff Area 5) in Georges River.

Mining-related subsidence can have the effect of delaminating erosion surfaces and bedding planes within and between strata. These effects are predicted to occur preferentially along the interfaces between materials with different elastic properties. Where broad scale upland subsidence occurs as a consequence of longwall mining, delamination, dilation and hence interfacial permeability enhancement is likely along the sub-horizontal interface between a sub-cropping Hawkesbury Sandstone and an outcropping Wianamatta Shale sequence.

A substantial portion of Area 3B is mantled by Wianamatta Shale-based soils occupying several catchments at the 1 – 2 km^2 scale which drain via steep (10 – 20%) slopes with sandstone outcrops southwest to the Native Dog Creek Arm of Lake Avon. One or more ferruginous springs may be induced in the slopes of the southwest-draining catchments over Area 3B.

Such an effect, if it does occur, is likely to be largely aesthetic rather than posing any adverse impact on stream ecology due to the relatively short length and high gradients of the ephemeral creeks potentially involved and the substantial dilution and dispersion that would occur at the Lake Avon shoreline.

Notwithstanding, specific water quality monitoring sites would be located in this part of Area 3B to provide early detection and ongoing assessment of this potential effect. Drainage of the Wianamatta Shale-based soil uplands to the northwest to tributaries of Donald's Castle and Wongawilli Creeks occurs over much longer distances of far gentler slopes and there are numerous intervening hanging swamps. It is considered unlikely that springs would be induced in this area and if they were, would be likely to occur around the margins of swamps or upslope of swamps and their effects be largely attenuated by those landscape features.

6.5 SWAMPS

There are a number of large upland swamps within Area 3. These swamps have been mapped and are described as Swamps 1a to Swamp 35b (see **Figure 5.1**). It is important to differentiate upland swamps into (at least) two types, which would usually be expected to exhibit distinctly different types of potential susceptibility to the effects of mine subsidence as follows:

1. The first type or 'braided stream swamps' are those which fringe, and have arisen from sand accumulation along well defined streams where there is a potential for scour of the sandy substrate of the swamp(s) above a certain stream power and erosive resistance threshold. The changes in grade that may result from mine subsidence are only likely to induce excessive shear in relatively low gradient swamps. Therefore the swamps at risk from scour and erosion as a result of longwall mining are those in which the stream is of a high order i.e. high flow and low gradient, has poor vegetation condition e.g. from prior drying (drought) and/or bushfire damage, and the longwalls lie perpendicular to the long axis of the swamp.
2. The second type or 'hanging swamps' occurs within broad scale, relatively low slope creek or tributary headwater areas. A significant body of evidence indicates that most if not all Type 2 swamps are 'embedded' in a broader scale 'hillslope aquifer' which provides the excess of precipitation over evapotranspiration (ET) which proportionally sustains them.

Type 1 swamps at risk from scour and erosion as a result of longwall mining are typically those lying well down the stream where there is sufficient upstream catchment to potentially provide high stream power.

The Landscape Impact Assessment (see **Attachment C**) swamps identified those downstream Type 1 in Area 3 which are considered possibly susceptible to scour effects enhanced by changes in grade due to mine subsidence are Swamps 2, 5, 7, 8, and 15a.

The Landscape Impact Assessment concludes that it is unlikely, that mine subsidence-induced scour effects would affect these swamps. Nevertheless, monitoring and assessment will be undertaken during the period if and when longwalls in Areas 3B and 3C mine across them.

Fracturing due to subsidence effects may become physically detectable at a central drainage line rock shelf or knick points in Type 2 swamps, but such fracturing is likely to be confined to sandstone that *already* contain, naturally, well weathered bedding planes and cross fractures due to the long period of exposure of such features. Therefore, it is predicted that further subsidence induced bedrock fracturing below these swamps is likely to be insignificant in terms of geochemical and/or hydrological impacts.

Hydrologic effects on this type of swamp from longwall mining are only likely to be significant where longwall mining subsidence-related effects have induced some significant changes to a broad scale subcatchment hillslope aquifer. Subsidence impacts to individual rock shelf or knick point will have no significant geochemical or ecological effect on the upgradient or down gradient portions of the swamp.

While it is considered unlikely on the basis of past experience that mine subsidence-induced hydrological effects will adversely affect these Type 2 swamps and more particularly, the substantial hill slope aquifers in which they are generally likely to be embedded, frequent monitoring and assessment will be undertaken during the period in which longwalls in Areas 3A, 3B and 3C approach or mine under them.

Several large upland swamps occur in the headwaters of creeks designated WC17 and Banksia Creek (SC10) over Area 3A. Swamp 12 is of Type 2 and Swamps 15a and 15b of Type 1. Several creek flow and/or water quality monitoring sites are proposed for Area 3A, which lie immediately downstream (in Wongawilli Creek and Banksia Creek) from these swamps. Strongly differential rates of subsidence along these swamps are not expected with the exception of one or two locations in Swamp 15a near Main Gate 10 and Tailgate 9 and hence it is considered unlikely that bedrock fracturing could occur at any but those two locations. Swamp 12 is largely offset from its draining stream and Swamps 15a and 15b lie at the headwater of their draining streams. It is not expected these swamps would be susceptible to scour under high rates of runoff unless very significant prior fire damage or other disturbance had occurred.

6.6 WATER QUALITY IMPACTS ON WATER SUPPLY RESERVOIRS

There is good evidence from over five years of monitoring that there has been no significant effect in the short or long term on either bulk raw water quality or drinking water quality in the Native Dog Creek Arm of Lake Avon, despite Native Dog Creek being directly mined under by Elouera Colliery longwalls, causing substantial creek bedrock fracturing.

Any input of water-borne contaminants (to Lakes Avon and Cordeaux) will likely be restricted to a possible erosive export of fine sands and clays and/or ferruginous precipitates near the mouths of minor creeks designated LA2, LA3, LA4 and LA5 (Lake Avon) and LC6, LC7 and LC8 (Lake Cordeaux) during mining of Areas 3B and 3C respectively. These creeks are all remote from their respective dam off-takes and outflows. Such zones would be localised to around the point of input to the Lakes and would be unlikely to have any significant impact on local freshwater ecology and would be undetectable in the bulk water supply quality.

Based on past experience from Wongawilli and Native Dog Creeks which were directly mined under by Elouera Colliery, it is also considered highly unlikely that there will be any adverse effect on bulk drinking water supply quality in the Lake Cordeaux or Lake Avon systems. Hence, Area 3 development would be compatible with raw water supply quality standards for the Lake Cordeaux and Lake Avon systems

6.7 MITIGATION MEASURES

Mitigation measures are outlined in detail within the Area 3A SMP. In relation to surface water diversion into sub-beds and geochemical effects, the major mitigation measure is the set back of longwalls from Wongawilli and Sandy Creeks, as detailed in section 2.2, to avoid or minimise subsidence induced impacts to these creeks. Site specific contingency measures to address particular geochemical effects have also been considered and could be deployed with the agreement of stakeholders if appropriate, and are outlined below. It is considered highly unlikely these measures would need to be implemented.

6.7.1 Mitigation of Acid and Heavy Metals Generation

With respect to possible remediation of the effects of excessive acid and heavy metals generation through upsidence fracturing of stream bedrock and/or rock bars, liming of excessively acidic streams and rivers is generally the technique of first choice for aquatic ecosystem restoration under stress from acidification and heavy metals.

A logical contingency measure for this proposal is to use a granular agricultural grade limestone ($CaCO_3$) to treat any proven point of chronic emergence of acidic, Fe and Mn-rich upsidence-induced sub-bed diversion flows, especially if such pools were located within 250m of Lake Cordeaux.

Emplacement of limestone at any such location would provide a continual reactive surface for:

- The neutralisation of excessive acidity.
- Encourage the localized precipitation of Fe and Mn hydrous oxides with consequent adsorptive removal of potential eco-toxic trace metals.
- Increase the hardness of the water and encourage rapid settling of dispersed sodic 2:1 layer clays accelerating the rate of natural remediation of cracks in the bases of the pools.

Limestone is relatively insoluble except when pHs fall below about 6.5 and the dissolved products (calcium and carbonate alkalinity) are completely non-toxic, and would have no effect on Bulk Water Supply quality and hence would not adversely affect waters in Lake Cordeaux or Cordeaux River.

Water quality monitoring sites are carefully located to enable a means of isolating and assessing such occurrences to determine if remedial action is required.

6.7.2 Mitigation Measures for Ferruginous Springs

With respect to excessive precipitation of hydrous iron and manganese oxides and the consequent generation of local acidity (but not heavy metals) such as occurrence through the induction of ferruginous springs, it is noted that this occurs as a result of reaction with atmospheric oxygen.

This means that; if the precipitation/acid generation effect occurs too far down slope from the spring and hence impacts on a pool or inshore ecosystem in Lake Avon, the location of the zone of maximal oxygen can easily be moved upslope closer to the spring source.

This would simply involve the deposition of heavy rocks and boulders closer to the spring. This material could be obtained from local Hawkesbury Sandstone outcrops nearby and moved to the spring emergence point by manual labour. This will greatly increase turbulence and hence rates of oxygenation, precipitation of hydrous oxides and acid generation, allowing natural effects down slope to ameliorate the effects of the spring.

Another appropriate strategy is the development of an emergency response plan that ensures that wherever cliff instabilities and soil fissure openings are detected on steep slope of high to extremely erodible soils as a consequence of mine subsidence effects, suitable erosion control are rapidly implemented. These procedures could include manually filling-in of deep soil fissures and seeding with locally collected shrub seed.

Water quality monitoring sites will also be located in this part of Area 3B to provide early detection and ongoing assessment of this potential effect.

6.7.3 Mitigation Measures for Swamp Impacts

IC will deploy a network of shallow piezometers in hillslope aquifers over the subcatchment areas encompassing Swamps 12 and 15a and the general area of Banksia and Cascade Creek catchments. Similar networks will be progressively established over Area 3 wherever it is judged on geomorphic grounds that there is potential for a broad scale hillslope aquifer/upland swamp complex playing a significant role in the hydrology of the major local draining stream, i.e. specifically Sandy Creek, Wongawilli Creek or Donald's Castle Creek.

The other broad areas which merit monitoring in this regard are:

- Swamps 10 and 13 and the subcatchments of Creeks WC21A and WC21 (Area 3B); and
- Swamps 1a and 1b and the Creek DC1 and Upper Donald's Castle Creek sub-catchments which have been verified from our previous studies (Ecoengineers, 2006b) to provide a significant baseflow for Lower Donald's Castle Creek (Area 3B).

While it is considered unlikely on the basis of past experience that mine subsidence-induced hydrologic effects would adversely affect these Type 2 swamps and more particularly the substantial hill slope aquifers in which they are likely to be embedded, it is prudent to target them for frequent assessment during the period in which longwalls in Areas 3A, 3B and 3C approach or mine under them. There may be a future need to establish a hydrographic gauging station midway down Wongawilli Creek if shallow piezometer studies confirm a broad-based hillslope aquifer in the Creek WC21 subcatchment in order to make a hydrologic modelling assessment of its pre- and post-mining effects.

6.8 HYDROLOGY AND WATER QUALITY MONITORING PLAN

A water monitoring plan incorporating detailed provisions for water quality and hydrographic monitoring and the interpretation of data is provided in Appendix A of the Surface Water Quality and Hydrology Assessment (**Attachment B**). The monitoring program has been incorporated into the Area 3A SMP and the Statement of Commitments.

The water-related field work will concentrate in the first instance on regular visitation to main channel water quality/flow sites, main channel vicinity sand apron piezometers, upland piezometers surrounding, and downstream of, hanging swamps. These sites will be monitored for all key water quality parameters on a monthly basis for 12 months prior to mining, during mining and for an appropriate time following mining.

Additional water quality monitoring sites will be established for obtaining baseline data well prior to the mining of Areas 3B and 3C (in that order).

As all proposed longwalls are set back from the main channels of creeks, a key aspect of the monitoring plan deals with the early detection and subsequent investigation and assessment of any upsidence effects within tributaries.

If geochemical effects are detected just downstream of a confluence but not at the main channel upstream site which are judged to be possibly a consequence of subsidence-related effects, back-tracking of the tributary sub-catchment's both water quality and hydrologic behaviour would then be initiated.

The locations and numbers of routine water quality, hydrographic and piezometric monitoring sites are satisfactory for assessing the potential hydrologic and water quality effects of Dendrobium Area 3A and enabling rapid back tracking to any sites or sub-catchments where impacts are suspected.

6.8.1 Compensatory Measures

Longwalls within Dendrobium Area 3A, and the commitments proposed for the longwalls in Areas 3B & 3C, have been designed to avoid or minimise significant impacts to major creeks and the biota therein. Comprehensive management and monitoring programs have been proposed to rapidly evaluate and remediate any significant impact to the natural features within Area 3.

It has been predicted that any mining induced impacts will be of a minor nature and at a local scale. Given the predicted low level of impact, coupled with the avoidance/minimisation of impacts to major creeks that have been achieved at significant loss of minable resource via substantial longwall set backs from these natural features within Area 3, no compensatory measures in addition to detailed monitoring, management and rehabilitation commitments are proposed.

As outlined in the monitoring and management plans, considerable amounts of data, interpretation and analysis of many aspects of the environment will be generated and made available through this proposal. This will assist land and conservation managers better understand the nature and function of this landscape and the environmental values therein.

7 GROUND WATER AND HYDROGEOLOGY

GHD has undertaken an assessment of the likely hydrogeologic performance of the rockmass in Area 3 relating to proposed underground mining in the Wongawilli Seam (**Attachment F**). The assessment is based on the information gathered from downhole field testing conducted by IC in Area 3, together with an assessment of the measured performance of the rockmass in Area 1.

Particular hydrogeologic issues associated with the proposed underground coal mining activity relate to:

- The impact upon the stored water within Cordeaux Reservoir.
- The impact upon near-surface hydrology and potential loss of catchment yield via mechanisms for surface waters to be diverted into the underlying rockmass.
- The impact upon groundwater within the rockmass over the footprint of Area 3.
- An estimate of expected groundwater ingress to the workings.

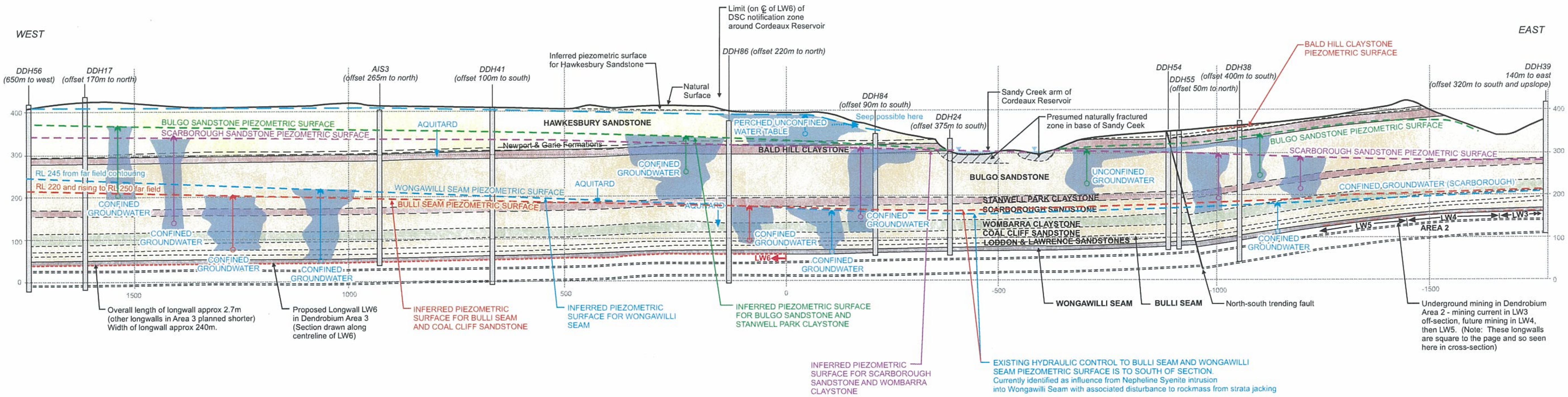
7.1 EXISTING GEOLOGICAL AND HYDROGEOLOGIC SETTING

In broad terms, the rockmass at Dendrobium Area 3 is geologically consistent with its structural setting within the Southern Coalfield - in that it encompasses a sub-horizontal sedimentary rock sequence. In a hydrogeological sense, the sedimentary sequence has produced a sequence of aquitards and aquifers – these being low permeability and relatively higher permeability strata respectively. The term “aquifer” is used cautiously here, and it should be considered only in a relative sense – i.e. these higher permeability strata are of higher permeability relative to the layers that act as aquitards. These aquifers do not constitute a viable water resource. Viable aquifers would require permeabilities three or four orders of magnitude higher than those in the lithologies present in Area 3.

It is important not to conceptualise these strata in the context of a readily extractable groundwater resource, since the hydrogeologic characteristics are not consistent with such an expectation.

The current situation at Area 3, in regard to hydrogeology, is that this sub-horizontal system of aquitards and aquifers (again, relatively speaking) exists as a consequence of the geology of Area 3. In particular, low permeability aquitards (Bald Hill Claystone, Stanwell Park Claystone and Wombarra Claystone) produce a hydrogeologic system governed by movement of groundwater in the horizontal direction. It is recognised throughout the Southern Coalfield that the aquitards govern the direction of groundwater flow, which is generally in the horizontal sense, rather than vertically. The data in Area 3 is consistent with presence of aquitards which direct horizontal flow (refer **Figure 7.1**).

By consideration of a type-section developed along the long-axis of Longwall 6, an understanding of the current hydrogeology has been developed. The main features are: that a number of independent groundwater systems have been inferred down through the rockmass; that significant de-pressurisation of the lower parts of the sedimentary sequence is observable; and that an external head control is acting upon the Bulli Seam and Wongawilli Seam in the broad area below Sandy Creek. The interpretation at present is that this external head control is related to the Nepheline Syenite intrusion within the Wongawilli Seam to the south of the typesection.



Source: Drg G302, GHD 2007

Cardno Forbes Rigby

BHP Billiton, Illawarra Coal
Dendrobium Area 3

Inferred Stratigraphic Piezometric Surfaces

scale | 1:1000 date | 10 September 2007

Figure 7.1

The interpretation includes a groundwater drainage connection to the Elouera workings to the southwest of Area 3.

From the piezometric pressures measured in the exploration boreholes, it is concluded that:

- the various stratigraphic units between the aquitards are separated hydraulically, and demonstrate independent groundwater systems - i.e. the groundwater responses are in harmony with the stratigraphy.
- Both unconfined and confined independent groundwater conditions apply down the stratigraphic sequence.
- Piezometric head reduces down the sedimentary sequence.

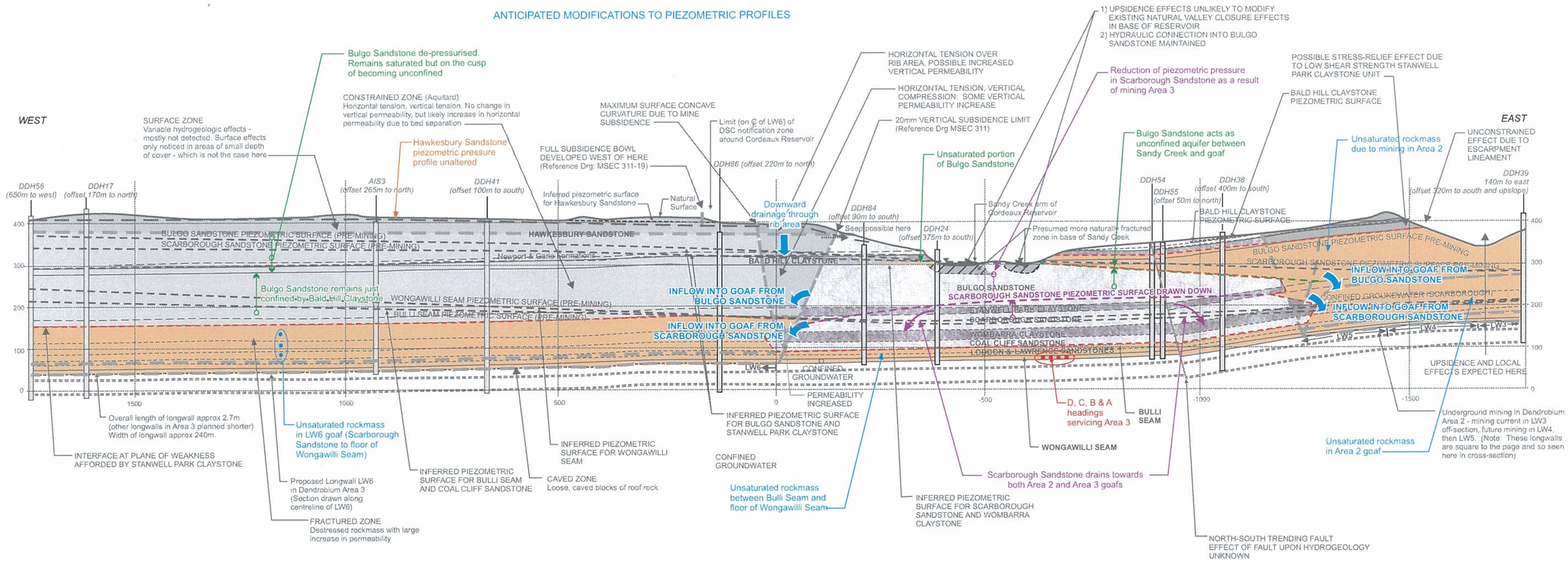
This clear separation of groundwater systems is attributed to past underground mining that has occurred in the region surrounding Dendrobium Area 3. In particular, mining has occurred in an arc from the south and east (in Elouera, Wongawilli and Nebo Collieries) in the Wongawilli Seam that has drained the rockmass. The effect of this drainage has extended into Area 3, and is observable as the separated groundwater profiles. The separation of the groundwater profiles has occurred because the integrity of the aquitards has been maintained.

Structural geological features of a vertical to sub-vertical nature (faults and dykes) that bound Area 3 are not dissimilar to features regularly encountered in the Southern Coalfield. These features do not influence the overall horizontal trend for the movement of groundwater throughout the sedimentary sequence. For example, evidence has not been established which indicates that the north-south fault on the eastern side of Area 3 (i.e. between Area 3 and Area 2) influences hydrogeologic response between the two Areas (refer **Figure 7.2**).

To the north, a faulted and disturbed area about 400 metres wide that is associated with the Dendrobium Dyke bounds both Area 2 and Area 3. In-seam exploration drilling did not detect differential piezometric pressures, nor high permeability zones in this faulted dyke zone, nor evidence of compartmentalised groundwater. Whilst this area has been impacted in a considerable manner in a structural geology sense, hydrogeologic impact has not been observed in the interpretation of the rockmass.

A flat-lying igneous intrusion in the Wongawilli Seam (nepheline syenite) abuts the southern boundary of the proposed mining in Area 3. Coal resource was lost and strata jacking has occurred as a result of the intrusion, which ramps up from an interfingering within the coal seam at the southern boundary of Area 3A to about 40m thickness a kilometre further to the south (refer **Figure 2.1**).

As discussed above, it has been inferred from the piezometric monitoring in Area 2 and Area 3 that the intrusion has impacted upon the hydrogeology of the rockmass. The effect is a draw down of the piezometric profiles of the Bulli and Wongawilli Seams in the area to the north of the intrusion, which is evidenced by lowering of these two piezometric pressure profiles. This effect is superimposed upon the separated groundwater profiles produced by the previous underground coal mining (refer **Figure 7.1**).



Source: Fig H316, GHD 2007

Cardno Forbes Rigby

BHP Billiton, Illawarra Coal
Dendrobium Area 3

Hydrogeologic Impact Post Mining of Area 2 & Area 3
Anticipated Modifications to Piezometric Pressures

scale | 1:1000 date | 18 October 2007

Figure 7.2

7.2 HYDROGEOLOGY IMPACT ASSESSMENT

Modification of the hydrogeology will occur as a result of longwall mining in the Wongawilli Seam.

The effects will involve both local and mid-field effects. Initial modification will occur as a result of the development of first workings within the Area. The effects upon the hydrogeology will be limited generally to the Wongawilli Seam, and to some degree to the overlying Bulli Seam and the rockmass within the 30m interburden. The effects will be limited to drainage of piezometric pressures within the Wongawilli Seam, with some ripple effects within the interburden and Bulli Seam. De-pressurisation within the Wongawilli Seam at a distance of about 1.5km is anticipated to be measurable in the westward direction. Little impact in the south and east is expected, as the seam has already been drawn down by past mining.

The local effects following longwall mining will include modification to the transmissivity and groundwater regime in the local rockmass immediately above the footprint of the longwall. This will include de-pressurisation of the groundwater regime within some of the stratigraphic units above the longwall panels in Area 3, though this will not occur in all of the stratigraphic units throughout the sedimentary rockmass. The de-pressurisation will have much the same character as observed in Area 1, and as anticipated in Area 2.

The mid-field effects will involve reduction of groundwater pressures of variable extent in the stratigraphic units from the Wongawilli Seam up to and including the Bulgo Sandstone. Reduction in piezometric pressures will be identifiable up to 1.5km from the longwall panels in Area 3A.

The evidence from the assessment identified above leads to the expectation that, whilst underground mining on Area 3 will clearly influence the hydrogeologic conditions through the effects of subsidence upon the rockmass, the effect will be concentrated in the lower parts of the rockmass including the stratigraphic units from the Wongawilli Seam up to the Scarborough Sandstone.

This means that whilst mining subsidence will reflect throughout the rockmass and report to the surface, the extent of mining subsidence influences upon the hydrogeology of the rockmass will be limited in upward migration. The Bald Hill Claystone and Stanwell Park Claystone aquitards govern the horizontal controls upon groundwater movement and the expectation is that their vertical permeability will remain largely intact post-mining, and so will maintain their effectiveness as aquitards. An increase in horizontal permeability in the aquitards is expected, but not to the detriment of the action of the aquitards in the vertical separation of groundwater movement and the maintenance of groundwater levels in the upper portions of the rockmass (refer **Figure 7.2**).

The consequence of this is an expectation that the current groundwater conditions, and their natural fluctuations, will remain unchanged in the Hawkesbury Sandstone whilst there will be a degree of de-pressurisation within the Bulgo Sandstone. It is expected however, to generally remain a confined aquifer. The Scarborough Sandstone and the other stratigraphic units down to the Wongawilli seam will become unsaturated within the mining goaf in Area 3. Between Area 2 and 3 the Scarborough Sandstone will drain towards both the area 3 and Area 2 goafs (refer **Figure 7.2**).

7.3 IMPACT ASSESSMENT ON NEAR-SURFACE HYDROLOGY AND POTENTIAL LOSS OF CATCHMENT YIELD

The predictions from the analytical modeling are:

- The proportion of rainfall that reports into the rockmass at depth through infiltration is small. Almost all the rainfall is accounted as a combination of: runoff; return to the atmosphere through evapo-transpiration; storage in near-surface soils and weathered rock; or reports into shallow aquifers – rather than infiltrates deeply into the rockmass. The proportion of rainwater that infiltrates deeply into the rockmass is about 1% to 2% of that which falls on the ground surface. The conclusions reported by Ecoengineers (2007) are consistent with this assumption.
- It follows that the source of almost all of the water that reports to Cordeaux Reservoir is through rainfall run-off from the ground surface rather than via deep groundwater infiltration and discharge. This applies both here at Dendrobium Area 3 and by extension, to the remainder of the catchment area given that similar geomorphic condition applies across the catchment of Cordeaux Reservoir.
- About 1.5% of the rainfall that falls over the footprint of Area 3A then infiltrates deeply into the rockmass. The footprint of Area 3A represents about 3.7% of the catchment of Area 3A, and therefore the deep infiltration into the rockmass represents less than 0.5% of the average depth of rainfall over the catchment.
- Existing groundwater (i.e. from the 1.5% of rainfall that infiltrates deeply into the rockmass) becomes inflow into the Sandy Creek arm of Cordeaux Reservoir. This occurs principally through seepage through the Bulgo Sandstone. A contribution of significantly lesser volume is provided by the Hawkesbury Sandstone through indirect seepage inflow to the reservoir (possibly also involving springs along outcrop above the Sandy creek arm of Cordeaux Reservoir).
- The predicted change from inflow to outflow at Cordeaux Reservoir is less than 0.2ML/day. This estimate includes essentially equal contributions from the loss of groundwater seepage inflow before mining (0.1ML/day) and an estimate of the outflow from the reservoir after mining Area 3A (0.1ML/day).
- The catchment yield is dominated by run-off. Nett impact upon the catchment yield in Area 3A as a result of mining of Area 3A is anticipated to be very small and not significant. This is predominantly because the flows within the rockmass are generally of low magnitude, and particularly are of low magnitude relative to the rainfall over the footprint of Area 3A.

7.4 IMPACT ASSESSMENT ON POTENTIAL WATER LOSS FROM CORDEAUX RESERVOIR

A specific appraisal of the impact of the underground mining in Area 3 upon the stored water within Cordeaux Reservoir has been conducted for the critical location at Sandy Creek. In the first instance, the analytical model has been calibrated for the existing conditions within the rockmass, as developed for the situation currently existing prior to mining in Area 3. An analysis has then been conducted to appraise the anticipated effects of mining upon the stored water, using the philosophies developed. The analysis has employed the results from the downhole packer testing conducted during the exploration program to develop permeability parameters relevant to the analysis, and has employed the results of the piezometric monitoring to establish the current hydrogeologic controls.

The predictions from the analytical modelling include:

- The hydrogeologic conditions within Area 3 will have a legacy of impact from the combined effects of: the natural sequence of relative aquifers and aquitards, this being a consequence of the sedimentary geological setting; mining in surrounding collieries that have suppressed the groundwater regime on a regional basis, producing a sequence of independent groundwater systems within the stratigraphic units; and the mining of Area 2.
- Prior to mining occurring within Dendrobium Mine, hydrogeologic conditions within Area 3 include flow of groundwater towards the south in the Bulli and Wongawilli Seams. This is reflected by suppressed total head values within the Bulli and Wongawilli Seams (and intervening stratigraphic units) beneath the footprint of the Sandy Creek arm of Cordeaux Reservoir. This effect will be an artifact of mining within surrounding collieries.
- The mining of Area 2 will change the seepage direction on the eastern side of the Sandy Creek arm of Cordeaux Reservoir through drainage into the Area 2 goaf. The principal mechanism for this is reversal of seepage direction within the Bulgo Sandstone, Scarborough Sandstone and Bulli and Wongawilli Seams as a consequence of the mining. Groundwater seepage inflow from the Bulgo Sandstone will still report to the reservoir at the Sandy Creek arm, but its magnitude will be reduced to 15% of the pre-mining situation (As discussed above, note that run-off is the major contributor to the reservoir. Run-off far exceeds the volume of seepage reporting into the reservoir, and is not included in this assessment).
- As a consequence of mining within Area 2, groundwater will be removed from the system through drainage under head control from the Bulli Seam beneath the Sandy Creek arm of Cordeaux Reservoir; from the Area 2 first workings in the Wongawilli Seam and longwall goafs through pumping; and through dewatering in the Wongawilli Seam at the ventilation shafts and their associated headings in the northwestern portion of Area 2.
- The development of mining in Area 3 will further modify the contribution to seepage inflow via the Bulgo Sandstone into the Sandy Creek arm of Cordeaux Reservoir. The groundwater seepage will become one of deficit, resulting in a comparable quantity of water being removed from the reservoir as was previously provided by seepage. This is a result of altered flow paths, with seepage now reporting into Longwall 6 as well as Area 2. The seepage into the Area 2 goaf will actually decrease as a result of drainage of groundwater towards Longwall 6 of Area 3A.
- The interception of seepage within the rib zone above Longwall 6 is attributed to the alteration in flow reporting to the Sandy Creek arm of Cordeaux Reservoir as seepage.
- Whilst the estimate of magnitude of seepage flows is dependent upon permeability estimates, it is believed that reasonable values have been adopted and the flows are in the range from “best estimates” to “upper bound” values. The actual loss from the storage is estimated to be less than 0.1ML/day. The acceptable loss of storage from Cordeaux Reservoir adopted by the Dams Safety Committee is less than 0.5ML/day - a target level that appears satisfied.

A credible mechanism for uncontrolled loss of water from the stored water within Cordeaux Reservoir has not been identified during the study.

7.5 ESTIMATE OF GOUNDWATER INGRESS TO THE WORKINGS

The contributory groundwater inflow sources into the Longwall 6 goaf are identified in **Table 7.1**, with the majority of the contribution being a result of infiltration through the wide footprint of the Bald Hill and Stanwell Park Claystone aquitards. Downward infiltration through the rockmass occurs over the full footprint of the longwall and hence becomes the main component at 64% of the groundwater reporting to the Longwall 6 goaf. Other sources of groundwater reporting into the Longwall 6 goaf are 10% vertically through the rib zone, whilst 23% reports through the Scarborough Sandstone.

The total groundwater seepage inflow reporting to the Longwall 6 goaf is estimated at 0.1ML/day for a two-dimensional model over the 250m width of Longwall 6. The extrapolated three dimensional estimate of overall Longwall 6 inflow to Area 3A is 0.8ML/day. Refer **Attachment F** for the detailed assessment.

Table 7.1 - Estimate of Seepage Reporting to Longwall 6

Source of groundwater inflow into Longwall 6	Estimate of groundwater inflow into Longwall 6	
	(L/day/metre run)	(ML/day over 250m width)
Vertical infiltration of rainwater through constrained zone above Longwall 6	246 (64%)	0.06
Vertical infiltration of groundwater through rib zone at eastern end of Longwall 6	37 (10%)	0.01
Horizontal groundwater flow through: Scarborough Sandstone, Bulli Seam and Wongawilli Seam	88 (23%) 16 (4%) 5 (1%)	0.02 < 0.01 < 0.01
Total nett inflow to Longwall 6 (including outflow at LHS model boundary)	383	0.10

7.6 MITIGATION AND MONITORING

The Area 3A longwall set back from Cordeaux Reservoir at the eastern (finishing) end of Longwall 6 have been selected by IC to minimise subsidence-induced effects upon the storage contained therein. There, the longwall approaches to within 280 to 380m of Sandy Creek (and the shortest distance is 260m in the adjacent northeast corner of Longwall 7).

By comparison these set back distances are more than the set back distances at Area 1 and Area 2. The distances are comparable to the short distances at the northern end of Area 2 and are greater than the shortest distances of Area 1. It follows that the performance of the rockmass will be comparable to the performance of Area 1 and Area 2 at its closest approach to the footprint of the stored water in Cordeaux Reservoir.

Similar design approaches will be used in the design of Area 3B and 3C longwalls to avoid water loss impacts on Avon and Cordeaux Reservoirs.

Existing instrumented boreholes in Area 3A in the rockmass between Area 3A and Cordeaux Reservoir will be used to monitor the consequences of the mining and to verify the predictions as outlined in the Area 3A SMP.

The proposed monitoring sites and methodology will be confirmed in consultation with the DSC as required, via a separate DSC review process.