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BHP Billiton, Illawarra Coal

Dendrobium Area 3

Predicted Hydrogeologic Performance

November 2007

GHD GEOTECHNICS

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EXECUTIVE SUMMARY

BHP Billiton, Illawarra Coal, propose underground longwall mining of the Wongawilli Seam in Area 3 of Dendrobium Mine. GHD Geotechnics has been commissioned by BHP Billiton to investigate the interaction between the mining activities and hydrogeology of the rockmass. 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;
- the loss of surface water to the mine; and
- an estimate of expected groundwater ingress

Available Data

Exploration of Area 3 by BHP Billiton has involved:

- collection of stratigraphic information;
- conducting downhole geophysical logging to assist in the characterisation of both coal and non-coal stratigraphic units;
- conducting downhole variable head hydraulic conductivity testing (referred to as "packer testing" and used to determine the permeability of the rockmass – ie the ability for water to move through the rockmass); and
- installation of vibrating wire piezometers at multiple levels downhole to monitor pore pressures within the rockmass (and hence to determine the piezometric pressure profiles throughout the rockmass).

This has permitted the development of an understanding of the hydrogeologic conditions applicable to Area 3 and an assessment of the interaction of underground coal mining with the stored water, particularly the critical area around the Sandy Creek arm of Cordeaux Reservoir.

In order to develop the conceptual understanding of the interaction of underground longwall mining with the hydrogeology of the rockmass, and to extend this to predict the consequences of mining, GHD Geotechnics have drawn upon:

- the results of the 1976 Reynolds' Inquiry;
- the results of a comprehensive field testing programme associated with comparable longwall mining in the Central Coast area of NSW;
- the results of exploration over and adjacent to longwall mining at Elouera Colliery; and
- the results from monitoring of Dendrobium Area 1 and Area 2.

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 – ie these higher permeability strata are of higher permeability relative to the layers that act as aquitards. 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 flow of groundwater – which is generally in the horizontal sense, rather than vertically. No evidence has been observed to suggest that this is not also the case for Area 3 as the data is consistent with the presence of aquitards that direct horizontal movement of groundwater within the rockmass.

By consideration of a type-section developed along the long-axis of Longwall 6, an understanding of the current hydrogeology of Area 3 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 the Sandy Creek arm of Cordeaux Reservoir.

Several hydrogeologic controls have been postulated to explain this local depression of the piezometric pressure to about RL160 within the Bulli and Wongawilli Seams. The possible interpretations are presented in Figure HG320, which has a background based on the mine working layout and local structural geology shown in Drawing G304.

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 type-section with a 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 - ie the groundwater responses are in harmony with the stratigraphy;
- both unconfined and confined independent groundwater conditions apply down the stratigraphic sequence; and
- 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 (ie between Area 3 and Area 2) influences hydrogeologic response between the two Areas. 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. The sill ramps up in thickness from interfingering with the coal seam at its edge at the southern boundary of Area 3A to about 40m thickness a kilometre further to the south. The sill then reduces in thickness to the south and west. The eastern margin could either be fault controlled and relatively thick, or the eastern margin could be further eastward than currently plotted. The nature of this eastern margin has yet to be resolved.

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 drawdown 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, and separate to, the groundwater profiles produced by the previous underground coal mining.

Mining Impact

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 drawndown 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 studies 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 – 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 much of 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.

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, and between the two Areas, the Scarborough Sandstone will drain towards both the Area 3 and Area 2 goafs.

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 the Sandy Creek arm of the reservoir. 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 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.

- 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 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 conditions apply 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 (ie from the 1.5% of rainfall that deeply into the rockmass) that becomes inflow into the Sandy Creek arm of Cordeaux Reservoir 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 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, swamps 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 predicted change from inflow to outflow at Cordeaux Reservoir is less than 0.2ML/day. Since this estimate includes essentially equal contributions from the loss of groundwater seepage inflow before mining and an estimate of the outflow from the reservoir after mining Area 3, the actual loss from the storage is half the total and thus is 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 - notwithstanding the nature of the extrapolation to the contribution to the entire reservoir, a target level that appears satisfied.

» The catchment yield is dominated by run-off. Nett impact upon the catchment yield as a result of mining of Area 3A is anticipated to be very small. This is predominantly because the groundwater 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.

The philosophy of the approach of the modelling which supports the assessment has been:

» Development of a model of the hydrogeology of the rockmass within the type-section for Area 3A, which is calibrated with the piezometric data available from the vibrating wire piezometer strings installed within exploration holes drilled throughout Area 2 and Area 3.

» Impose upon the model the groundwater drainage environment produced through the mining of Longwalls 3 to 5 in Area 2.

» Then also impose the groundwater drainage constraints produced through the mining of Longwall 6 in Area 3 upon the model of the type-section.

A set of figures and drawings has been prepared to assist in explanation of: the background to the hydrogeologic interpretation; the essence of the appraisal of current conditions; and to follow through the hydrogeologic assessment of the impact of mining in Area 3. These figures, as a group, present:

- A conceptual model of groundwater processes and the identification of independent groundwater regimes throughout the rockmass.
- An explanation of the pre-mining processes and the relationship between surface waters and the deeper groundwater system (in advance of underground mining impacts).
- The predicted post-mining processes and groundwater routing occurring between surface waters and the deeper strata, and showing predicted routing of waters through the rockmass where cracking/dilation of strata has occurred over the mined working section.
- An appraisal of the processes occurring between the reservoir and the proposed longwall goaf in Area 3, demonstrating the quantity of expected egress from the stored waters of Cordeaux Reservoir as well as the expected volume of seepage into the longwall goaf.

1. INTRODUCTION

BHP Billiton proposes continuation of underground coal mining of the Wongawilli Seam in Dendrobium Mine, which is situated within the Southern Coalfield of New South Wales. Extraction of coal will be conducted using longwall mining methods. BHP Billiton has previously extracted Longwalls 1 and 2 in Area 1 and has approval for extraction of coal in Longwalls 3 to 5 in Area 2. At the time of preparation of this report, longwall mining was being concluded in Longwall 3, the first longwall of Area 2. following the completion of coal extraction in Area 1.

Dendrobium Mine has development consent for underground coal mining in Areas 1, 2 & 3 and BHP Billiton seeks to modify the current approval for Dendrobium Mine in terms of the footprint of Area 3. Area 3 has been separated into three sub-areas for mining purposes, which have been called Areas 3A, 3B & 3C - the layout of the proposed mining areas within Area 3 is shown in Figure 2.1 below. BHP Billiton also propose to submit a Subsidence Management Plan for the part of Area 3 identified as Area 3A.

GHD Geotechnics has been commissioned by BHP Billiton to investigate the interaction between the mining activities and hydrogeology of the rockmass. This report has been prepared to provide an assessment of the existing and predicted hydrogeologic performance of the rockmass that controls the interaction of the mining with the stored water, surface water and groundwater. Particular hydrogeologic issues associated with the proposed underground coal mining 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; and

» an estimate of expected groundwater ingress.

It is noted that a further pre-requisite for mining of Area 3 is endorsement from the Dams Safety Committee, whose particular interest is the security of the stored water in Cordeaux Reservoir. Application to the Dams Safety Committee as part of a separate approval process will be made subsequent to the current application to the Department of Planning and the Department of Primary Industries. The assessment contained herein will form a significant component of the hydrogeologic assessment that will be submitted to the Dams Safety Committee for their consideration.

2. MINING SETTING

Dendrobium Area 3 is situated within a mining province that contains some of Australia's best coking coal resources which have been exploited since the 1880's. Coal from the Wongawilli Seam is an essential component of the "Illawarra Blend" premium coking coal, which is known for its specific steelmaking qualities. Dendrobium Area 3 is adjacent to: Areas 1 & 2; mining in the Wongawilli Seam in Elouera, Nebo and Kemira Collieries; and mining in the overlying Bulli Seam in Mt Kembla, Kemira, and Cordeaux Collieries. An impression of the surrounding workings can be gained by reference to Figure 2.1.

As was the case for Area 1 and Area 2, the proposed underground longwall mining in Area 3 will be undertaken in the working section of the Wongawilli Seam. The working section is up to a maximum of 3.9m thick. The floor of the Wongawilli Seam has an overall gentle dip to the northwest across Area 3A and has floor seam levels that range from about Reduced Level (which references to the Australian Height Datum) RL90m in the southeast (end of Longwall 10) to RL25m in the northwest (start of Longwall 6) across the footprint of Area 3A.

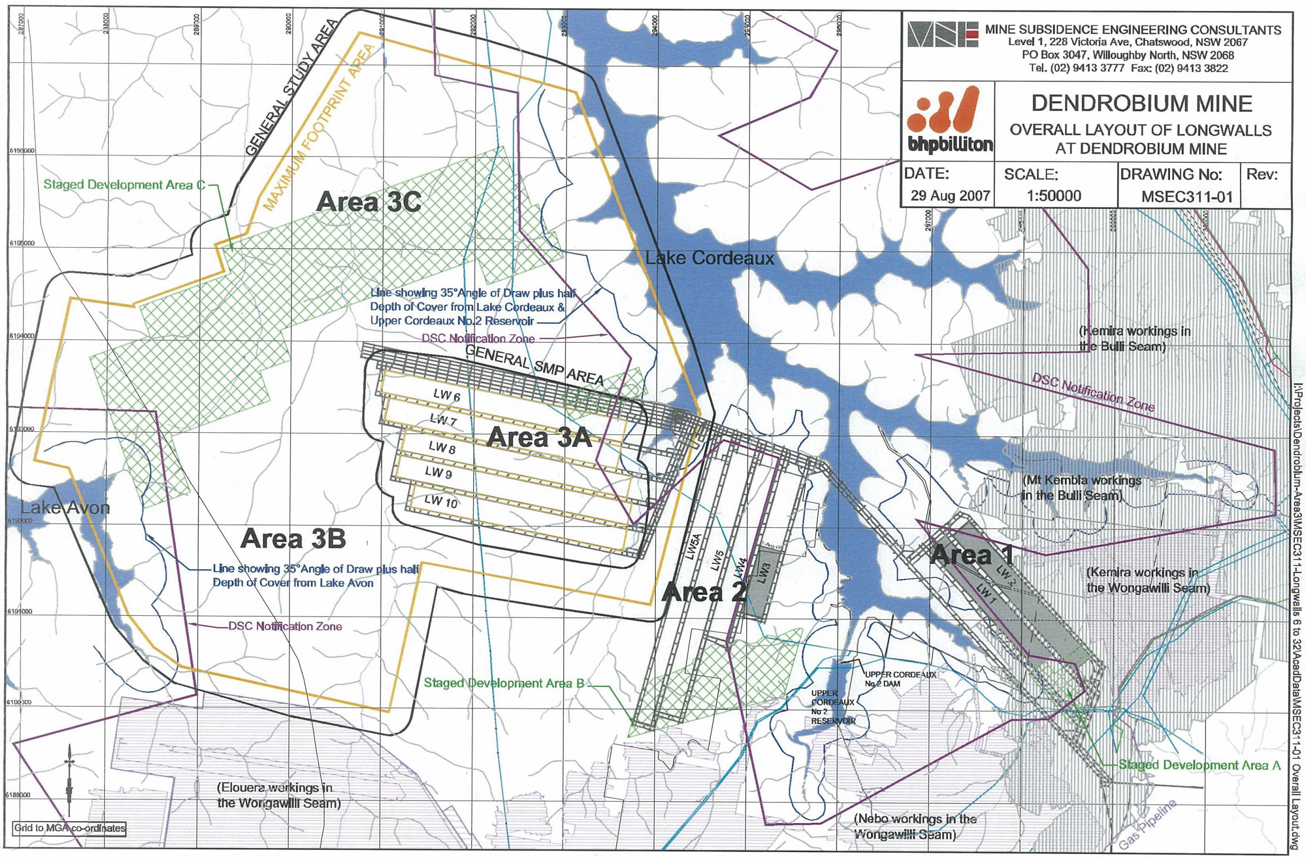

Figure 2.1: Layout of proposed mining areas within Dendrobium Area 3

(Ref: MSEC311, 2007, Drawing 01)

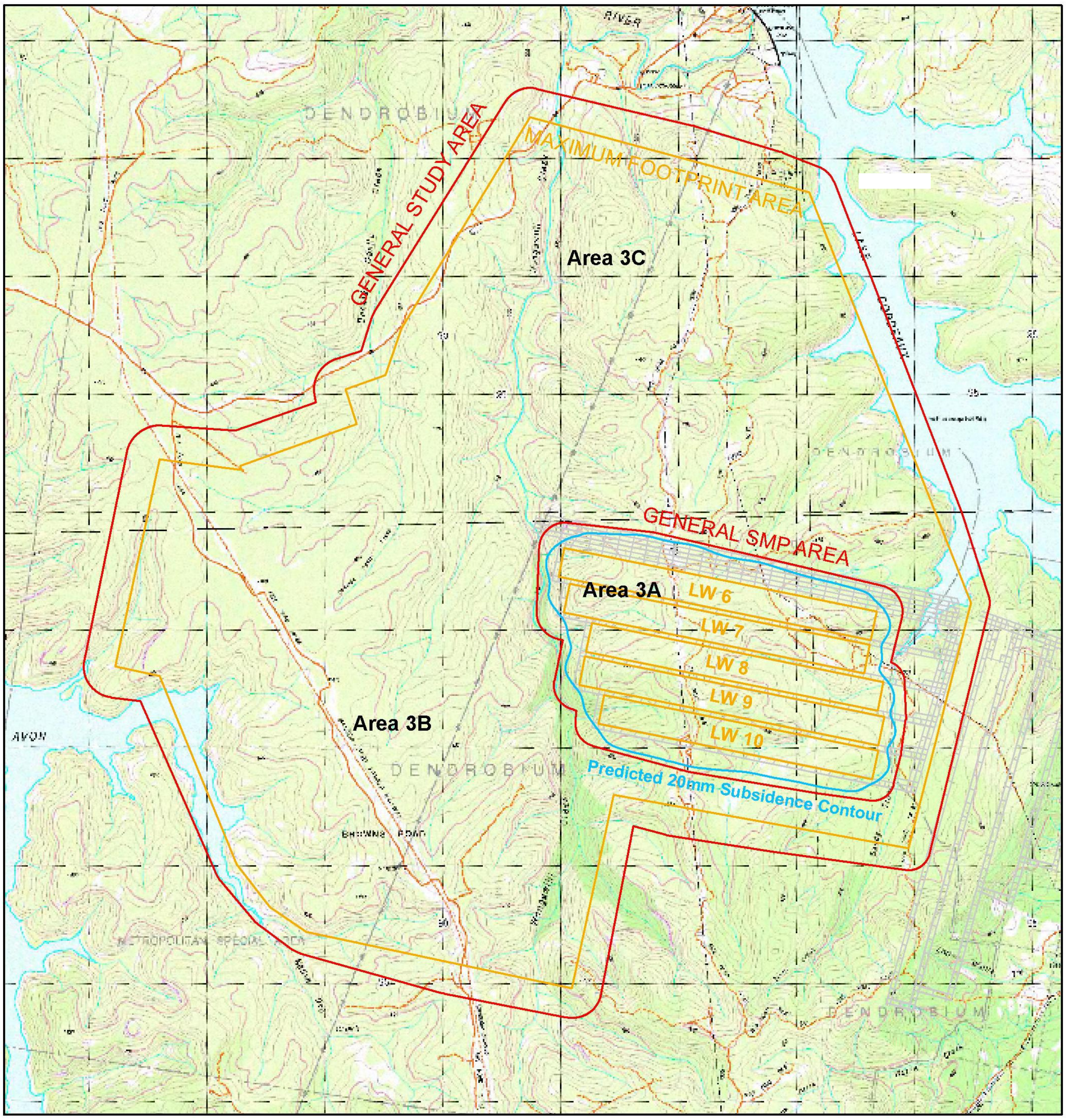

Figure 2.2: Longwalls 6 to 10 and the Maximum Longwall Footprint Area
(Overlaid on Part of CMA Maps Numbered Avon River 9029-3-S and Wollongong 9029-2-S, originally 1:25000 scale, grid lines at 1km spacing)
(Ref: MSEC311, 2007, Fig 2.1)

As can be seen in Figure 2.1, the longwalls in Area 3 do not undermine Cordeaux Reservoir nor Avon Reservoir. As can be seen on Drawing G301 and Figure HG301 in more detail, Longwall 6, which is the first and northernmost longwall in Area 3A, has its eastern end within the Dams Safety Committee's Notification Area as it approaches the Sandy Creek arm of Cordeaux Reservoir (see purple line in Figure 2.1). The current finishing line for Longwall 6 is about 200m within the Notification Area whilst it is 280 to 380m from the full supply level of the Sandy Creek arm of Cordeaux Reservoir (the full supply level is about 500 to 550m from the boundary of the Notification Area).

The Study Area (see Figures 2.2 and 2.3) lies within the Sydney Metropolitan Catchment Area, which is a special declared area controlled by the Sydney Catchment Authority (SCA). In addition, the proposed Longwalls 6 to 10 in Area 3A are partly located within the Dams Safety Committee (DSC) Notification Area for Cordeaux Reservoir. The maximum footprints for the future longwalls in Areas 3B and 3C are partly located within the DSC Notification Areas for Avon Reservoir and Cordeaux Reservoir, respectively.

The longwalls in Area 3 propose to extract coal from the Wongawilli Seam, which underlies the Bulli Seam with an interburden thickness of approximately 20 metres (floor-to-floor distance of about 30m). The Bulli Seam has not been extracted and is not proposed to be extracted in Area 3 as it has been judged to be uneconomic.

The floor of Longwall 6 ranges from about 280m to 240m (west to east) below the Full Supply Level (FSL) of Cordeaux Reservoir (FSL RL 303.73). Note that the depth of cover from the natural surface to the mining interval is greater than the nominal depth below full supply level of Cordeaux Reservoir, ranging from 300 to 370m cover across the footprint of Longwall 6. This is discussed further in MSEC (2007), whilst an impression of the depth of rock cover over the Wongawilli Seam along Longwall 6 can be gained by reference to Drawing G303.

2.1 Existing Mining

The footprint of Dendrobium Area 3 is adjacent to existing coal mining activities. Coal mining has occurred within the Wongawilli Seam to the east and south of Area 3, and in the overlying Bulli Seam (ie about 30m higher seam floor to seam floor) from the east to the north. Dendrobium Mine is situated near the southern boundary for economic mining of the overlying Bulli Seam and the northern limit for mining of the Wongawilli Seam. The layout of adjacent colliery's workings is provided in Figure 2.1 and also on Figure HG320.

In the Wongawilli Seam, Dendrobium Area 3 is adjacent to:

> Longwall mining within <u>Area 2</u>, which is to the east between the Sandy Creek and Cordeaux River arms of Cordeaux Reservoir. Mining is currently approved for 3 longwalls (Longwalls 3 to 5) within Area 2 which run in a north-south direction (whereas the longwalls in Area 3 are proposed to run east-west). At the time of writing, Longwall 3 was approaching its finishing line at the north end of the Area. The southern end of Area 2 is controlled by a combination of the Cordeaux Crinanite and previous workings in Nebo Colliery. A further longwall, Longwall 5A, is proposed on the western side of Longwall 5A and is the subject of separate application for approval.
>
> Mining extraction has been completed in <u>Area 1</u> which is situated to the east of Area 2 and to the north-east of the Kembla Creek arm of Cordeaux Reservoir (and south of the

Goondarrin Creek arm of the reservoir). Longwalls 1 & 2 were mined in a south-easterly direction in Area 1 during the latter half of 2005 and during 2006.

The tunnel entry into Dendrobium Mine runs between the longwall mining area of Kemira Colliery and the early bord-and-pillar mining within Nebo Colliery. (In passing, it is noted that the Dendrobium pit top was refurbished from the Nebo Colliery pit top). The Kemira longwall goaf has been used for storage of Dendrobium minewater. This operation has involved inward pumping with later extraction, so that the Kemira goaf acts as a sedimentation pond for the Dendrobium minewater. The Kemira Wongawilli Seam workings were accessed through an inter-seam drift down from the Kemira Bulli Seam workings. The Nebo Colliery workings were established from a number of portals coincident with the Wongawilli Seam subcrop along the Illawarra Escarpment, and are some of the earliest workings in Nebo Colliery.

To the south and west of Nebo, Wongawilli Colliery operated bord-and-pillar workings that are south of Area 3A, and are to the south of the Dendrobium Nepheline Syenite intrusion of the Wongawilli Seam. The Wongawilli Colliery workings abut Nebo Colliery's workings. To the north of Wongawilli Colliery, Elouera Colliery has mined 17 longwalls in the Wongawilli Seam. Longwall 8 in Elouera Colliery is the northernmost of these and abuts the proposed Dendrobium Area 3B.

Dendrobium Area 3 does not underlie previous Bulli Seam workings. However, Area 1 was partially overlain by the Bulli Seam workings within Mt Kembla Colliery. These workings were produced using bord-and-pillar mining methods. In addition to the Dendrobium Area 1 longwalls, also underlying the Mt Kembla workings are the Kemira Wongawilli Seam longwalls. The goaf of these will have collapsed up into the Mt Kembla Colliery Bulli Seam workings, and produced a hydraulic connection. Abutting the northern boundary of Mt Kembla Colliery, Kemira Colliery mined the Bulli Seam with bord-and-pillar methods. These workings are believed inundated to about RL193m. A small portion of the Mt Kembla Bulli Seam workings are anticipated to be similarly inundated to the same level. Cordeaux Colliery mined the Bulli Seam to the north of Mt Kembla Colliery using bord-and-pillar methods, and mined to the north-west of the bord-and-pillar workings using longwall methods. Cordeaux Colliery has temporary surface seals and its longwalls are inundated to about RL-85m (in the Bulli Seam). Mining in the Bulli Seam continues northward along the seam subcrop to Metropolitan Colliery at Helensburgh and north-westward to Appin and West Cliff Collieries. Workings in Tahmoor Colliery in the Bulli Seam are a significant distance to the west.

As a consequence, therefore, Dendrobium Area 3 is abutted by its own Area 2 current workings and previous workings in the Wongawilli Seam from the east around to the south. In the overlying Bulli Seam, Dendrobium Area 3 has neighbouring workings from the east to the north.

2.2 Mine Plan for Area 3

The critical element for the security of the stored water during and following longwall mining in Area 3A is the integrity of the rockmass between Longwall 6 and the stored water contained within the Sandy Creek arm of Cordeaux Reservoir. The governing situation for Area 3A is the eastern end of Longwall 6 since this is the location of closest approach of the mining in Area 3 to the stored water within Cordeaux Reservoir.

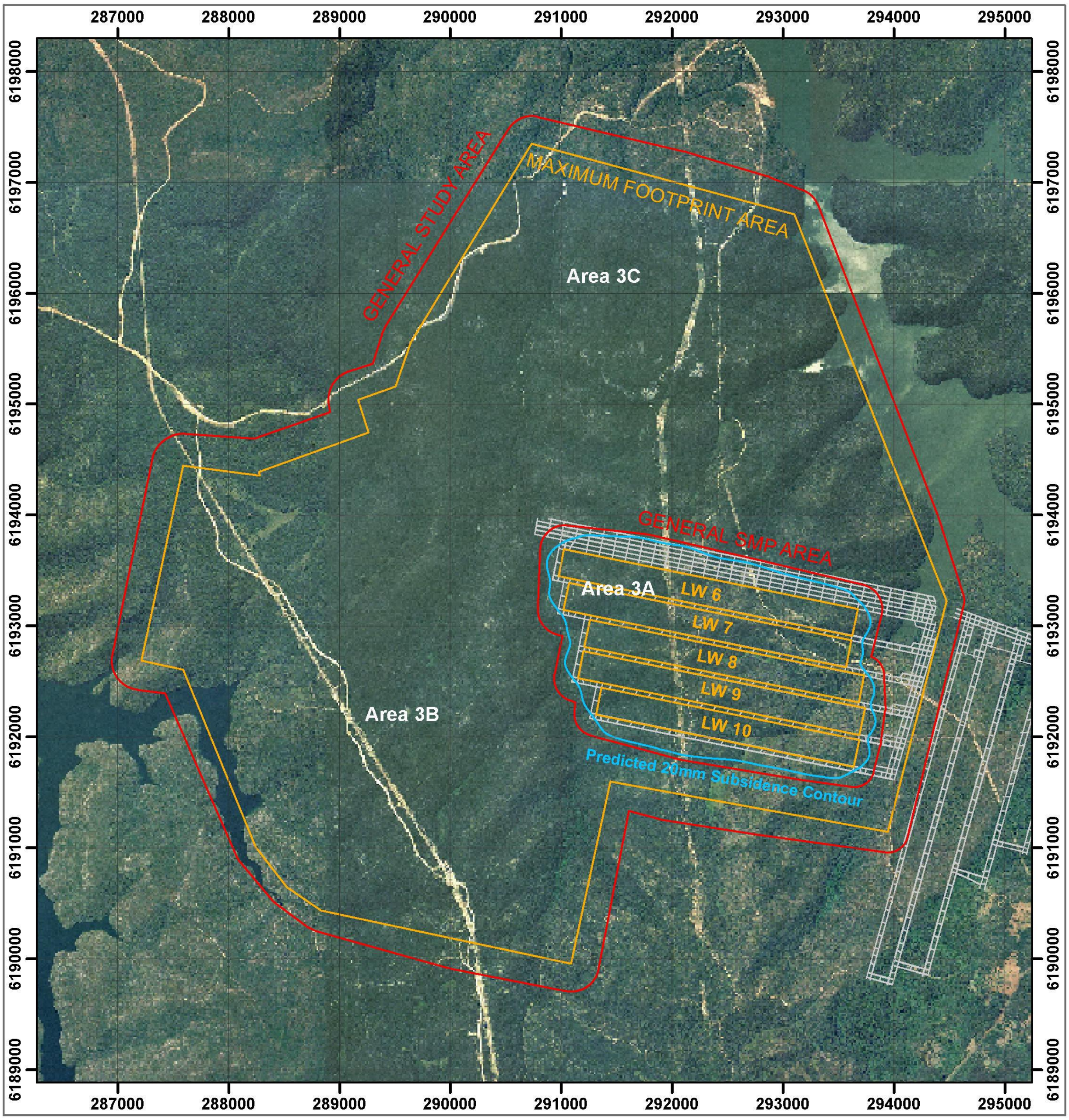

Figure 2.3: Aerial Photograph Showing Longwalls 6 to 10 in Area 3A, the Maximum Longwall Footprint for Areas 3B and 3C, the General Study Area and General SMP Area

(Ref MSEC311, 2007, Fig 1.1)

The proposed layout of Longwalls 6 to 10 within the Wongawilli Seam in Area 3A is shown in Drawings G301 & G302. The proposed longwalls in Area 3A were set back from Wongawilli and Sandy Creeks such that the maximum predicted parameters along these creeks were less than the above targets. These set backs have necessitated the sterilising coal resources that otherwise could have been extracted. Whilst MSEC has assessed that major impacts will not occur along Wongawilli and Sandy Creeks, it is still possible that minor impacts could occur along these creeks. It is proposed that the future longwalls in Areas 3B and 3C would also be set back from Wongawilli Creek using the same methodology described above.

The depth of cover to the Wongawilli Seam within the Study Area varies between a minimum of 255 metres, below Lake Cordeaux on the eastern side of the Study Area, and a maximum of 425 metres below the ridgeline on the western side of Wongawilli Creek. The depth of cover above the proposed longwalls in Area 3A varies between a minimum of 255 metres at the finishing (eastern) end of Longwall 10, and a maximum of 400 metres above the tailgate of Longwall 6. The seam floor within the Study Area generally dips from the south-east to the north-west.

The Wongawilli Seam in Area 3 is nominally 10 metres thick and contains numerous bands of non-coal material. The economic section of the Wongawilli Seam is the basal 3 to 4 metres. BHP Billiton has reviewed the nature of the banding in Area 3 and has proposed to extract a constant height of 3.9 metres. To ensure roof and floor conditions suitable for a longwall mining operations, various bands within the coal seam are proposed to be targeted to achieve the overall extraction height.

The surface level contours, seam floor contours and depth of cover contours are presented in MSEC311 (2007) and are shown in Drawings Nos. MSEC311-03, MSEC311-04 and MSEC311-05, respectively. Wongawilli Seam Floor contours are also provided on Drawing G302.

2.3 Overview of Longwall Mining Methodology

The coal at the project is proposed to be extracted using longwall mining techniques. MSEC (2007) provides an explanation of this process, some of which is reproduced below.

A cross-section along the length of a typical longwall at the coal face as shown below in Figure 2.4.

The coal is removed by a shearer which cuts the coal from the coal face on each pass as it traverses the width of the longwall. The roof at the coal face is supported by a series of hydraulic roof supports, which temporarily hold up the roof strata, and provides a working space at the coal face. The coal is then transported by a face conveyor belt which is located behind the shearer. As the coal is removed from each section of the coal face, the hydraulic supports are stepped forward, and the coal face progresses (retreats) along the length of the longwall.

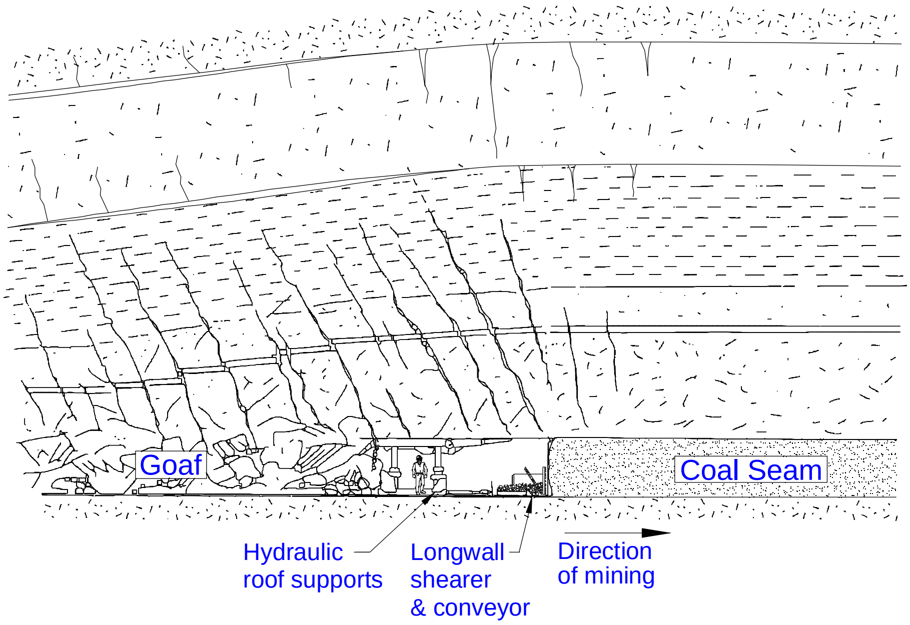

Figure 2.4: Cross-section along the Length of a Typical Longwall at the Coal Face
(Ref MSEC311, 2007, Fig 3.1)

The strata directly behind the hydraulic supports, immediately above the coal seam, is allowed to collapse into the void that is left as the coal face retreats. The collapsed zone comprises of loose blocks and can contain large voids. Immediately above the collapsed zone, the strata remains relatively intact and bends into the void, resulting in new vertical factures, opening up of existing vertical fractures, and bed separation. The amount of strata sagging, fracturing, and bed separation reduces towards the surface.

At the surface, the ground subsides vertically as well as moves horizontally towards the centre of the mined goaf area. The maximum subsidence at the surface varies, depends on a number of factors including longwall geometry, depth of cover, extracted seam thickness and geology. The maximum achievable subsidence in the Southern Coalfield is of the order of 65 % of the extracted seam thickness.

2.4 MSEC Subsidence Predictions

MSEC (2007) reports the maximum predicted systematic subsidence parameters resulting from the extraction of proposed Longwalls 6 to 10 in Area 3A. A comprehensive suite of predictions and a summary of the maximum predicted travelling tilts and strains during the extraction of each proposed longwall is provided in MSEC311 (ibid), to which reference should be made for details.

It is to be noted that these estimates are for subsidence of the ground surface and do not represent the effects throughout the body of the rockmass. The magnitude of movement throughout the rockmass will be variable, with a maximum vertical movement at the longwall itself following retreat of the hydraulic roof supports.

3. HYDROGEOLOGICAL SETTING

3.1 Geological Setting

The geology of the Dendrobium Area mainly comprises sedimentary sandstones, shales and claystones of the Permian and Triassic Periods. Area 3 is situated within broadly similar geological conditions as Area 1 and the bulk of Area 2 (ie excluding the Crinanite intrusion at the southern end of Area 2). Some details of the geology in the Southern Coalfield are provided in Appendix A as a means of understanding the context of the stratigraphic units at the site within the regional geology. The appendix contains an extract from NSW DMR (2000) which is particularly directed towards the geology of the rockmass above the Illawarra Coal Measures - principally being the Narrabeen Group and the overlying Hawkesbury Sandstone – these stratigraphic units being those of interest in the hydrogeology for the mining in Area 3.

The sandstone units vary in thickness from a few metres to as much as 120 metres. The major sandstone units are interbedded with other rocks and, though shales and claystones are quite extensive in places, sandstones predominate.

The stratigraphic units in the Dendrobium Area are, from the top down:-

- The Hawkesbury Sandstone
- The Narrabeen Group
- The Eckersley Formation

The **Narrabeen Group** contains the Newport Formation (sometimes referred to as the Gosford Formation), the Bald Hill Claystone, the Bulgo Sandstone, the Stanwell Park Claystone, the Scarborough Sandstone, the Wombarra Shale and the Coalcliff Sandstone.

The **Eckersley Formation** contains sandstones, shales and minor coal seams and forms the upper section of the Illawarra Coal Measures. The Bulli Seam lies directly above the Eckersley Formation and the Wongawilli Seam lies directly below it.

The surface geology within the area can be seen in Figure 3.1 which shows the proposed longwalls in Area 3A and the maximum footprint for Areas 3A, 3B and 3C overlaid on a partial copy of the Southern Coalfield Geological Map (NSW DMR, 1999).

It can be seen from the above figure that the surface geology in the area generally comprises Hawkesbury Sandstone (Rh), with small isolated areas of quaternary soils (Qs) and Bald Hill Claystone (Rnz). Whilst not shown at this scale, Bulgo Sandstone outcrops around the shore of Cordeaux Reservoir at the Sandy Creek arm of the reservoir. There are also some small isolated areas within Area 3B, which are not shown in the above figure, which have been identified as comprising Wianamatta Shale (Rwb).

The stratigraphic unit of hydrogeologic importance is the Narrabeen Group, as it is the rocks of this unit that separate the stored water from the mining horizon. It is therefore the rocks of this unit that govern the magnitude of the interaction.

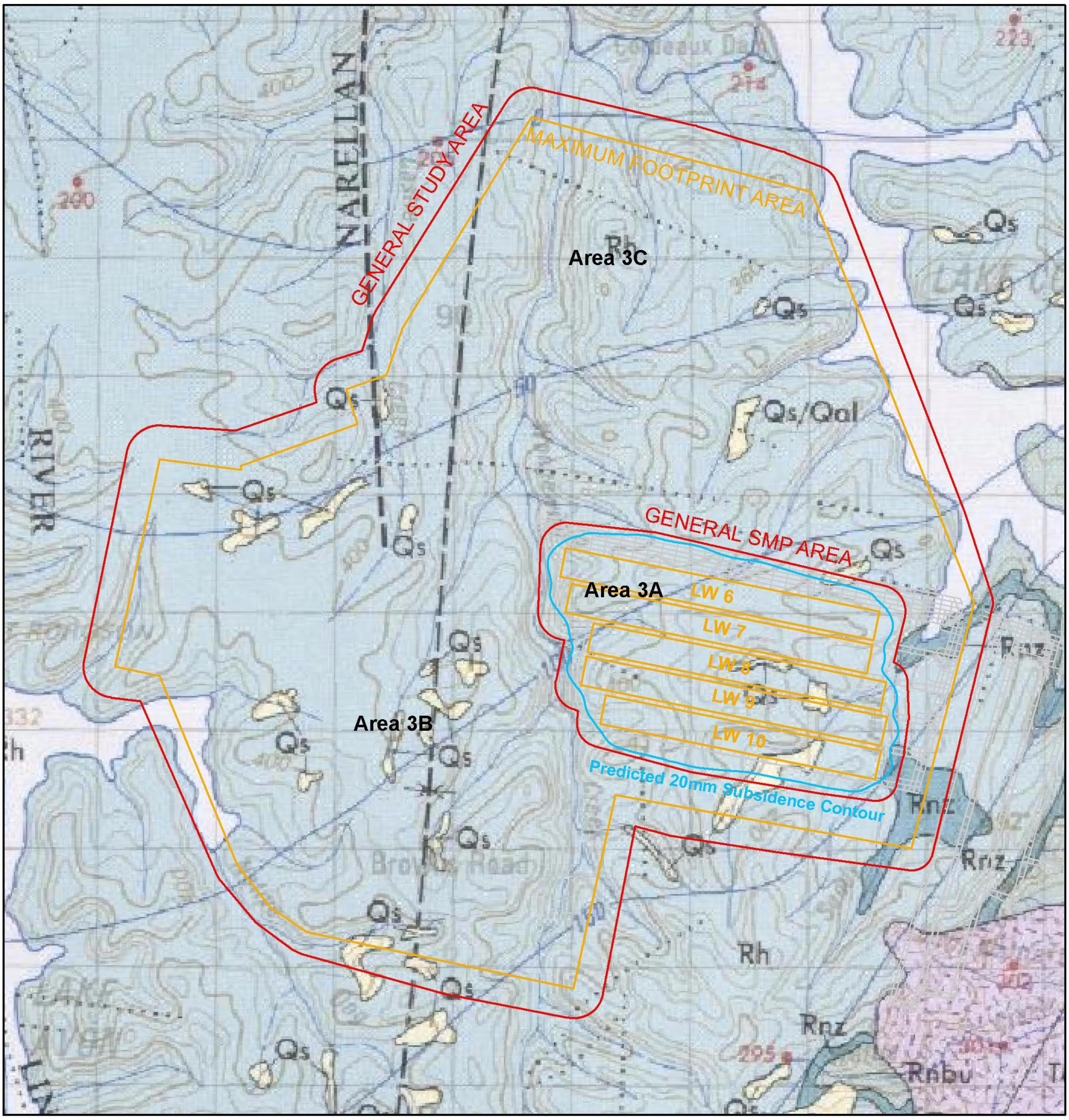

Figure 3.1: Surface Geology at Dendrobium Area 3

(Ref MSEC311, 2007, Fig 1.3)

Details of the geology of Area 3 are provided in BHP Billiton (2007). The geological setting of importance to the hydrogeology consists of gently dipping sedimentary strata from the Narrabeen Group to Hawkesbury Sandstone. Within each stratigraphic unit, the rock types are reasonably consistent and identifiable on a regional scale (see Appendix A). The alternate sequence of stratigraphic units produces a series of rock units that alternate between broadly sandstone units and broadly claystone units, albeit with various interbeds within each stratigraphic unit. The local overall regional dip of these units is about 2^o towards the northwest, which is consistent with Area 3 being situated on the southern limb of the Sydney Basin geosyncline. Naturally, local variations in dip occur within the sedimentary setting.

The stratigraphic units broadly reflect their hydrogeologic performance by the nature of their rock units. The claystone units (Bald Hill Claystone, Stanwell Park Claystone and Wombarra Claystone) are generally of the lowest permeability (or transmissivity) and act as aquitards. The sandstone units (Hawkesbury Sandstone, Bulgo Sandstone, Scarborough Sandstone, Coal Cliff Sandstone, Loddon Sandstone and Lawrence Sandstone) are generally of higher permeability and act relatively as aquifers in the system. [Note in passing, that the term “aquifer” is used in the sense that it is relative to the characteristics of the claystone aquitards units, and should not be interpreted to imply that these units currently could be commercially exploited as aquifers].

The sedimentary rockmass has been intruded by igneous sills (horizontal features) and igneous dykes (typically vertical features). The major geological features in the area of the proposed longwalls are presented on Drawings G301 & G302, and appear as well in Figures HG301 to HG304. Refer also to Drawing No. MSEC311-06 (MSEC 2007).

One of he most noteworthy igneous structures within Dendrobium Area 3 is the sill identified as the Dendrobium Nepheline Syenite. The Wongawilli Seam has been intruded and replaced by the Nepheline Syenite to the south of Area 3A and to the west of Area 2. The Nepheline Syenite has lifted the sedimentary pile above it as a result of its intrusion of the Wongawilli Seam. The thickness of the intrusion increases up to about 40m along its eastern faulted boundary. The approximate location of the sill is shown in the abovementioned drawings and figures, though the margin of the sill will be refined as further geological investigations are undertaken.

Area 3 is bounded to the north by the Dendrobium Dyke Zone (DDZ1) that may have associated minor faulting. Geological structure DDZ1 forms a practical limit to the mining within Area 3A, and controls the current mine layout and northward limit of Areas 3A and 3B. DDZ1 consists of a sequence of dykes and minor faults over a width of about 350m. The dykes are believed to be vertical to sub-vertical and to have typically intruded along pre-existing fault or joint traces. Where intersected by horizontal directional drilling from the workings or in surface exploration holes targeting the zone (e.g. medium radius drillhole Dendrobium DDH58) the dyke material was interfingered with cindered coal and consists of clayey material of variable strength. No differential piezometric heads either side of the dyke were reported.

Several geological structures have been identified at seam level near the proposed longwalls in Area 3A, including a fault and dyke near the finishing ends of Longwalls 9 and 10 which project from the eastern margin of the Nepheline Syenite intrusion. A series of faults have also been identified to the south-west of Longwall 10, within Area 3B.

Along the western sides of Areas 3B and 3C, a cindered zone has been identified which may well provide the western economic limit of the Wongawilli Seam in these two areas. As for the Nepheline Syenite, the locations of the geological structures will be refined as further geological investigations are undertaken by BHP Billiton.

In common with the rest of the Southern Coalfield, the in-situ horizontal stresses at the Dendrobium Mine are relatively high. SCT Operations has reported that the maximum horizontal stress ($\sigma_{H\ max}$) is 14 MPa to 16 MPa at 200 metres depth of cover and 20 MPa to 24 MPa at 450 metres depth of cover. The maximum principal stress direction, based on borehole breakout data, is NE to SW (032° – 065° relative to True North).

The rocks of the Hawkesbury Sandstone and the Narrabeen Group are of relatively low permeability at depth and have a limited capacity to facilitate migration of water from the surface into the proposed mine workings. This capacity is further reduced by the relatively high level of *in situ* horizontal stress.

3.2 Inferred Stratigraphy and Piezometric Surfaces

The sequence of (relative) aquifers and aquitards means that the movement of groundwater is generally in a horizontal sense. As a consequence, whilst there will be a degree of naturally occurring movement of groundwater across the aquitards in the sequence, the majority of movement will be horizontal with little mixing between units – in the absence of interruption to the hydraulic characteristics of the stratigraphic units through underground mining.

In an area of limited external influences and without mining influence, hydrostatic groundwater conditions normally would be anticipated, notwithstanding the sequence of relative aquifers and aquitards, and the general horizontal nature of groundwater movement. The concept of hydrostatic conditions within the rockmass is explained in Figure HG311 and discussed in Section 5. Hydrostatic conditions mean that the piezometric pressures throughout the sediment pile have a value of total head that is the same for each unit. Whilst this total head value may not necessarily be equivalent to the ground surface, the value will be the same for each stratigraphic unit. That will mean that a piezometer installed at any depth within a borehole penetrating the geological stratigraphy with hydrostatic groundwater conditions will record the same total head - when the piezometric head (recorded at the piezometer) is summed with the position head (RL of the piezometer tip) - much the same as if installed at various depths within a body of water, and hence the term “hydrostatic”.

The inferred stratigraphy for Area 3 is presented Figure HG305. This is a type-section along the centreline of Longwall 6. The interpretation is provided in Drawing G303, which should be referred to for details. The data used to derive the section include:

- Airborne laser survey (ALS) contours of the ground surface (per BHP Billiton);
- Stereo aerial photograph and orthophoto coverage;
- Borehole information packs incorporating: lithology logs; downhole geophysical logging (that provide background to the lithological logging, and assists in detailed appraisal of particular downhole intervals, and their correspondence between borehole for correlation purposes); borehole survey and collar co-ordinates - all per BHP Billiton;
- The field results of downhole packer testing conducted under the direction of BHP Billiton;

» Piezometer installation details and regular piezometric data of the various piezometer strings that installed downhole within Areas 3 and 2, with data coverage variously from October 2004 to July 2007 (per BHP Billiton);

» Geological interpretation of stratigraphic unit contours (floor contours and thickness isopachs) covering the mining and exploration area (per BHP Billiton); and

The inferred surfaces of piezometric pressure for the conditions prior to mining Areas 2 & 3 are based on the data provided by individual piezometers (from the downhole strings of piezometers in various boreholes identified on Figure HG304) with recognition of the stratigraphic and topographic setting. The individual piezometer records were appraised for their response since installation, and values were selected that are representative of the pre-mining equilibrium piezometric pressure conditions. Selected values were then contoured over Areas 3 & 2 to establish broad area trends. This permitted projection of the piezometric surface onto the type-section, together with appraisal of the individual results, as depicted on Figure HG305. [Note that the individual piezometers are presented on Drawing G303 (for the same section as shown on Figure HG305) which includes upward facing arrows indicative of the piezometric head recorded by the piezometers.]

The lithological logs are used in the development of the stratigraphic model of the overlying rockmass throughout the Dendrobium area – for example, see Drawing 303. This drawing presents an inferred cross-section along the long-section of Longwall 6 and has been adopted as a type-section for Area 3A. The type-section includes the lithological logs of the various boreholes that are adjacent to the section and have been projected onto it from various distances. The projection has been performed as normal to the section line and has adopted the recorded collar level of the borehole. The style of this projection should be noted when viewing the section - as the projection has not been along dip, some relative displacements of the graphic representation of the lithological logs relative to stratigraphic boundaries will occur.

The packer testing consists of the staged pressure testing of downhole intervals to determine the rate of inflow into the formations downhole during the course of the testing. The exploration boreholes within which downhole packer testing has been conducted in Area 3A are identified on Drawing G302 and also on Figure HG303. The packer test results are interpreted for permeability parameters for each test – see Figure 3.2. Downhole profiles of permeability permit correlation with stratigraphy (see Figure 3.3), and the development of statistical understanding of the distribution of test results throughout the stratigraphic units – see Figures 3.4 & 3.5.

Appendix C contains the packer reduction sheets for each of the packer tests conducted across the boreholes in Area 3 as identified on Figure HG303. Appendix C also contains copies of the packer permeability value adopted from the reduction of the field test results, in the form of a series of figures – Figures PD84 to PD98.

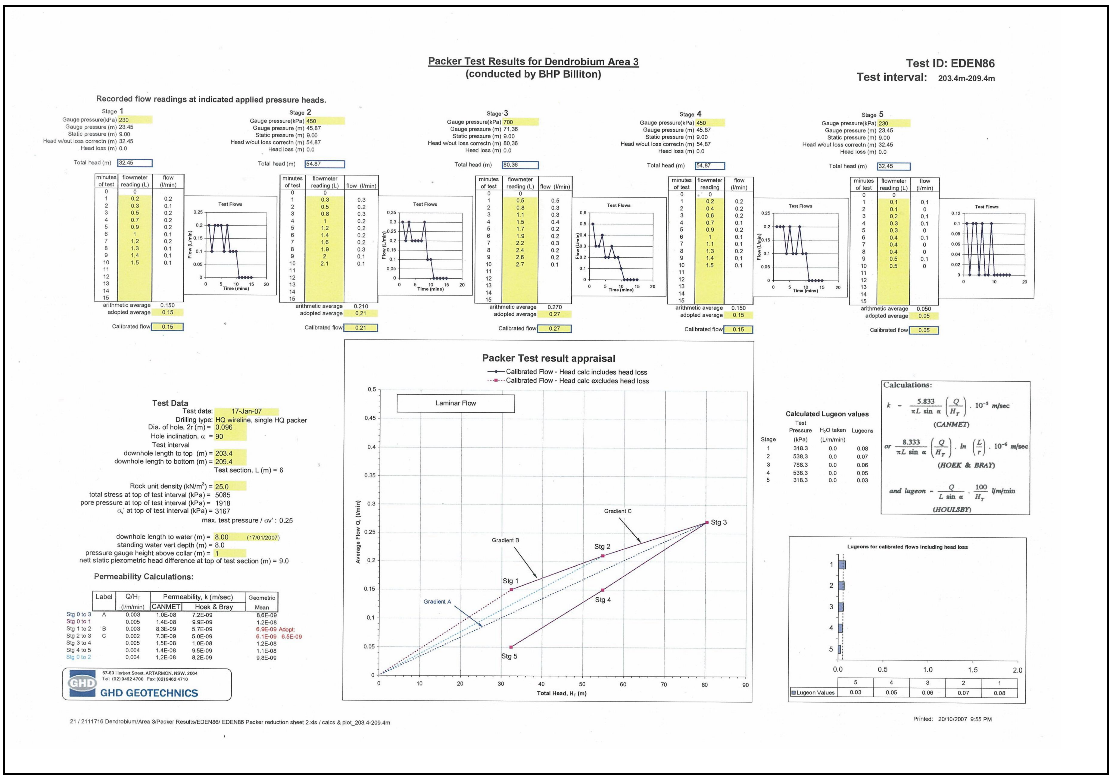

Figure 3.2: Indicative packer test Result from a single test result

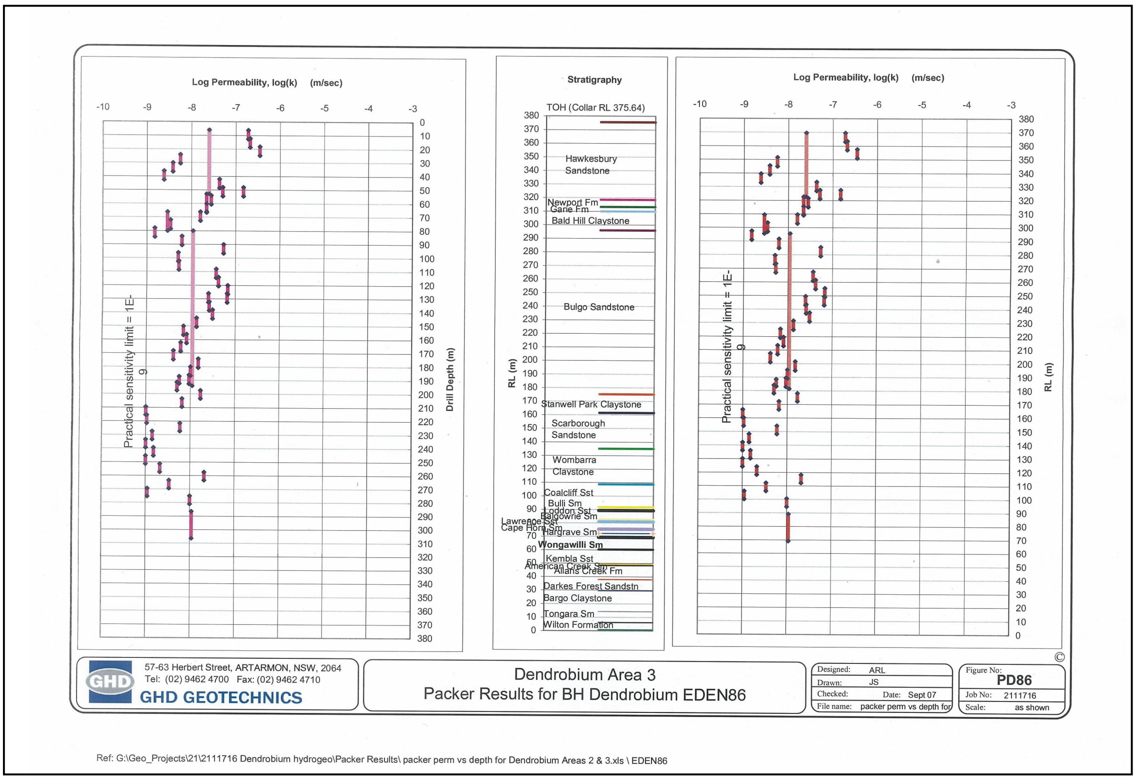

Figure 3.3: Downhole packer-based permeability test result profile

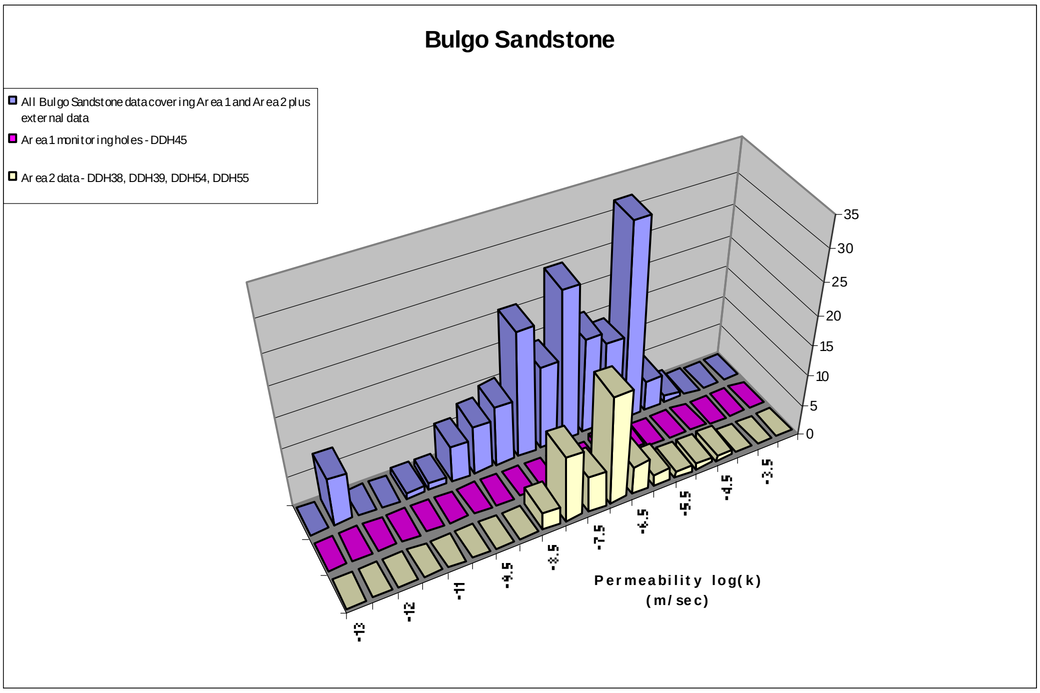

Figure 3.4: Comparative permeability distribution within a stratigraphic unit

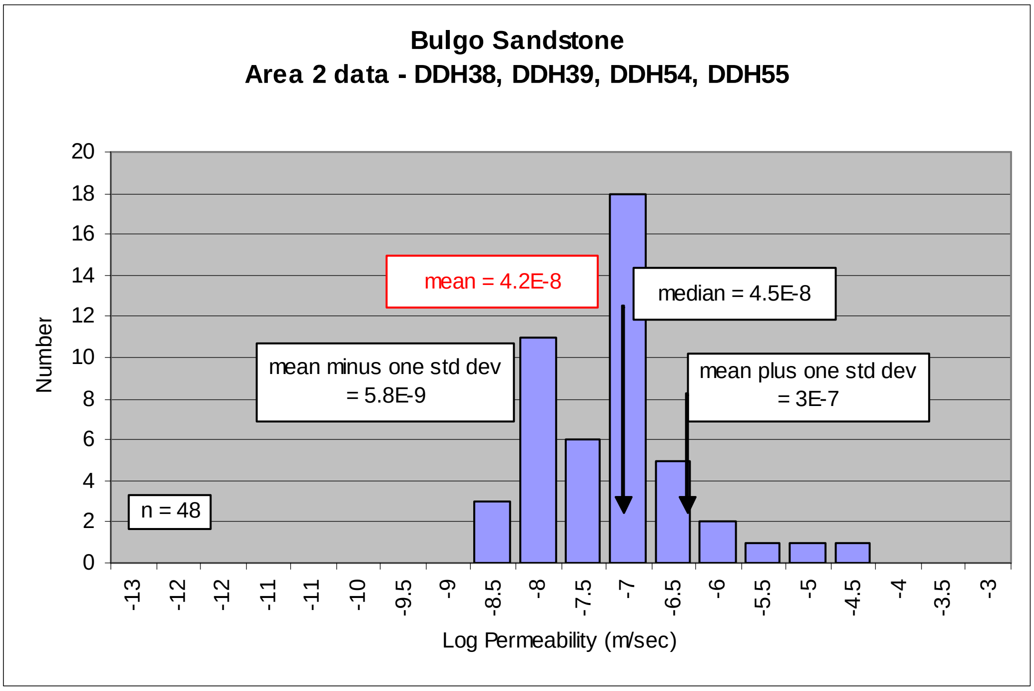

Figure 3.5: Statistical Distribution of Permeability Parameters in a stratigraphic unit

Piezometers are selectively installed downhole in strings of vibrating wire piezometers tips. The piezometer tips record pore water pressure at the installed position – the piezometer strings are grouted into place downhole. The vibrating wire piezometers are connected to dedicated data loggers at the ground surface adjacent to the borehole collar. This permits the regular "reading" of piezometric pressures. Much of the readings in the Dendrobium area are "read" on an hourly basis (ie 24 times a day). The response of the piezometers with time permits the establishment of base piezometric pressure readings throughout the rockmass. The exploration boreholes furnished with downhole instrumentation in Area 3A is presented on Drawing G302 and also on Figure HG304.

3.3 Existing hydrogeology of Area 3

The interpretation is based on the type-section that has been developed along the axis of Longwall 6 which is a two-dimensional appreciation of the relatively complex interbedded hydrogeology. The interpretation of the piezometric conditions within the rockmass prior to mining, together with the stratigraphy encountered by the exploration program, is presented on the long-section shown on Drawing G303. The conclusions reached by the assessment are also presented diagrammatically on Figure HG305. This figure consists of the same long-section through Area 3A as produced on Drawing G303. The section is drawn as a long-section through Longwall 6, and covers Area 3A from the Sandy Creek arm of Cordeaux Reservoir (right of centre) to well towards the western end of Longwall 6 (left hand side). The section extents to the east (right) to include the northern end of Area 2. Note that whilst the section is a long-section through Area 3A – wherein the proposed longwall panels are oriented with their long-axis in the east-west direction – the section is a cross-section through Area 2 (since the layout in Area 2 consists of 3 parallel longwalls oriented in a north-south direction).

The important elements of the appraisal (November 2007) of the hydrogeology include:

» The presence of distinct, and different, piezometric surfaces (groundwater table) for various groups of stratigraphic units throughout the sedimentary profile.

» The distinct piezometric surfaces are consistent with conclusions drawn by the Reynolds Inquiry (1976), specifically the recognition that the movement of groundwater was generally in the horizontal direction, this being a result of the stratigraphic sedimentary sequence in the rockmass, which is controlled by geological formations of lower relative permeability. This means that the hydrogeology of the Southern Coalfields in the broad sense is controlled by a sedimentary sequence of aquifers and aquitards, as confirmed by the geochemical monitoring conducted within Dendrobium Areas 1 & 2. Further, the coal seams within the sedimentary pile are typically of relatively high permeability and therefore act as aquifers themselves, in addition to the sandstone units.

The main hydrogeologic description for the stratigraphic units is:

Aquitards: Bald Hill Claystone, Stanwell Park Claystone and Wombarra Claystone.

Relative Aquifers: Hawkesbury Sandstone, Bulgo Sandstone, Scarborough Sandstone and Coal Cliff, Loddon & Lawrence Sandstones.

Aquifers: Bulli Seam, Balgownie Seam (perhaps) and Wongawilli Seam.

[*Note:* The Hawkesbury Sandstone is an unconfined aquifer, the other aquifers are confined]

The values of permeability established for each of the stratigraphic units from the analytical analysis, which is described in Appendix B, are shown in Table 3.1. The units of highest permeability within the Permo-Triassic sequence are the coal seams. However, their relatively small thickness in comparison with the sandstone units will mean their transmissivity is of less contrast.

Piezometric pressure surfaces have been established by employing the results for individual piezometers in each stratigraphic unit and assigning a representative piezometric surface across a type-section for Area 3A. These piezometric surfaces have been used in the development of Figure HG305.

Note that Figure HG305 includes upward facing arrows within the stratigraphic units that are indicative of the piezometric head inferred to exist currently in that stratigraphic unit. The piezometric surface is also assigned a blue shading to promote its position.

Table 3.1: Current permeability estimates for stratigraphic units

Aquifers		**Aquitards**	
Stratigraphic Unit	**Permeability, k**	**Stratigraphic Unit**	**Permeability, k**
Hawkesbury Sandstone	3E-8 m/sec	Bald Hill Claystone	5E-9 m/sec
Bulgo Sandstone	6E-8 m/sec	Stanwell Park Claystone.	3E-9 m/sec
Scarborough Sandstone	2E-7 m/sec	Wombarra Claystone.	1E-9 m/sec
Coal Cliff, Loddon & Lawrence Sandstones	1E-9 m/sec		
Bulli Seam	1E-5 m/sec		
Wongawilli Seam	5E-7 m/sec		

Note: The permeability values reported in the table use scientific notation, where the "E" represents the exponential to the power 10 – eg 2E-6 is equivalent to 2×10^{-6}. Scientific notation has been adopted for printing clarity.

With reference to Figure HG305, it is noted that:

» Separate groundwater bodies exist down through the rockmass (ie hydrostatic conditions do not exist throughout the rockmass). The piezometric profile exhibits an unconfined near-surface perched water table in the Hawkesbury Sandstone, and then separate confined groundwater (of lesser total head) down the stratigraphy. [The confined groundwater situation is indicated by the position of the piezometric head surface being above the overlying confining aquitard].

» The Hawkesbury Sandstone exhibits an unconfined groundwater table that uniformly has its surface near the natural ground surface.

» The main claystone units are acting as aquitards and are separating the piezometric pressure profiles. This effect can also be seen on the uppermost two diagrams on Figure HG309.

» The Bulgo Sandstone exhibits a confined groundwater situation, but only marginally so, in that the piezometric surface is situated above the Bald Hill Claystone. This is just above the upper limit of the Bulgo Sandstone, and hence the surface remains "confined" in Area 3A.

Towards the eastern end of the inferred section, the Bulgo Sandstone may well have just moved into an unconfined condition – see note on Figure HG305 just to the west of the Sandy Creek arm of Cordeaux Reservoir.

The piezometric surface falls from the west and separately from the east towards the Sandy Creek arm of Cordeaux Reservoir, which is a natural head control of the Bulgo Sandstone.

The Bulgo Sandstone piezometric surface remains distinctly different to the Scarborough Sandstone in Area 2, and the response of the Bulgo Sandstone at the eastern (right) side of Figure HG305 may well include drainage into the (unnamed) creek over Longwall 4.

» In a similar fashion, the Scarborough Sandstone has a piezometric surface above its confining aquitard, the Stanwell Park Claystone. The piezometric surface for the Scarborough Sandstone is at an elevation equivalent to the main body of the Hawkesbury Sandstone and hence is confined by the Bald Hill Claystone. The gradient of the piezometric surface is towards the east, with an essentially uniform gradient. At the Sandy Creek arm of Cordeaux Reservoir, the piezometric surface for the Scarborough Sandstone is equivalent to the top of the Bulgo Sandstone and is essentially equivalent to full supply level (FSL) of Cordeaux Reservoir. This would appear a coincident only as the piezometric surface of the Scarborough Sandstone is independent of the Bulgo Sandstone.

The piezometric surface for the Scarborough Sandstone appears to be suppressed on the (eastern) right hand side of the inferred section, presumably as a result of the influence of mining in Area 2. It would appear that de-pressurisation of the Scarborough Sandstone has occurred, with the piezometric head approaching an unconfined condition (ie. approaching down towards the top of the unit) in the middle of Longwall 3 of Area 2 in advance of mining.

» The Bulli Seam and Wongawilli Seam piezometric surfaces are clearly distinguishable between each other and are significantly lower than the sandstone units above them. The pressure difference between these coal seams and the overlying sandstone units in the area of the Sandy Creek arm of Cordeaux Reservoir is about 150 metres head in Borehole DDH84. The broad suppression of the piezometric surfaces within the Bulli and Wongawilli Seams is believed related to previous mining in the broader local area – including Elouera Colliery workings to the south, and Wongawilli, Nebo, Mt Kembla and Kemira Collieries along the Illawarrra Escarpment, and perhaps Cordeaux Colliery workings to the north.

In addition, there is an existing external control on the Bulli and Wongawilli Seams (as discussed below) which is superimposed locally upon the piezometric pressure profile of the seams.

A specific effect from the workings in Area 1 and the first workings in Area 2, whilst expected, has not been identified in the piezometer records covering Area 3 up to March-April 2007.

» The interpretation is based upon Area 3 piezometric data up to March and April 2007, at which time the face of Longwall 3 was over 1.6km to the south of the type-section as retreat had just commenced in Longwall 3. This is considered representative of the pre-mining influences upon Area 3, since no influence from either the longwall retreat or the first workings was specifically discernable from the piezometer results. For example, for the piezometers within the Scarborough Sandstone, a uniform piezometric pressure gradient towards the Cordeaux River arm of Cordeaux Reservoir was demonstrated.

» The interpretation assumes that the piezometric pressures are controlled (in terms of pressure) by an existing external control (external to the type-section) in the region beneath the Sandy Creek arm of Cordeaux Reservoir. The total head values increase both to the east and west of this location. The external controls are influencing both the Bulli and Wongawilli Seam piezometric pressures in a similar manner. The controls limit the total head in the seams in this local area to about RL162 and RL156 respectively. These represent piezometric heads of about 60m for the Bulli Seam and 80m for the Wongawilli Seam (see discussion in following section).

» The presence of the steeply dipping, north-south striking, normal fault between Area 2 and Area 3 does not provide a control mechanism upon the current piezometric surfaces. The fault has been interpreted by BHP Billiton as through-going vertically across the full thickness of the sedimentary sequence from Wongawilli Seam to Hawkesbury Sandstone. Should the fault act as a hydraulic control, it would likely be one of inflow through connection with Cordeaux Reservoir to the north of Area 3 – see fault trace in Figures HG301 and HG302. This is not the case. The position of the fault further precludes it acting as a control as it is east of the inferred control location.

  Projection northward towards Longwall 6 of Area 3 of Dendrobium Dyke structure DD1, which is adjacent to the eastern side of the Nepheline Syenite, provides a more viable mechanism to ultimately link southward and then westward to the Elouera longwall panels.

» The similar response of the piezometric pressures of the Bulli Seam and Wongawilli Seams, and that their response is different to the overlying sedimentary rockmass, is consistent with an absence of aquitards within the coal seam interburden (Coal Cliff Sandstone, Loddon Sandstone and Lawrence Sandstone) in the first instance, and the effectiveness of the Wombarra Claystone as an aquitard in the second instance.

» It is also noted that the drainage effect upon the rockmass from previous mining in the general area is observed in the Wongawilli and Bulli Seams but that this effect is isolated from the overlying Scarborough and Bulgo Sandstone units.

» The north-south trending fault (DF1) is situated in a hydrogeologic position that is comparable to the two ventilation shafts under construction at the north western corner of Area 2. The suppression of the piezometric pressures by the shafts is not viable as shaft construction is current and effects upon the piezometer readings have not been observed. The shafts are also to be fully lined above the Wongawilli Seam, and hence can be expected not to have an impact in the long-term other than through drainage of the Wongawilli Seam itself.

» Based on an assessment (in press) conducted by BHP Billiton of geological structures encountered elsewhere in the Southern Coalfield, it has been concluded that significant water-bearing geological structures are essentially unknown, or certainly in a very small minority. In addition, mining of North West Mains headings in Area 2 towards the shaft locations, is currently heading towards the fault to ultimately mine through it. Observation of water flow into the headings is limited to very minor water entry ("drippers" mainly) in the roof of the headings, though it is noted that the fault is yet to be mined through. It is currently concluded that the fault acting as a hydraulic structure is of very low likelihood.

In summary, the main current hydrogeologic features of Area 3A are:

» the perched water table exists in the Hawkesbury Sandstone;

» several separate groundwater conditions currently exist throughout the rockmass, probably related to past underground mining of the surrounding region;

» consistent hydrogeologic conditions are interpreted to persist across the stratigraphy; and

» de-pressurised conditions exist in the Bulli and Wongawilli Coal Seams in Area 3A in advance of mining.

The sources of water into the system are:

» rainfall across the area, which averages 3.3mm/day (based on rainfall records available from the pluviometer gauge at Lake Cordeaux pump station monitored since Dec 2003).;

[It is noted that the pluviometer gauge is relatively close to the site at a distance of 3km, though it is situated closer to the rain shadow provided by the Illawarra Escarpment than Area 3. This notwithstanding, the contribution provided by rainfall to the seepage analysis far outweighs the infiltration capacity of the rockmass at depth, and hence the assumed rainfall distribution is acceptable for the analyses that have been conducted.]

» groundwater travelling laterally through the rockmass;

[It is noted that the contribution to groundwater is a very minor proportion of the average rainfall depth falling upon Area 3A – see Section 5.]

» stored water in Cordeaux Reservoir.

3.4 Postulated Explanation for Existing External Control upon the Piezometric Pressures within Area 3A

With reference to Figure HG320, the possible mechanisms that could produce this effect within the Bulli and Wongawilli Seams include:

1. A drainage network that utilises the margins of the Nepheline Syenite intrusion to the south of Area 3A. The drainage path includes the rockmass at the Nepheline Syenite margins which is fractured as a result of the combination of faulting and strata jacking from the intrusion into the Wongawilli Seam. The postulated drainage path then connects through pillar-extracted workings and the south-western faulted margin of the intrusion into the northern longwall extraction area of Elouera Colliery. This is a rather tortuous drainage route, but can be established below a Wongawilli Seam contour of RL160. The south-western faulted zone includes a throw of 50m, which is another challenge to the interpreted

mechanism, though this is balanced by the number of faults along this margin of the sill. The Elouera longwall workings are flooded to about RL65 giving a fall of close to 100m over a path length of about 2.5km, which is reasonable for drainage via this mechanism to be feasible.

2. Northward drainage through the north-south fault between Area 2 and Area 3. The mechanism requires drainage along the fault trace to a "sink" that will permit a drawdown of pressure head. In this instance, this requires cross-measure drainage from such as a permeable fault into abandoned and drained workings. Wongawilli Seam workings in Kemira Colliery's longwall panels are up-dip and do not therefore provide a downslope head control mechanism. The Bulli Seam workings in Kemira Colliery would achieve the potential for downward drainage but the workings have become inundated to a level that makes the mechanism unreasonable, and would if anything lead to drainage into Area 3 via such a mechanism, rather that the reverse of outward drainage. This makes the mechanism not viable.

   It is additionally noted that such fault controlled drainage has not been recognised or observed by BHP Billiton in underground workings elsewhere in the Southern Coalfield.

   Further, such a mechanism requires that the plane of the north-south fault not be continuous vertically such that it does not connect with the stored water of Cordeaux Reservoir under which it projects. Cotemporaneous sediment deposition and faulting is known in the Southern Coalfield (eg at Coal Cliff Colliery), which could remove the fault trace within the Bulgo Sandstone at reservoir impoundment level. However, the combination of high permeability at a depth of 200m below reservoir level with removal of fault trace at ground level becomes an unlikely combination.

3. Down-dip drainage to the north through the Wongawilli and Bulli Seams. This mechanism requires drainage to workings such as those of Cordeaux Colliery 4.5km to the north of Area 3. Cordeaux Colliery has temporary surface seals and its Bulli Seam and limited Wongawilli Seam workings are currently being permitted to become inundated with groundwater. Whilst suppressed groundwater within the Bulli and Wongawilli Seams is possible via this down dip mechanism, a concentration of a local effect on the type-section of Area 3 is not feasible – without the presence of an unreported geological structure for which no evidence is apparent on the Cordeaux Colliery record tracings. A broad effect across the Area, rather than a concentrated effect, would thus be expected, which places the viability of this mechanism in doubt.

From the shape of the piezometric surface, it is clear that the external control is one of drainage from the type-section. It is therefore concluded that the control is not connected to Cordeaux Reservoir since that would result in inflow and hence elevated piezometric pressures, rather than the depressed pressures inferred on the section. (It is necessary to have the depressed shape of the piezometric surface to match with the data available from the downhole piezometers).

It is proposed that the control is produced by a drainage system linked through the Nepheline Syenite intrusion to the workings in Elouera Colliery. Whilst mining has since ceased in that northern portion of the longwall block at Elouera, the potential for the hydraulic control is viable.

BHP Billiton have advised that inundation of the workings by minewater has reached the main heading servicing Elouera Longwalls 7 & 8 (see Figure HG320). The long-term scenario may change, but this current water level does not preclude drainage into Elouera from Dendrobium Area 3A and thereby provides an explanation for the current hydraulic control apparent in the type-section through Longwall 6 of Area 3.

It would, on first impression, be expected that the depression of the Wongawilli and Bulli Seam piezometric pressures is related to the current first workings in Area 2. However, the gradients of piezometric pressure surface (as generated from the observed downhole piezometer strings) do not support such an interpretation.

4. IMPACT UPON HYDROGEOLOGY BY MINING

The assessment (November 2007) is based upon the abovementioned data that was made available from the on-going exploration work conducted by BHP Billiton in Dendrobium Area 3. In addition, the results from exploration within Area 1 and Area 2 were employed, together with the results of hydrogeologic monitoring in Areas 1, 2 & 3 before, during and after underground mining in Areas 1 and 2.

Longwall 1 was the first longwall mined by Dendrobium and was the closer (of the two longwalls) in Area 1 to the Kembla Creek Arm of Cordeaux Reservoir. Longwall 1 was mined in a direction principally parallel to Kembla Creek, was conducted to the north of the footprint of Cordeaux Reservoir (ie. was not beneath the stored water of the reservoir) and occurred at a depth that was about 130 m below fully supply level (FSL) of Cordeaux Reservoir (note that the depth is beneficially much greater in Area 3). In Area 2, Longwall 3 is currently being mined parallel to the Cordeaux River arm of the reservoir. By comparison, the planned mining in Area 3A, and in particular for Longwall 6, is in a direction that is not parallel to the stored water, and is close to being "end-on" to the Sandy Creek arm of the reservoir. This is a more favourable orientation, as a consequence of three-dimensional drainage effects.

4.1 Influence of underground Mining

Mining beneath a sedimentary sequence interrupts the existing hydrogeologic conditions. The changes are both short term (and dynamic in their nature) and longer term with broad area modification of subsurface drainage.

The effects of underground coal mining are a consequence of:

» the development of roadways (or headings, or first workings) within the Wongawilli Seam;

» the physical removal of the coal seam by longwall mining methods;

» the subsequence caving collapse of the roof of the mining interval (production of the goaf);

» the upward migration of the roof collapse (to a limit determined by bulking of the caved material);

» downward flexure of strata above the caved material due to the "soft" support provided by the collapsed material in the goaf;

» to an upward limit achieved through arching within the rockmass over the mining interval.

The findings of the Reynolds Inquiry (1976, pp65-67) into mining under or in the vicinity of stored water included:

» "There remain, notwithstanding the extensive mining, retarding layers which inhibit the vertical flow of water from a continuing horizontal flow system. Thus there remain leaky aquifers and not in the strict sense confined aquifers. No one has denied that there is some vertical flow…..but be too small to measure."

» “The evidence shows that, notwithstanding the mining and the disturbance of the strata, horizontal flow systems have not been destroyed, though they may have been modified and it follows that there is no such vertical hydraulic continuity between these systems as to create a significant drainage of water towards the mine opening and it also follows that there remains at the base of the lower aquifer system such a retarding layer as will not permit downward drainage therefrom of measurable magnitude…..notwithstanding the disturbance of the strata involved in the intensive mining.”

» “The findings….do not destroy a view which is based upon the experience of sub-aqueous mining that, if the cover is sufficient in relation to the mining method employed, poorly permeable zones in a generally central zone will not be so affected by fracturing, joint opening, joint slippage, bed separation or bed slippage as to lose their retarding qualities.”

  (The comments particularly relate to the interpretation of downhole testing which “was chosen as being the nearest example available in the southern Coalfield of the type of panel and pillar partial extraction which the proponents of mining under stored waters advocate. It can fairly be said that the fracturing and increased permeability which these tests demonstrated were not substantially at variance with the theory expounded during this Inquiry as to the effect of total extraction”.)

» “The evidence supports a view that a cover of 60m of undisturbed strata of the Narrabeen Group is desirable.”

An important feature of the Reynolds’ inquiry was the recognition that the movement of groundwater was generally in the horizontal direction, this being a result of the stratigraphic sedimentary sequence in the rockmass, controlled by interbedded geological formations of lower relative permeability.

Briefly, this means that the hydrogeology of the Southern Coalfields in the broad sense, is controlled by a sedimentary sequence of aquifers (in a relative sense) and aquitards. Further, the coal seams within the sedimentary pile are typically of relatively high permeability and therefore act as aquifers themselves, in addition to the sandstone units. These are the units of highest permeability, and relative to the other units are aquifers (in this relative sense) – see Section 3. In a broad sense, it is reasonable to conclude that the claystone and shale units act as aquitards, these including the Bald Hill Claystone, Stanwell Park Claystone and Wombarra Claystone.

Underground coal mining modifies the hydraulic nature of the rockmass as a consequence of collapse and caving of the mining interval, in addition to the associated upward migration of the caving and loosening of the rockmass above the mining interval.

4.2 Central Coast Study

This influence was studied in the Central Coast (Forster, 1995) and led to an understanding of the interaction of underground mining and the hydrogeological impacts upon overlying rock strata – see attached copy of Figure 5a from GHD LongMac (2004) that contains the essence of the model presented by Forster (1995). That model was extended through application of the essence of Figure 5a and presented in Figure 5d of GHD LongMac (2004), a copy of which is attached herein.

The essence of the model is the identification of various zones within the rockmass about the longwall extraction. The positions of the zones are shown on Figure 5d, and are:

Caved Zone – immediately above the mining interval, involving lose caved blocks of sedimentary rock collapsed from the roof of the mining interval once support otherwise provided by longwall chocks is removed by retreat of the longwall face. The upward migration of the caved zone is limited by bulking of the collapsed loose rocks, which occupy a greater volume than solid rock. This will naturally vary as a result of the nature of the rockmass and its natural defects, though typically ranges from about 5 to 10 times the height of the mining interval – i.e. 15 to 30m in the case of mining at Dendrobium.

Fractured Zone – overlying the caved zone, this disturbed zone contains a de-stressed rockmass that is supported upon the caved zone. The fractured zone contains a rockmass that has sagged downwards and consequently suffered significant bending, fracturing, joint opening and bed separation. Its upward extent is a result of downward flexure of the strata, with the upper limit frequently controlled by bed separation on low strength strata. The fractured zone is based on hydrogeologic response, and the upper limit was determined on the basis of downhole testing. The work by Foster (1992) supported an upward migration limit for this hydrogeologic zone of between 20 and 33 times the thickness of the mining interval in a longwall environment, and the latter (33) height is equivalent to 0.42 x width of the longwall.

Constrained Zone – the constrained zone acts as an aquitard and comprises the confined rockmass above the fractured zone "which have sagged slightly but, because they are constrained, have absorbed most of the strain energy without suffering significant fracturing or alteration to the original physical properties. Some bed separation or slippage can be present as well as discontinuous vertical cracks (usually on the underside of thick strong beds). Weak or soft beds in this zone may suffer plastic deformation (Forster and Enever, 1992). This is the most relevant zone to the maintenance of near surface piezometric pressures and hence, the near-surface groundwater table. Forster and Enever also comment that the constrained zone is the most relevant to sub-aqueous mining and must form an effective barrier to vertical drainage). The conclusions drawn were that the vertical permeability's of rocks strata in this zone were not increased significantly by the mining at the Central Coast. Although their theoretical model recognised some minor increases in vertical permeability over the rib zone, this was not detected in the field testing program. While some increases in horizontal permeability were detected due to mining, these do not affect the integrity of the constrained zone" (Forster and Enever, ibid).

Surface Zone – consists of unconfined strata at the ground surface in which mining induced tensile and compressive strains may result in the formation of surface cracking or ground heaving. A literature survey of the reported thickness of the surface zone was reported by Forster & Enever (ibid). Their conclusion was that this zone had a thickness less than 30 metres. For the Central Coast study, a thickness of 15 m was adopted, though it was noted that near effects due to mining (such as strains) would have been absorbed without observable effects due to the nature of the overburden soil and rock – despite being subjected to surface strains in excess of 88 mm/m.

Rib Zone – exists at the sides and end above the longwall extraction area. The rib zone is broadly above the line of the coal mining rib at the edge of the underground workings and its outward limit is determined by the subsidence "angle of draw" – see MSEC (2007). The rib zone provides a transition from the subsiding rockmass to the rockmass over solid (unmined) coal for each of the other zones. Within the rib zone, horizontal tension is expected, with consequent increases in permeability – in the horizontal sense adjacent to the surface area and in the vertical sense adjacent to the constrained area.

4.3 Hydrogeologic Interpretation of Impacts of Underground Mining

The hydrogeologic interpretation of the mining induced zones is:

Caved Zone	-	high permeability zone with voids in existence.
Fractured Zone	-	large increase in bulk permeability.
Constrained Zone	-	no change in vertical permeability though a likely increase in horizontal permeability due to bed separation.
Rib Zone		variously increased vertical or horizontal permeability as suits position relative to adjacent zones.
Surface Zone	-	little observable effects, mostly not detectable.

[Note that this work excludes the situation of stress concentration, valley closure and upsidence in valleys and gullies.]

The conclusions reached by Forster & Enever (1992) included that full extraction mining (both longwall and mining by bord-and-pillar with pillar extraction) was feasible in the Central Coast beneath free water bodies provided a solid rock cover of 45 times the extracted height (plus 10m contingency) was present. For the longwall width of 200m in that study area, this represents a competent cover of 0.3 of the width of the panel (ie 0.3W).

Notwithstanding the discussion previously in regard to the predominance of horizontal flow throughout the rockmass of the Southern Coalfields, within the Constrained Zone over mined longwalls there will be a component of vertical drainage of groundwater, albeit impeded by aquitards.

4.4 Background Studies in Dendrobium Region

Dendrobium Area 1

The broad conclusions of the Centra Coast study were supported by the results of hydrogeologic monitoring of Dendrobium Area 1. The results obtained from a combination of monitory (of piezometric pressures within the rockmass between Cordeaux Reservoir and Longwall 1) and mine water balance, permitted back analysis of the hydrogeologic performance of the rockmass as a consequence of the underground mining in Longwall 1, conclusions reached by the appraisal of monitoring data and the back analysis include:

» Importantly, a similar response in the piezometers following mining was observed in both Monitoring Sites 1 & 2.

» Post retreat of Longwall 1, the piezometers in the Bulgo Sandstone and Stanwell Park Claystone remained unaffected. A minor rise was observed in the Bulgo Sandstone (believed to be an external environment driven effect) and a minor drop in the Stanwell Park Claystone.

» The piezometric response of the Scarborough Sandstone is uniform throughout the thickness of the stratigraphic unit. Following retreat of Longwall 1, the total head was just below the top of the unit, indicating that this aquifer has become partially de-saturated and behaving as an unconfined aquifer.

» The total head in the Wombarra Claystone dropped, and the unit became de-pressurised to some extent, though remains a confined aquifer.

» The piezometers in the Coal Cliff Sandstone exhibited significant reduction in total head, and indicate that this unit has been de-pressurised in a major way. This is consistent with its stratigraphic and hydrogeologic position, and its location adjacent to the mining of the Wongawilli Seam. There is evidence from the initial readings of piezometer P8 in DDH45C (see Figure HG22) that the Coal Cliff Sandstone unit was at least partially an unconfined aquifer prior to longwall mining, presumably as a result of drainage to the Nebo Mains and Area 1 development work.

The important issues are:

» The response at Site 2 was similar to Site 1.

» The Stanwell Park Claystone maintains its integrity as an aquitard.

» The Wombarra Claystone maintains its integrity as an aquitard.

» The results achieved equilibrium conditions following the mining of Longwall 1. Little additional change, if any, is expected in the piezometric pressures within the rockmass. In terms of the consequences upon the piezometric pressures within the rockmass between Area 1 and the stored water in the Kembla Creek arm of Cordeaux Reservoir, the physical position of Longwall 2 on the northern side of Longwall 1 leads to the conclusion that these will be minor as a result of the mining of Longwall 2.

The conclusions drawn from the assessment of the piezometric response (in the longitudinal sense) include:

- o The total head in the Bulgo Sandstone and Stanwell Park Claystone units (in the rockmass between Longwall 1 and Cordeaux Reservoir) was essentially unaltered by the mining activity. It could be argued, by extension, that this means that the head in these units is unaltered over the longwall goaf, and that the integrity of the Stanwell Park Claystone as an aquitard there has been maintained.
- o The total head in the Scarborough Sandstone is reasonably uniform throughout the unit. As a result of mining in Longwall 1, the total head reduced to a level comparable to the top of the stratigraphic unit as a consequence of de-pressurisation. The unit became an unconfined aquifer in Area 1.
- o Independent partial de-pressurisation of the Wombarra Claystone also occurred as a result of mining, whilst significant de-pressurisation of the Coal Cliff Sandstone Unit occurred.
- o The piezometers typically showed a pressure reduction upon approach of the longwall to the monitoring site – when the longwall was of the order of 150 to 200m from the

monitoring site. Essentially equilibrium piezometric head conditions were achieved in each of the stratigraphic units relatively rapidly once the longwall had retreated passed the monitoring sites.

- o The extraction of Longwall 2 in Area 1 (on the north eastern side of Longwall 1 - see Figure HG320) did not modify the longitudinal piezometric profiles between the monitoring sites within the rockmass between Longwall 1 and the Kembla creek arm of Cordeaux Reservoir, nor the gradient across the rockmass to wards the reservoir, as would intuitively be expected (since the effects of mining within Longwall 2 would be masked by the presence of Longwall 2).

The results obtained from piezometer readings at the monitoring sites for Area 1 were used to back-analyse the bulk permeability values for the stratigraphic units within the rockmass between Longwall 1 and Cordeaux Reservoir. Analyses were conducted for both the pre-mining and post-mining situations. The results employed:

» Data obtained from the monitoring sites from the strings of vibrating wire piezometers installed within the rockmass.

» Reservoir storage levels within Cordeaux Reservoir, as provided by the website operated by the Sydney Catchment Authority.

» The geometry of the stratigraphic units obtained from the investigative drilling conducted for instrument installation.

» The results of measurements conducted for water balance within the mine. This uses data from: pumping rates into and out of the mine at various pump stations; air humidity measured into and out of the mine; and moisture deficits through water removed from the mine with coal. Selection of inferred values of seepage by groundwater, through consideration of the water balance, were used to calibrate results obtained from the analysis. This was in combination with assumptions on the boundary conditions of the analytical model’s boundary conditions – both flow and head at these boundaries.

Conclusions from the back-analysis include that:

» The piezometric responses can be matched through detection of permeability parameters that are within the ranges established from the investigatory downhole testing.

» The inferred seepage volumes reporting to Nebo Mains and Longwall 1 can be replicated with these same permeability parameters.

» For the measured piezometric pressures to occur, then the stratigraphic units which act as aquitards are required to maintain a degree of their integrity within the rockmass above the longwall goaf. In particular, whilst the bulk permeability of the Wombarra Claystone over the longwall goaf has increased by two orders of magnitude (range of 150 to 180 times) to permit a match with piezometric responses, this unit is not free-draining (other than in a relative sense when compared to the assumed intact permeability) over the longwall goaf.

» Between 89% and 94% of the water reporting to Longwall 1 from the Kembla Creek arm of Cordeaux Reservoir does so through the Scarborough Sandstone unit. This is presented diagrammatically on Figures HG24 and HG25.

» As discussed in Appendix B, the quantity of groundwater reporting to Longwall 1 from the reservoir as a proportion of the flow recorded at the longwall is less than that depicted on Figures HG24 and HG25. (This is a direct consequence of the effects of symmetry combined with the means used for calibration of flows reporting to Longwall 1). It follows that:

  o A 50% loading is believed applicable to the estimate of the flow contribution from the Kembla Creek arm of Cordeaux Reservoir of the total flow which reports to Longwall 1. About 90% of this reports through the Scarborough Sandstone unit (ie about 45% of the total contribution).

  o The estimate of the representative horizontal permeability of the Scarborough Sandstone unit at Site 2 through back-analysis is between k_H = 3E-7 and 4E-7m/sec. With reference to Figure P203, wherein permeability estimates from packer testing in Area 1 are presented, these values fall within the range of results, and exhibit slightly higher permeability than the mean and median values (see also discussion in Section 3.5 following).

Elouera Mine

Two boreholes were specifically drilled over a mined longwall and in the adjacent rib at Elouera Colliery to provide data from previous longwall mining in the Southern Coalfield. These boreholes were drilled and tested to provide additional field data to address particular issues raised by the Dams Safety Committee prior to their approval to mine Dendrobium Area 1.

Elouera Colliery is located immediately south of Dendrobium Area 3B, and mined the Wongawilli Seam by longwall methods. The testing locations offering an opportunity to identify the consequences of longwall mining in the Wongawilli Seam upon the adjacent rockmass, as was the situation at Dendrobium Area 1. Part of that reporting of the borehole drilling and testing by Strata Control Technology (SCT, 2005) included an assessment of the distribution of zones produced by longwall mining within the overburden strata above and beside the Elouera longwalls – see SCT Figure 8 (copy attached).

In regard to SCT Figure 8:

» Zone 1 refers to the zone of strata disturbance, identified as the Caved Zone by Forster & Enever (1992).

» Zone 2 refers to the zone of large downward movement that develops in an arch shape, or perhaps flat-topped triangular shape (in recognition of horizontally bedded stratigraphy) above each longwall panel. Strata within Zone 2 typically experience initial dilation on bedding planes followed by downward movement under the influence of gravity. In high stress areas, horizontal shear fracturing can result in much closer fracture spacing as a result of the high horizontal stress. The boundaries of Zone 2 are defined by a change in the magnitude of downward movement from about 0.2 to 0.5 m. The height of the arch appears to be about equal to the panel width, i.e. 1.0 W.

» Zone 3 is a zone of strata dilation around the edges of Zone 2, where mining induced movements are less than about 0.2 m. Subsidence data for vertical sag of overburden strata suggests an upward limit of about 1.4 W to 1.6 W above the mining interval.

» Zone 4 is zone of strata compression and some lateral shearing located over chain pillars.

» Zone 5 is a zone where subsidence occurs but strata separation occurs only as a result of dilation during shear movements without a reduction, effective confinement. Lateral shear planes are likely to occur at the base of zone 5.

This interpretation and assessment is based on the results of extensometer monitoring over active longwall extractions. The zones are based on rock mechanics interpretation, as is reasonable. However, no hydrogeologic response is included in the data. It is reasonable to conclude that there is not the conflict between the interpretation of SCT and that of Forster & Enever, merely a degree of difference in focus.

By amalgamation of the two interpretations, and with experience from Dendrobium Areas 1 & 2, it is concluded that SCT's Zone 2 could well incorporate both the Fractured and Constrained Zones of Forster & Enever. The issue is one of degree of flexure and ductility of the aquitards within the overburden strata, and their consequent ability to accommodate subsidence, albeit with increased permeability but without complete loss of integrity in hydrogeologic sense.

For general situations and as sufficient overburden thickness permits, the conclusions are:

1. A Caved Zone of high permeability will exist immediately above the mined area to a height of 5t to 10t (5 to 10 times the height of the mining interval).
2. A Fractured Zone will exist above the Caved Zone, and extend to a height of about 0.4 W (0.4 times the width of the panel) above the floor of the mining interval). Within the Fractured Zone, large increases in permeability occur,
3. A Constrained Zone will exist above the Fractured Zone, probably in an arch shape, up to a height of 1.5 m or to within 15 to 30 metres of the ground surface within which little variation in vertical permeability exists, but increases in horizontal permeability occur through shearing and limited bed separation.
4. A Surface Zone that experiences limited impact when the depth of cover over the mining interval is in excess of 1.5 W (i.e. 1.5 times the longwall panel width).

For Dendrobium Area 3A, this means:

i. A Caved Zone 15 to 30 metres above the floor of the mining interval – ie to the Bulli Seam. (Note that a heavily fractured zone will also exist to a comparable depth below seam level as a result of unloading).

ii. A Fractured Zone to a height of about 100 m above seam level, ie to the Stanwell Park Claystone.

iii. A Constrained Zone above that to within 15 to 30 metres of the natural surface (where vertical subsidence of up to about 1.4.m is expected – MSEC, 2007).

The lateral extent of these zones will be essentially limited to the footprint of the longwall panels.

Dendrobium Area 2

Five monitoring sites were established within the rockmass between Longwall 3 (Area 2) and the stored water of Cordeaux Reservoir. Three of these monitoring sites (Sites 7, 8 & 9) each consist of a pair of piezometer strings installed adjacent to the northern part of Longwall 3 where the distance between the stored water and the footprint of Longwall 3 is the shortest. Each monitoring site provides coverage of the stratigraphy down to the Wongawilli Seam from near to the surface. Each monitoring site consists of a vertical monitoring string and a separate string of piezometers installed within a borehole that was inclined towards Longwall 3. This is a similar philosophy as was adopted for two of the Area 1 monitoring sites (Sites 2 & 3) – the difference being the absence of a third piezometer string oriented towards the reservoir.

Two rows of exploration boreholes adjacent to the southern end of Longwall 3 were employed as the other two monitoring sites (Sites 5 & 6). The line of piezometer strings within Site 5 (the southernmost monitoring line) consists of the exploration holes drilled through the Cordeaux Crinanite intrusion, and therefore monitor the hydrogeologic interaction of the mining with the intrusion.

The philosophy for the monitoring sites within Area 2 is the same as for the Sites in Area 1 – viz: to monitor the performance of the rockmass between the stored water in the reservoir and the mined longwall – in this case, Longwall 3.

To date, no significant nor systematic reduction in piezometric pressures within the rockmass at Monitoring Sites 5 to 9 has been observed. A response within each of the two piezometers installed within the Scarborough Sandstone and that within the Wombarra Claystone in DDH50 (part of the oblique line of Site 6) has been observed, though a response from the piezometer within the Bulli Seam and the Stanwell Park Claystone is not observed. A response of the piezometers within DDH39 (to be undermined in the middle of Longwall 3) has also been observed, which is to be expected as mining approached this location.

No response from the piezometers surrounding the southern part of Longwall 3 of Area 2 was observed during or following the inflow event of June 2007. During this discrete event (not repeated to date, though not yet "tested" with another period of intense rainfall), 57ML of water reported to the Area 2 pump stations. The water was identified as Scarborough Sandstone pore water from its geochemistry – as discussed below.

However, the mining in Longwall 3 has influenced many of the piezometers installed within the Scarborough Sandstone – by way of example, within DDH38 which is positioned over Longwall 5A, within DDH39 which is positioned over the northern end of Longwall 3, and to a lesser extent piezometers within such as DDH74 at Monitoring Site 7). The piezometers within the Scarborough Sandstone unit in DDH38 and DDH39 depressurised several metres head of piezometric pressure in response to the early stages of Longwall 3. This response occurred when the longwall face was at distances of up to 1.25km from the piezometers (24 April 2007). Another depressurising response occurred in August, which was when the longwall face was about 425m from DDH39. This second response led to the Scarborough Sandstone piezometers becoming de-saturated. De-pressurisation of the Scarborough Sandstone is consistent with the proposed hydrogeologic model. Similar to the second response, piezometers installed in the Scarborough Sandstone at Monitoring Site 2 (Area 1) responded at distances of 350m to the approach of the longwall face.

Piezometric responses by piezometers installed within the Wongawilli Seam have been observed in the records, as would be expected as a result of the mining. Much less response by piezometers within other stratigraphic units across Area 2 has been observed.

4.5 Hydraulic Connectivity

Geochemical monitoring of the minewater reporting to Longwalls 1 & 2 (Area 1) and Longwall 3 (Area 2) has demonstrated, through the fingerprinting of analytes, that stored water from Cordeaux Reservoir has not reported to the workings. The assessment of the geochemistry of the minewater identified it as comparable to Bulli Seam and Wongawilli Seam porewater. The geochemical fingerprinting of minewater in Area 1 demonstrated that there was no hydraulic connection to the overlying Scarborough Sandstone. The only variation in minewater quality is through interaction with stored water within the abandoned Mt Kembla workings – that mine water is more saline, but importantly is older than the early 1950's (through Tritium count). A decrease in salinity of the Area 1 minewater, which would result from dilution through the introduction of groundwater from the overlying strata (eg Scarborough Sandstone), has not been observed. Within Area 2, the minewater is again of similar quality as the Bulli and Wongawilli Seams, again indicating that the introduction of stratigraphically higher and overlying sources of water into the minewater has not occurred. An exception occurred during the extraction of Longwall 3 in June 2007, when a discrete inflow event occurred which had water chemistry indicative of a Scarborough Sandstone source.

It is reasonable to expect that it will take many years, if not decades, for the steady state conditions used for analysis of groundwater movement to become established, though connection stratigraphically upwards could occur quite rapidly. It could be argued that the absence of geochemical fingerprints consistent with stored water could be seen as inconclusive of the longer-term performance. This notwithstanding, importantly the geochemistry demonstrated that short-circuiting of the system – say, through undetected geologic structures – had not occurred. This is a crucial outcome of the geochemical monitoring as it demonstrates that the tenets of the hydrogeologic model have been verified, particularly in regard to the absence of through-going geological structures which would adversely impact the volume of seepage of stored water from the reservoir.

During the extraction of Longwall 3 in Area 2, the fingerprinting served to positively identify that the increased flow of water into the workings of Longwall 3 (Area 2) during this discrete event in June 2007 was water derived from Scarborough Sandstone, and not from any other source (such as directly from Cordeaux Reservoir). Minewater flows following the inflow returned to pre-inflow values, as did the geochemistry of the minewater.

As part of the appraisal associated with the discrete inflow event, the surface terrain above the footprint of Longwall 3 was mapped for evidence of surface cracking by BHP Billiton. Surface cracking was reported to the Dams Safety Committee – see Figure 4.1. Not withstanding the surface cracking observed, the quality of the minewater was consistent with porewater from the Scarborough Sandstone and was not consistent with surface inflow. It is concluded that the surface cracking, whilst being readily apparent, did not provide a means for a connection between surface water and underground. The depth of the cracks, whilst impractical to sound, is concluded to be finite in depth and clearly did not provide direct connection to the mine workings. This is consistent with the interpretations from the studies discussed above.

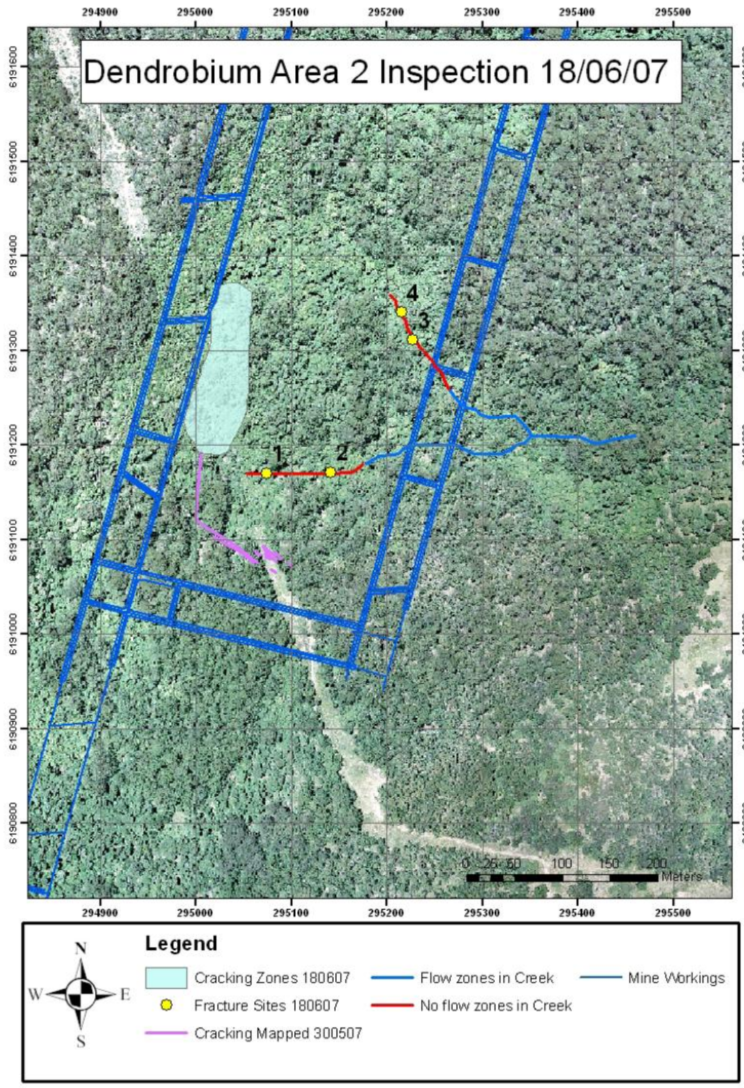

Figure 4.1: Mapped surface cracking over the southern end of Longwall 3, Area 2 (BHP Billiton)

Near surface effects, such as upsidence at Wongawilli Creek (between Areas 3A & 3B) and ephemeral creeks throughout the area, are of minor impact to the broader rockmass hydrogeology covered herein. The upsidence issue is discussed *inter alia* by Ecoengineers (2007). Upsidence effects at the Sandy Creek arm of Cordeaux Reservoir are assumed, on the basis of the off-sets of the longwalls in Area 3A (as discussed in MSEC, 2007), to have minimal effect upon the broader rockmass. In addition, importantly natural creek forming processes will have produced similar effects within the creek over a geological timeframe. Additional upsidence as a consequence of mining is considered minor given the assumption in the modelling that a zone of permeable rockmass naturally exists currently about the base of the Sandy Creek arm of Cordeaux Reservoir.

The issue of shallow upland aquifers within the Hawkesbury Sandstone is discussed in detail within Ecoengineers (2007). In terms of the assessment conducted herein, the near surface rockmass has not been incorporated or specifically considered, as a result of consideration of the following:

(i) that packer testing has not been conducted in the immediate near-surface zone (on a practical basis), and hence data is not available;

(ii) that the surface weathering products (topsoil, residual clays, colluvium and shallow weathered bedrock, noting that the soils are poorly developed) have not been considered within the stratigraphy as an identified unit; and

(iii) that such a unit would be thin in a relative sense and hence be of minimal contribution to the modelling of the rockmass as a whole, particularly for the case of near-surface layers with high permeability/transmissivity (even with high storativity).

Dilatancy of the rockmass, particularly in the uppermost 20 to 30m of the Bulgo Sandstone either side of the Sandy Creek arm of Cordeaux Reservoir, is conceivable as a consequence of shearing during creation of the mine goafs. The mechanism involves slope displacements with the potential for release into the steep slopes at Sandy Creek at Cordeaux Reservoir. The rock mechanics consequence of this is the potential for the development of “horizontal” shears within the rockmass, with the hydrogeologic consequence being an increase of permeability in the horizontal direction. Analyses were conducted to address this possibility within Appendix B. Therein, an allowance for a 5-fold increase in horizontal permeability was incorporated within the analyses, applied conservatively in the uppermost 30m of the Bulgo Sandstone (since it connects with the stored water within the Sandy Creek arm of the Cordeaux Reservoir. The likelihood of this occurrence, however, is assessed as being in the realm of “barely credible” (Ref: Appendix C of AGS 2007c) as the more feasible zone for shearing is within the base of the overlying Bald Hill Claystone. Consequently, the effect of dilatancy of the upper portion of the Bulgo Sandstone is not considered to impact upon hydrogeologic considerations. In the event of shearing within the Bald Hill Claystone, the more plastic nature of this rock unit mitigates the development of dilatant conditions and an increase in horizontal permeability is counter intuitive. The development of a zone of conjugate shear surfaces would further reduce the potential for hydraulic connectivity.

The presence of discrete rockmass fracturing (for example over the rib zone) is not specifically accommodated other than through selection of the adjusted permeability values. Modelling of discrete fractures is impractical. As discussed above for the observed cracking over the southern end of Longwall 3, there is in any event there is no factual evidence that such cracking connects with other than strata at depths of less than 30m, which is relatively shallow in the overall stratigraphic sequence.

5. HYDROGEOLOGIC INTERPRETATION FOR MINING IN DENDROBIUM AREA 3

From the data available as a consequence of the exploration program conducted by BHP Billiton, and in recognition of the preceding discussion on the hydrogeologic influences at play as a result of longwall mining within the Wongawilli Seam in Area 3, a series of interpretive figures have been developed to explain the inferred hydrogeologic conditions (within Area 3A) and the expected hydrogeologic responses to underground mining in Longwall 6.

The figures are:

Figure HG305	Inferred Stratigraphic Piezometric Surfaces
Figure HG306	Anticipated Influences upon Hydrogeology by Underground Mining
Figure HG307	Consequences upon Groundwater regime
Figure HG308	Consequences of Mine Subsidence upon Hydrogeology
Figure HG309	Piezometric Profiles – existing and post mining

5.1 Influences upon hydrogeologic conditions as a result of future mining in Area 3A

The potential influences upon the hydrogeology of Area 3 as a result of mining are identified in Figure HG306. The identification of the various zones above the longwall mining interval that are shown in the figure have been developed using the philosophy discussed above.

The Caved Zone has been shown as about 10 times the height of the mining interval (10t) and the height of the Fractured Zone as 0.4 times the width of the longwall panel (0.4W). The surface zone has been assigned a depth of 30 metres, on the basis of the published information and the experience at Jutts Crossing and Marhneys Hole near Appin, though it is accepted that it could well be significantly less as current evidence suggests a value closer to 20m.

The outcome of adoption of these dimensions is a Constrained Zone with a thickness of about 200m over Area 3A.

5.2 Consequences of Mining upon Hydrogeology of Area 3A

The anticipated impact of subsidence due to mining in Area 3A upon the rockmass over and adjacent to the longwalls is provided in type-section on Figure HG307. The principal effects are:

» The development of a drained portion of the rockmass in the Caved Zone and significantly de-pressurised in the Fractured Zone.

» The prediction of little change of vertical permeability to the rockmass in the Constrained Zone, though an expectation for increased horizontal permeability.

» The prediction of little, if any, effects upon the Surface Zone, with the exception of a potential short term effect upon the geological confining strata over the rib line of Longwall 6.

» Changes in horizontal permeability of the rockmass in the Constrained Zone over the longwall goaf, and an increase in vertical permeability in the Constrained Zone in the Rib Zone at the end of the longwall panel.

To assist in appreciating the consequence of mining upon the rockmass, Figure HG309 provides diagrammatic profiles of the existing piezometric pressure distribution at two locations through the rockmass – one situated over the main body of Longwall 6 and the other through the rockmass that is situated between the footprint of Area 3A and the Sandy Creek arm of Cordeaux Reservoir. Figure HG309 also provides diagrams showing the inferred modifications to these two profiles as a result of underground mining in Area 3.

In developing an understanding these profiles, reference should be made to the series of figures from Figure HG310 to Figure HG313:

An example developed on the form of conditions within Area 3A is presented on Figure HG310. Therein, a series of standpipes and vibrating wire piezometer tips are shown. The standpipes are shown with a limited intake length at their base. A vibrating wire piezometer could be installed in preference to the open standpipe, with the tip located at the same position within the rockmass as the intake location of the standpipe. In reality, multi-level downhole instrumentation is used, wherein a number of instruments are grouted into place at targeted levels down the exploration borehole, as seen towards the centre of the figure. This installation of instrumentation is conducted after the hole has been advanced by coring, packer testing could well have been conducted, and geophysical logging of the hole has been conducted. The triangular distribution on the right hand side is a diagram of hydrostatic conditions, meaning that throughout the rockmass the water pressure records the same total head, which in this example, is represented by the groundwater table.

The hydrogeologic sequence is a series of aquitards and aquifers. The uppermost aquifer is termed “unconfined” as the upper water surface is at atmospheric pressure. The other aquifers are “confined” since the water pressure head they indicate is above the top of the stratigraphic unit.

The concept of hydrostatic conditions within the rockmass is explained in Figure HG311. The assumption remains that hydrostatic conditions exist throughout the rockmass, and hence the water pressure throughout the rockmass records the groundwater table. The triangular distribution on the right hand side has been complemented with the introduction of a series of horizontal lines. Each of these horizontal lines is equivalent to the vertical lines recording pressure head at each of the standpipe bases and the vibrating wire tips. The important feature is that the horizontal pressure lines align with the outer edge of the triangle, and do produce a “hydrostatic distribution” as a result.

The left hand side of Figure HG311 includes an explanation the terms “position head” and “piezometric head”, which sum to produce “total head”. The total head is constant across the piezometers (vibrating wire piezometers tips and standpipes), notwithstanding that the position head changes from instrument location to instrument location.

Figure HG312 presents a situation where non-hydrostatic conditions exist. Here it can be seen now that the water level observed in the standpipes, and the water pressure measured by the vibrating wire piezometer tips, is no longer uniform throughout the sequence of aquifers in the rockmass. Now, the total head reduces in this example as the instruments are placed deeper in the rockmass. This is termed “non-hydrostatic”. The non-hydrostatic conditions can also be observed in the diagram on the right, where now the horizontal pressure lines do not line up with the hydrostatic triangular profile.

Figure HG313 provides an example where non-hydrostatic conditions still apply, but also that one of the aquifers at depth has become unconfined. The aquifer which contains Piezometer P2 now records a piezometric head that produces a total head that is less that the level of the aquitard above it, and hence is termed “unconfined” notwithstanding its depth within the stratigraphic profile. Note that Piezometer P1 records the same piezometric head, but because the total head is above the level of the confinement of the aquifer, it remains “confined”.

Having said that, by reference to Figure HG309, the current non-hydrostatic piezometric pressure distribution can be recognised in the upper two diagrams, wherein several separate pressure distributions down through the rockmass can be recognised at both profile locations. In particular, the two upper profiles show that the piezometric head for the Bulgo Sandstone is lower than for the Scarborough Sandstone, and in turn the coal seams are lower again. Interestingly, the monitoring data shows that the Wongawilli Seam piezometric pressures are higher than the Bulli Seam, which is indicative of greater de-pressurisation of the Bulli Seam.

The lower two diagrams on Figure HG309 depict the anticipated hydrogeologic response to mining at each of the two profile locations P1 & P2.

The principal effect is for drainage of the Caved Zone and the Fractured Zone in Profile P1 over the longwall panel. A consequent effect is de-pressurisation of the Scarborough Sandstone and additional de-pressurisation of the Bulli Seam and Wongawilli Seam intervals in the rockmass at profile location P2 (ie the rockmass between the mining footprint and the Sandy Creek arm of Cordeaux Reservoir). The de-pressurisation is a result of drainage into the goaf of Longwall 6 and the Area 2 goaf.

5.3 Consequences upon Groundwater Regime

The predicted consequences upon the groundwater regime in the type-section for Area 3A are presented in Figure HG308. The consequences include:

» De-pressurisation of the combined Bulli and Wongawilli Seam interval, with a consequent, conventional drainage of groundwater into the longwall goaf. This will occur across the type-section, including not only the footprint of Area 3A, but also with interaction with the existing effects due to Area 2, and will extend beyond the footprint of Area 3A.

» De-pressurisation of the Scarborough Sandstone between the footprints of Area 3A and Area 2, being additional de-pressurisation over that presently recorded in the Scarborough Sandstone. The confined aquifer within the Scarborough Sandstone may well become unconfined for a large extent of this unit of the rockmass beneath the Sandy Creek arm of Cordeaux Reservoir and to the east towards Area 2. Depressurisation of the Scarborough Sandstone into Area 3B & 3C is expected by analogy.

» The integrity of the Bald Hill Claystone and the Stanwell Park Claystone is expected to be principally maintained as a result of their ductility and their inclusion within the Constrained Zone, or in the case of the Stanwell Park Claystone, its position in proximity to the Constrained Zone. It follows that the expected impact upon the groundwater regime of the Bulgo Sandstone over Longwall 6 is a reduction of piezometric pressure, but that confined groundwater conditions will be maintained in this unit.

» Little or no effect upon the Hawkesbury Sandstone is expected, principally as a result of the presence of the Constrained Zone that will protect the integrity of the Bald Hill Claystone aquitard.

» Displacement of the western slopes to the Sandy Creek arm of Cordeaux Reservoir is expected as a consequence of the alteration of the stresses within the rockmass over Longwall 6. Localised cracking, some adjustment of local seepage areas (should they exist) and outward displacement is expected.

» Some upsidence and minor valley closure that might occur in the floor of the Sandy Creek arm of Cordeaux Reservoir (see MSEC 311, 2007) will superimpose upon the naturally present valley closure and bottom heave that has previously occurred (over a lengthy timeframe). Additional consequences of a hydrogeologic nature are not expected.

Apart from the issues directly identified above with the Sandy Creek arm of Cordeaux Reservoir, similar consequences upon the hydrogeology throughout Area 3 are expected.

5.4 Predicted mine subsidence impacts upon hydrogeology of rockmass through analytical modelling of type-section for Area 3A

An analytical hydrogeologic analysis has been conducted upon the model presented as the type-section in Drawing 303 and Figure HG305. The analysis has been conducted using the code Seep\W. The technique is discussed in Appendix B, and the appendix includes: the details of the analysis; the method of correlation with existing conditions; the development of representative permeability values that satisfy the hydrogeology; and the outcomes from the results. The modelling is based upon steady state conditions in a two-dimensional model.

The philosophy of the approach of the modelling that supports the assessment has been:

» Development of a model of the hydrogeology of the rockmass within the type-section for Area 3A, that is calibrated with the piezometric data available from the vibrating wire piezometer strings installed within exploration holes drilled throughout Area 2 and Area 3.

» Impose upon the model the groundwater drainage environment produced through the mining of Longwalls 3 to 5 in Area 2.

» Then also impose the groundwater drainage constraints produced through the mining of Longwall 6 in Area 3 upon the model of the type-section.

The method of analysis required an initial estimate of boundary head conditions and strata permeability. These were adjusted iteratively to close onto predictions for the piezometric surfaces inferred from an assessment of the field readings. Once a satisfactory combination of boundary controls and permeability parameters were established for the pre-mining situation, these parameters were adopted for on-going analysis due to the mining, firstly of Area 2 and then within Area 3.

The discussion above on the consequences of subsidence upon the rockmass, was in conjunction with the adopted parameters, to produce modified parameters in the zones throughout the model that are sequentially influenced by the mining activities in both Area 2 and Area 3 within the type-section. The analytical model was tested whenever and wherever practical for internal consistency, and for overall predictive sense. The adopted modifications to the various rock units, reflecting the influence of mining upon them and their positions within the caved, fractured, constrained and surface zones, as well as the zones within the rib zone, are shown in Figure HG314. The changes to the permeability values reflect the philosophy presented in Figure HG306 to HG308.

Whilst the details of the analyses are providing in Appendix B, the results are provided diagrammatically on Figures HG315 to HG319.

Mining in Area 2

Figure HG315 provides an understanding of the consequence of mining in Area 2 upon the rockmass. It is assumed that, although application is being made by BHP Billiton for mining in Longwall 5A as a back-up mining location, such mining does not occur within the model. The presence of ventilation Shaft 3 is included in the model, permitting drainage from the Wongawilli Seam at that location. The points of interest include:

» The rockmass in the goaf above Longwalls 3, 4 and 5 becomes unsaturated as a result of the caving and fracturing of the rockmass.

» The model has assumed that the integrity of the Stanwell Park Claystone as an aquitard is maintained above the goaf of Area 2, and hence there is an upper limit to the unsaturated extent of the goaf. Nevertheless, the modification to the drainage of the Scarborough Sandstone above the Area 2 goaf, promotes the development of an unsaturated rockmass within the Bulgo Sandstone between the Sandy Creek arm of Cordeaux Reservoir and Area 2 above the Stanwell Park Claystone.

» The piezometric surface for the Scarborough Sandstone is drawn down over a distance equivalent to about 1.5km, with modification discernable out to the rockmass over the future Longwall 6.

» However, downward drainage within the Bulgo Sandstone leads to a lowering of the piezometric surface within the Scarborough Sandstone, and it just becomes unconfined in the rib zone above Longwall 5. The upstream control remains the stored water within the Sandy Creek arm of Cordeaux Reservoir.

» Despite the rockmass becoming unsaturated within the Scarborough Sandstone over the Area 2 goaf, the Bald Hill Claystone and Hawkesbury Sandstone do not become unsaturated. There is a reduction of pore pressures though as a result of a component of downward hydraulic gradient.

» Drainage into the goaf of Longwall 5 occurs from the Scarborough Sandstone and the Bulli Seam.

Note that the ventilation shafts will be fully lined from the ground surface to the Wongawilli Seam, and as such the effect of the ventilation shafts is confined to interception and abstraction of groundwater within the Wongawilli Seam. Further, the headings that connect the ventilation shafts to the workings will act in concert to produce producing a combined effect of groundwater drainage over a local area within the rockmass.

Mining in Area 3

The consequences of mining in Area 3 in addition to mining in Area 2 are provided in Figure HG316. In this figure, the four north-south headings between Area 2 and Area 3 (that will service Area 3) are included in the analytical model. The points of interest include:

- The development of an unsaturated rockmass in the goaf over Longwall 6 in a similar manner to the development earlier over Area 2.
- The direction of groundwater drainage within the Constrained Zone (Bulgo Sandstone mainly) above the footprint of the Longwall 6 goaf will predominantly be vertical between rainfall infiltration and the Fractured Zone of the longwall goaf.
- The piezometric surfaces of the Wongawilli Seam and Bulli Seam are equivalent to the floor of the Wongawilli Seam, not only in the mining footprint but in the seams where they are located between them.
- The Scarborough Sandstone piezometric surface drains into both goafs, though remains a confined aquifer between them.
- The Bulgo Sandstone piezometric surface has reduced, but has just remained confined. The surface is positioned just within the base of the overlying Bald Hill Claystone.
- Again, the Hawkesbury Sandstone has not become unsaturated over the mining of Longwall 6.

5.5 Groundwater flow estimates

The flow regime for the conditions existing prior to mining, and the cases following the mining in Area 2 and additionally in Area 3, are presented diagrammatically in Figures HG317, HG318 and HG319 respectively. Flows were determined in the analytical model using flux sections at locations throughout the models. The estimated flows are represented on the figures as blue arrows, which are oriented to indicate the flow direction and annotated with proportional flow values.

Note that the flow values shown here are in all case proportional to the inflow of groundwater into Longwall 6 following the completion of it being mined and the establishment of steady-state conditions (ie the flow values have been made proportional to this reference seepage throughout each model, and do not represent seepage values *per se*). Also note that the values reported upon Figures HG317 to HG319 are based upon the analysis for Cordeaux Reservoir at full supply level.

For the inferred existing conditions prior to mining, the type-section demonstrates that drainage of groundwater is generally towards the Sandy Creek arm of the reservoir from both directions. The main source of groundwater inflow is through the Bulgo Sandstone. Remember that the analysis is concerned with groundwater, and does not address rainfall run-off, the volumes of which far exceed the groundwater flow throughout the analytical model.

The results following mining of Area 2 are presented on Figure HG318. Here the points of interest include:

- The inflow to the reservoir from the Bulgo Sandstone in this case is reduced to 15% of the inferred existing conditions prior to mining. Note that this refers to the section of the Sandy Creek arm of Cordeaux Reservoir to which this model applies – see below.
- At the head control location beneath the Sandy Creek arm of Cordeaux Reservoir, the outflow from the model at the Bulli Seam and Wongawilli Seam has reduced significantly and inflow is occurring at Wongawilli Seam level (whereas outflow occurred for the pre-mining situation). This means that the influence of the head control beneath the Sandy Creek arm of the Cordeaux Reservoir has changed its nature as a constraint.
- Contributions to the inflow into the goaf of Longwall 5 are occurring throughout the rockmass on the eastern side of the reservoir, with flow in the Bulgo Sandstone, Scarborough Sandstone, Bulli Seam and Wongawilli Seam all travelling in an easterly direction. Whilst there is a link to the groundwater inflow to the reservoir, drainage into the goaf of Longwall 5 is not directly related. The modelling suggests that a reliable measure of the inflow into or out of the stored water in Cordeaux Reservoir cannot be obtained by reference specifically to the groundwater flow reporting to the longwall goaf.
- The flow in the left hand (western) side of the model is similar to the pre-mining situation.

The results for mining in both Area 3A and Area 2 upon the type-section are provided on Figure HG319. The points of importance include:

- Inflow now occurs at the Sandy Creek arm of Cordeaux Reservoir, with the inflow being equal to the previous flow into the reservoir.
- Much of the diversion of inflow to Cordeaux Reservoir occurs in the rib zone of the Longwall 6 goaf, with downward drainage observed there.
- The flows leaving the model on the right hand side have reduced significantly. The flow reporting into Longwall 5 is about a quarter of the value when mining was restricted to Area 2 alone. In a comparable vein, the flow reporting to the ventilation shafts is about a tenth of the previous value.
- The flow on the Area 2 side of the Sandy Creek arm of Cordeaux Reservoir within the Bulgo Sandstone has increased by about 50% towards the Area 2 goaf, but the flow in the underlying Scarborough Sandstone has reversed direction (ie is now towards the Area 3 goaf).
- The flow from Longwall 6 is about 5 times the inflow from the Sandy Creek arm of Cordeaux Reservoir, and therefore also 5 times the flow previously reporting to Cordeaux Reservoir prior to mining. This is attributed to rainfall flowing directly into the goaf, and the interception of rainfall through the rib zone of the goaf, together with re-direction of flow towards Area 2.

Note that the variation of inflow through the Hawkesbury Sandstone due to rainfall is a result of variation in suction pressures promoted by the presence of the mining goafs beneath them.

Table 5.1: 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

Table 5.2: Estimate of groundwater seepage at Sandy Creek arm of Cordeaux Reservoir

Source of groundwater inflow at Sandy Creek arm of Cordeaux Reservoir	Estimate of groundwater movement	
	(L/day/metre run)	(ML/day over 250m width)
Bulgo Sandstone seepage into reservoir prior to mining (reservoir storage at average RL299.3 and at FSL at RL303.7)	83 77	0.02 0.02
Bulgo Sandstone seepage into reservoir after mining of Area 2 (reservoir at FSL)	12	< 0.01
Bulgo Sandstone seepage from reservoir after mining of Area 2 & 3 (reservoir at FSL)	-76	-0.02

Table 5.3: Estimate of seepage reporting to Longwall 6 throughout Area 3A

Groundwater inflow into Longwall 6 (two-dimensional modelling)		Crude estimate of 3-D groundwater inflow into Longwall 6
(L/day/metre run)	(ML/day over 250m width)	(ML/day)
383	0.1	0.8

Table 5.4: Estimate of change in seepage from inflow to outflow at the Sandy Creek arm of Cordeaux Reservoir

Inflow into Cordeaux Reservoir pre-mining (2-D model)	Outflow from Cordeaux Reservoir after mining Area 2 & Area 3 (2-D model)	Nett differential for Sandy Creek arm of Cordeaux Reservoir 250 metre longwall width		Crude extrapolation for Longwall 6 of overall differential impact upon Cordeaux Reservoir (3-D inflow)
(L/day/metre run)	(L/day/metre run)	(L/day/metre run)	(ML/day)	(ML/day)
77	-76	153	0.04	0.16

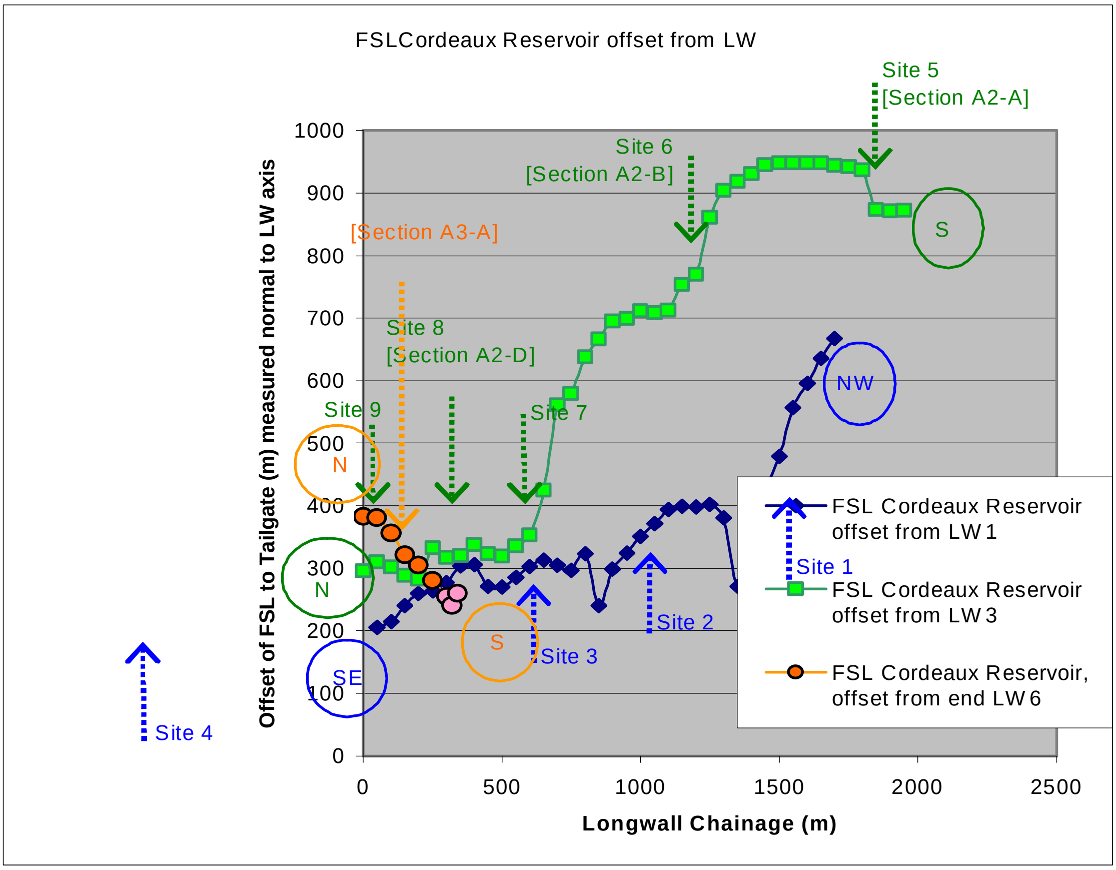

Figure 5.1 Distribution of Horizontal Distances to footprint of Cordeaux Reservoir FSL from Longwall Panels

Note that the three pink shaded dots for Area 3 are from Longwall 7, and are at the southern limit of the Sandy Creek arm of Cordeaux Reservoir.

The results for the type-section are expected to be representative of Area 3A.

The flow estimates from the modelling are presented in Appendix B and are selectively reported in Tables 5.1 to 5.4.

The contributory groundwater inflow sources into the Longwall 6 goaf are identified in Table 5.1, 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.

Table 5.2 presents estimates of the seepage inflow and outflow at the Sandy Creek arm of Cordeaux Reservoir. The estimates of steady-state groundwater seepage flows for the two-dimensional model are very small. Before mining of Areas 2 & 3, inflow to the reservoir is of the order of 0.02ML/day across the 250m width of Longwall 6, and is reversed to 0.02ML/day outflow from the reservoir after mining of Area 3.

Table 5.3 provides an estimate of total groundwater seepage into Longwall 6 through a crude extrapolation from the two-dimensional analysis to a three-dimensional situation. The extrapolation is based on simple flow-net construction for steady-state seepage from the shoreline of Cordeaux Reservoir between its Sandy Creek arm and Cordeaux Dam itself, doubled to accommodate the lesser known southern half of the model. [Three-dimensional analytical modelling will be no more precise than this until the geological and hydrogeologic model is understood across and outside Areas 3B and 3C]. The two-dimensional estimate of groundwater seepage into Longwall 6, which is applicable for the width of the Sandy Creek arm of Cordeaux Reservoir, is 0.1ML/day. The extrapolated crude three-dimensional estimate of steady-state groundwater seepage into the goaf of Longwall 6 is 0.8ML/day. Whilst the extrapolated estimate is undoubtedly crude as a consequence of its method, the estimate is based on flow through the rockmass that contains the footprint of Area 3C. This means that the estimate of overall seepage flow to Area 3A will be reduced significantly as a result of interception of groundwater in Area 3C, when mining occurs within it. A similar significant effect upon groundwater seepage reporting to Area 3A will occur as a result of the mining of Area 3B.

Table 5.4 provides an estimate of the change in groundwater seepage at the Sandy Creek arm of Cordeaux Reservoir - 0.04ML/day. Table 5.4 also provides an estimate, via the same crude extrapolation, of nett differential seepage change at the Sandy Creek arm of Cordeaux Reservoir as a result of the mining of Longwall 6.

Note that the estimated values are small, and in general terms reflect the relatively low permeability values for the rockmass. As discussed below, a very small proportion of the rainfall infiltrates deeply into the rockmass.

5.6 Comparison of drainage paths

The distance of the offset from the Sandy Creek arm of Cordeaux Reservoir at the eastern (finishing) end of Longwall 6 has been selected by BHP Billiton to minimise subsidence-induced effects upon the storage contained within the Sandy Creek arm of the reservoir (see MSEC311, 2007). Longwall 6 approaches to within 280 to 380m of the Full Supply Level of the stored water (and the shortest distance is 260m in the adjacent northeast corner of Longwall 7). The measured plan distances of the off-sets across the ends of these longwalls are presented in Figure OSD-4. Note through reference to Figure HG302, Figure HG 303 and Drawing G302, that the extent of the boundary with the stored water is limited to this end of Longwall 6 and to part of the end of Longwall 7.

The data presented on Figure 5.1 shows by comparison that the lengths across the finishing end of Longwall 6 are not less than the off-set 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.

The off-set distance is a measure of the interaction of the mining with the stored water – in general terms, the greater the distance, then the less the interaction. It follows that seepage reporting into the longwall panel should be no greater that similar short distances at Area 1. In fact, the three dimensional effect (as opposed to a more uniform two dimensional drainage effect at Area 1) will promote less seepage that the similar situations in Area 1 and Area 2.

A crude estimate has been made on the contribution of the greater Cordeaux Reservoir to seepage reporting into the goaf of Longwall 6. This estimate is necessarily crude when compared to the complexity of the flow regime in the two-dimensional model, and is intended only as an indication of total potential total flow volumes. It is also noted that the drainage paths taken for water to seep from the reservoir to the Area 3 goaf is up to 3 times the nominal plan distance of the off-set distance. This is a result of a significant portion of the drainage being eastward initially within the Bulgo Sandstone (ie towards Area 2) before draining from the Bulgo Sandstone down to the Scarborough Sandstone and then changing direction to drain westward.

In terms of the overall effect, it is noted that most of Area 3A has significantly longer off-set distances. This follows as a consequence of the divergence of east-west layout of the Area 3A workings from the shape in plan of Cordeaux Reservoir which trends to the northwest. Whilst the governing location is the finishing eastern end of Longwall 6 and its position relative to the Sandy Creek arm of the reservoir, an extrapolation to an estimate of the whole of Area 3 is more challenging. In truth, this becomes a true three-dimensional modelling exercise. The challenges with such a model include limits on current geologic boundaries and data on piezometric pressures away from the current exploration boreholes.

5.7 Uncontrolled Loss of Stored Water

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

5.8 Impact upon Catchment Yield

Rainfall over Area 3A becomes either run-off or enters the groundwater system. The run-off flows via overland flow to either Sandy Creek (at the eastern end of Area 3A) and hence into the Cordeaux Reservoir or flows via Wongawilli Creek (at the western end of Area 3A) into the

Cordeaux River below Cordeaux Dam. Rainwater that does not run-off enters the groundwater system. The near-surface portion of the groundwater system includes poorly developed soils and predominantly weathered sandstone bedrock. The near-surface system generally has higher storativity and transmissivity than the rockmass at depth, and is also subjected to evapo-transpiration.

The groundwater model consists of:

- Deep infiltration of rainfall into the Hawkesbury Sandstone stratigraphic unit.
- Migration of that infiltration to various parts of the groundwater system, principally horizontally, with a proportion occurring as groundwater seepage into the reservoir at it Sandy creek arm. The inflow to the storage varies with reservoir level – the inflow decreases as storage level rises. A small proportion of seepage to the reservoir occurs from the Hawkesbury Sandstone.
- A depression in the piezometric surface exists within the Bulli and Wongawilli Seams in the area beneath and to the west of the reservoir.
- The underground mining of the Wongawilli Seam in Area 2, and thence in Area 3A, modifies the rockmass drainage. The direction of seepage throughout the rockmass is modified as a result.

As a result of longwall mining, and the consequent modification to the hydrogeology of the rockmass over the longwall panel, a potential exists for loss of surface water run-off over Area 3A. To provide an assessment of this, a comparison has been made of the groundwater flow through the near surface rockmass for the pre-mining and post-mining situations, using the results of the analyses provided in Appendix B and as reported in Figures HG317, HG318 & HG319.

The assessment has involved an appraisal of the nett loss of yield from the catchment, and is based on the groundwater flow analysis reported in Appendix B. The flow of rainwater that reports into the rockmass as groundwater has been determined from the analytical output – eg see the rainfall components identified in Figures HG317 to HG319.

A point to note is that the infiltration that is inferred from these calculations is a low proportion of average rainfall. This means that a small proportion only of the rainfall reports into the main body of the rockmass - ie the majority of rainfall either becomes run-off, is stored near surface or is subject to evapo-transpiration. The low proportion of rainfall reporting into the rockmass is a consequence of the permeability values identified within the rockmass at depth. The surface effects due to near-surface soils and the weathered rockmass at shallow depth are not included in the assessment. In this regard, the shallow aquifers discussed in detail by Ecoengineers (2007) are not accommodated. The conclusions reported by Ecoengineers (ibid) are consistent with this assumption.

Rainfall over Area 3 represents a volume of about 4,000ML per annum. Under pre-mining conditions, the summation of rainfall that penetrates to a moderate depth into the Hawkesbury Sandstone rockmass of Area 3 is of the order of 100ML per annum – ie 2.5% of the rainfall – meaning that about 3,900ML per annum ultimately runs-off. Only a very small proportion of the rain that falls over Area 3A infiltrates into the rockmass, and it is reasonable to presume that similar conditions prevail over the rest of Area 3. Pre-mining, this is accompanied by groundwater seepage that outflows from the analytical model to the Sandy Creek arm of Cordeaux Reservoir at a rate of 35-40ML per annum, though perhaps more realistically 10-15ML per anum (see discussion on extrapolation towards the end of this section). The higher 40ML per annum value represents 1% of the 4,000ML of rainfall that falls on average over Area 3A.

Following the mining of Area 2, the prediction of inflow into the rockmass within Area 3A is marginally changed but essentially remains similar, as intuitively would be expected. There are some changes in flow direction in the rockmass to the east of the Sandy Creek arm of Cordeaux Reservoir, as discussed earlier and as shown in Figures HG315 and HG318.

Following the mining of both Area 2 and Area 3A, the modelling proposes that in excess of 200ML per annum of rainfall now reports into the rockmass over Area 3A. This doubles the infiltration relative to the pre-mining conditions and that following the mining of Area 2. The infiltration into the rockmass over Area 3 goaf increases from 2.5% of the average annual precipitation to 5% of the rainfall over the footprint of Area 3. The increase in infiltration is perhaps initially counter-intuitive, but it is a consequence of unsaturated conditions developing over the mining goaf leading to an increase in suctions through the rockmass. It is for a similar reason that there was a marginal increase in infiltration of the rockmass following the mining of Area 2 in the model. The consequence to groundwater movement about the Sandy Creek arm of Cordeaux Reservoir is outflow from the stored water into the Bulgo Sandstone is now promoted, rather than the inflow that was predicted prior to mining. Through linear extrapolation of the two-dimensional modelling, the seepage from the stored water into the Bulgo Sandstone stratigraphic unit is estimated as 35 to 40ML per annum (ie 0.04% of the reservoir's active storage volume of 93,640ML), though the seepage volume is likely to be closer to 10-15ML per annum (as a consequence of the extrapolation technique). As before, the higher estimate of 40ML per annum is equivalent to 1% of the 4,000ML of rainfall that falls on average over Area 3A, and Area 3A is a small proportion of the catchment area for Cordeaux Reservoir.

It is mentioned above that this assessment does not include the effects of evapo-transpiration. Since the changes inferred represent such a small quantity of the total average annual rainfall, the conclusion that the effect is negligible for this case is reasonable.

In addition, the footprint of Area 3 is 3.3km^2, though perhaps up to 4.5km^2 should the contribution from the angle of draw (see MSEC, 2007) be included. The catchment area for Cordeaux Reservoir is 91km^2 (Sydney Catchment Authority website). The footprint of Area 3 is less than 5% of the catchment area (3.7% to 4.9% respectively) which means that the change in groundwater movement in Area 3 is a small element within 5% of the catchment area for rainfall.

Finally note that the assessment will be high in terms of total volume of groundwater that reports as seepage into the Sandy Creek arm of Cordeaux Reservoir. This is a consequence of extrapolation of a two-dimensional model to represent the three-dimensional conditions around the Sandy Creek arm of the reservoir. In essence, linear extrapolation of the two-dimensional model will over-predict groundwater seepage into the reservoir storage because of the limited extent of the embayment in the reservoir. This does not detract from the application of the analytical model to this critical area, but does provide a caveat on linear extrapolation to estimate the three-dimensional situation.

5.9 Hydrogeologic Rockmass Monitoring

It is a necessary part of confirmation of the predictions for verification to be conducted during mining of Area 3, and particularly during the mining of Longwalls 6 and 7 of Area 3A.

Existing instrumented boreholes in Area 3A (see Drawing G302 and Figure HG304) in the rockmass between Area 3A and the Sandy Creek arm of Cordeaux Reservoir will be used to monitor the consequences of the mining and to verify the predictions.

Additional monitoring sites are proposed, consisting of 2 sets of twin monitoring holes with vibrating wire piezometer strings installed downhole. This will be in the same fashion as the instrumentation installed at Monitoring Sites 7, 8 & 9 in Area 2, which were based on the philosophy employed for Monitoring Sites 2 & 3 from Area 1. The monitoring Sites in Area 3A will be situated between Sandy Creek and the finishing end of Longwalls 6 & 7, situated at sites as field constraints permit. Measures to limit the risk of instrumentation shearing will be employed.

The vulnerability of instrumentation to shearing of the rockmass requires consideration within this assessment, as does the practicality of establishing drill sites within the Metropolitan Water Catchment Area with limited surface access.

The monitoring programme will be in accordance with the BHP Billiton Monitoring Management Plan (BHP Billiton, 2007a). This will involve comparison of piezometric pressure changes within downhole strings of vibrating wire piezometers with the water balance within the mine. Geochemical analysis of underground waters will also be part of the protocol.

5.10 Statistic Appraisal

The analyses to date have been conducted with permeability values established for each of the stratigraphic units. These have been developed through adjustment of permeability parameters, within an expected data range, to fit the piezometric pressure profiles, which have been based on head values established from readings recorded by the strings of vibrating wire piezometers throughout Dendrobium Areas 2 & 3.

Statistical assessment of the database of packer-derived permeability estimates is to be conducted. The task will also permit further verification of the values adopted in the analyses. With the statistical distributions, a sensitivity study (using the principles of a Monte Carlo simulation) will be conducted to develop defensible estimates of likelihood for the groundwater flows (an issue raised by the Dams Safety Committee during their approval of mining within the Notification Area for Dendrobium Area 2).

5.11 Consequences of the mining of the remainder of Area 3

Within this study, it has not been practical to assess the consequences of mining within the other sub-areas within Area 3 – viz: Area 3B in particular. The reason for this primarily is a result of limited piezometric coverage within Area 3B which otherwise limits development of an understanding of the existing piezometric surface across the Area.

The identification of geological boundary conditions, particularly on the western margin, remains to be conducted so that the geological model of the Area can be established. Exploration for development of the geological model must precede hydrogeologic analysis and assessment.

Nevertheless, the stratigraphy will be known and the depth of cover over the mining interval will be established prior to mining. Furthermore, in the same fashion as for Areas 1 & 2, as well as Area 3A, longwall extraction will not occur under the reservoirs.

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