appendix 7

Groundwater Assessment

West Wallsend Colliery

Hydrogeological Assessment for Continuing Operations Project

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Executive summary

As part of the West Wallsend Colliery Continued Operations Project, an assessment has been made of the likely impact of the future proposed coal extraction on the local groundwater regime, with regard to the Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources 2009. This assessment utilized the results of several previous hydrogeological studies to evaluate the potential for any adverse impacts on the groundwater regime. The previous work showed that, there are three potential sources of groundwater in the region:

- alluvial aquifers;
- the near-surface weathered rock aquifer; and
- fractured rock aquifers (including coal seam aquifers).

Potentially, the most important of these sources is found in the alluvial sediments, which fill the broad valleys of the creeks that flow into Lake Macquarie. The West Wallsend Colliery mining lease (CCL 718, CCL725 and ML 1451) covers the catchment area of two of these creek systems. These are the Cockle Creek catchment (and its tributaries including Burkes Creek and Diega Creek) and the catchment of Palmers Creek (including Ryhope Creek and Central Creek).

Previous investigations have been carried out in Cockle Creek to determine the nature and importance of the alluvial aquifer in the area underlain by the mine in LW 27, 28 and 31. These investigations showed that the alluvial deposits in this area contain a series of water-bearing zones of sand, silty sand and clayey sand, with only minor gravelly bands, interbedded with less permeable clay and sandy clay layers. The results indicated that the alluvial groundwater resource in this area is of minor significance, due to its variable quality, and limited volume.

In the Palmers Creek catchment, a previous investigation was carried out in Ryhope Creek to examine the nature and extent of the alluvium. The results confirmed that the alluvium in Ryhope Creek is relatively thin but is similar to that intersected in Cockle Creek. No single major aquifer was identified in the deposits, and hence, the alluvial groundwater resource in Ryhope Creek was considered to be of minor significance, due to its variable quality, and limited volume.

The previous investigation also examined the alluvium in Palmers Creek itself, even though this area will not be undermined as part of this project. The investigations found water bearing sand and gravel zones, which are probably fed from the main aquifer zone that is known to exist in the alluvium to the south of the Palmers Creek channel in this area. This groundwater is exploited in several bores further downstream, and it is considered to be an important resource.

In summary, the continuous underground mining area includes minor areas of alluvium in the upper catchments of stream valleys, but does not contain significant aquifers. Given the small volume of alluvial sediments affected, and the absence of aquifer-quality strata, the volumes of groundwater are highly likely to be very low.

The weathered rock aquifer is generally widespread across the lease area, and includes all the near-surface permeable weathered rock. While the groundwater quality can be very good in this aquifer, its occurrence and distribution are very patchy. Fractured rock aquifers occur at depth in the coal measure strata. These include jointed coal seams and localised jointed or fractured zones, often adjacent to major faults. Flows are mostly relatively small in these zones, and water quality is generally poor and suitable only for stock use. In the continued underground mining area, there is no evidence of any significant occurrence of either the weathered rock aquifer or any fractured rock aquifers. For this reason, and since there is no exploitation of the groundwater from either of these sources within this area, the risk to these aquifers was determined to be negligible and no further evaluation was made as part of the current study.

Based on the available knowledge of the local hydrogeological regime gained from the previous investigations, the major potential hydrogeological risk associated with the future proposed mining in the lease area was determined to be:

> *Ground surface movements and/or the fracturing of the overburden strata associated with the extraction of the West Borehole Seam has the potential to drain any aquifers in the alluvial deposits, and impact on the amenity of any current or future users of these groundwater sources.*

The potential impact of future mining on the aquifers in the alluvial deposits depends on two factors;

- the depth of cover between the mine and the base of the alluvium; and
- the height of interconnected fracturing above the mine opening.

In order to determine the impact of the proposed future mining on the near surface aquifers, the height of the fractured zone above the proposed mine workings (defined as the height of interconnected fracturing that could transmit water from the strata to the mine opening) was established based on several years of previous experience, incorporating a qualitative evaluation of local geological and mining conditions. This was then compared with the depth of cover over the two sections of the continued underground mining area to determine the probability of an adverse impact on the aquifers.

Based on this evaluation, the depth of cover in the continued underground mining area was divided into sub-areas representing Very High, High, Medium or Low probability of impact on any water resources in the surface alluvial aquifers. In order to determine overall impact of the proposed future mining on the aquifers, it was necessary to identify the zones where the alluvium overlaps areas with expected Very High, High and Medium potential for an adverse impact. This was achieved by overlaying the depth of cover contours over the map of the areal extent of the alluvium in the continued underground mining area.

This exercise revealed that there are some small alluvial areas in Ryhope Creek to the south of the continued underground mining area which would have a High and Very High probability of an adverse impact, but rearrangement of the mine plan has ensured that these areas will not be undermined. There are also several small zones within the continued underground mining area where the probability of an adverse impact on the alluvium due to mining is considered to be Medium because of the limited depth of cover to the mine workings. The vulnerable alluvial areas in the Medium probability category are located in first and second order streams in the Cockle Creek, Diega Creek and Central Creek catchments. While the probability of an adverse outcome for these areas is considered to be Medium, the magnitude of the risk depends on the consequences of the adverse outcome.

In determining the potential consequences, several aspects were identified as being significant, including the following:

- while the alluvium may contain water-bearing zones, it is highly unlikely that any significant aquifers exist in the alluvium;
- there are no known users of the alluvial groundwater; and
- the contribution of these areas to the groundwater flow in the alluvial aquifers further downstream is negligible.

It was therefore concluded that any aquifers in the continued underground mining area, will be of minor importance, so that the consequences of an adverse outcome will obviously be less than would be the case for extraction under a major aquifer.

Having identified the potential consequences and the probability categories, it was necessary to develop a risk matrix to assist in the evaluation of the hydrogeological risks in the continued underground mining area. The matrix included five risk categories, from VERY HIGH to VERY LOW. This risk matrix was used to determine the need for any mitigation or monitoring measures in the alluvial areas that will be undermined. Since the alluvial areas identified as having a Medium probability of an adverse impact contain only minor aquifers, the assessed risk falls into the LOW RISK category in the risk matrix. Despite the relatively low risk, monitoring is still recommended for some areas to confirm the conclusions of the study and check for any unexpected adverse impacts.

Previous monitoring in Cockle Creek has shown that the extraction of longwalls 27, 28 and 31 at depths of cover as low as 125 metres (Medium probability category) produced negligible impacts on the alluvial groundwater. This monitoring is still being carried out and it is recommended that it can now be discontinued. No additional monitoring is required for the very small areas of Cockle Creek alluvium that will be undermined at similar depth in the future longwall panels. The situation is similar for the Central Creek alluvium, where the area with a Medium probability of an adverse outcome is also very small.

The Diega Creek alluvium in the continued underground mining area is also in the LOW to VERY LOW risk categories, and should be similarly unaffected by the proposed extraction. Nevertheless, Diega Creek has been undermined extensively further to the east, and concerns have been raised in the past by local residents over the impact of mining on the creek. This led to the installation of three groundwater bores in the creek downstream of the continued underground mining area, and ongoing monitoring of these bores appears to indicate that there have been no adverse effects on the groundwater from previous mining. However, because of the previous mining history, two monitoring bores have been sited in the Diega Creek alluvium to confirm the conclusions of this study, and assist in allaying any concerns of local residents.

The Ryhope Creek alluvium, while not located within the continued underground mining area, and containing no major aquifer of significance, is deemed to be of interest, as it flows into Palmers Creek, which contains a major alluvial aquifer. Although the alluvium in the creek will not be undermined, it is within six hundred metres of the proposed longwall panels in both the western and southern domains on the southern side of the lease area. In addition, a local nursery utilizes groundwater from the alluvium in the creek. Because of the distance of the proposed mining from the creek, it is considered highly unlikely that there will be any impacts on the groundwater in the alluvium. However, as a precaution, three monitoring bores have been installed in the creek valley to monitor the groundwater in the alluvium.

Like Ryhope Creek, Palmers Creek will not be undermined by any future longwall panels, the nearest of which will be located more than 300 metres to the north. Nevertheless, because of the importance of the alluvial aquifer in the creek and the shallow depth of cover, an existing registered bore has been selected for ongoing monitoring.

A final review of the potential for any regional hydrogeological impacts from the proposed future mining was carried out and it was determined that there would be no regional impacts. Groundwater usage in the project area is consistent with the requirements of the Hunter Unregulated Rivers and Alluvial Water Sharing Plan 2009.

1. Introduction

West Wallsend Colliery currently extracts coal from the West Borehole Seam, in CCL 718, CCL725 and ML 1451 south of Killingworth near Newcastle, New South Wales. The mine is operated by Oceanic Coal Australia Pty Ltd (OCAL) on behalf of the Macquarie Coal Joint Venture, and current underground operations in the mine utilise longwall mining techniques. OCAL is wholly owned by Xstrata Coal (Australia) Pty Limited.

The mine lease covers an extensive area roughly bounded by George Booth Drive in the north, the Sugarloaf Range in the west and, in the east, by the Newstan Colliery boundary, which lies east of the Wakefield Road. Most of the mining to date has been carried out in the northern and eastern parts of the lease, and has included some bord and pillar workings with pillar extraction and more than 30 longwall panels. The current longwall mining operations are located in the northern domain on the western side of the Sydney-Newcastle F3 Freeway, which bisects the West Wallsend Colliery holding.

In 2004, OCAL produced a Subsidence Management Plan (SMP) for the northern and southern domains, to identify and characterise any surface and subsurface features in the lease area, and assess the likely impacts of the proposed mining on those features. As part of the SMP process, a detailed evaluation of the local hydrogeology in the two domains was carried out, and a report was prepared to summarise the findings of the investigations. Subsequently, additional mine planning activities resulted in a significant change to the mine layout in the former southern domain, and a reassessment of the likely impacts of the proposed extraction on the hydrogeology was undertaken. This study also included part of what is known as the western domain.

These studies recommended that groundwater observation bores be established in certain areas to provide background data on the groundwater conditions over a period of at least two years prior to mining, so that any impacts from future mining could be determined.

Since the life of mine plan for the colliery has now been finalised, OCAL is seeking the continuation of mining activities under one approval which will apply to all future mining operations. In accordance with requirements of the Mining Act 1992, Part 3A approval must be obtained under the EP&A Act before mining can continue in the lease area. The project to gain this approval, known as the Continued Operations Project, amongst other aspects, will require an assessment of the likely impact of all future proposed coal extraction on the local groundwater regime. To assist with this project, OCAL have engaged Aurecon to consolidate the available hydrogeological data from past investigations, make an assessment of the likely impact of the proposed mining on the groundwater regime, and confirm that the recommended groundwater monitoring program is adequate.

This report presents the results of the study.

Water usage in the project area is subject to a number of regulatory requirements, including the Hunter Unregulated Rivers and Alluvial Water Sharing Plan 2009, which comes under the Water Management Act 2000. Proposed mining operations are consistent with the requirements of the Plan.

2. Scope of investigations

The West Wallsend Continued Operations Project covers the future extraction of 13 longwall panels in the southern and western domains of the West Wallsend Colliery, on both the western and eastern sides of the F3 Freeway (Figure 1). These longwall panels cover an area of some 900 hectares, and the current assessment was essentially limited to this area (termed the 'continued underground mining area' in this report).

The scope of works for this study included the following activities:

- Provide a description of the local hydrogeological regime, based on the results of previous studies in the region;
- Confirm the extent of all alluvial areas, and produce a map showing the extent of the alluvium;
- Characterise existing groundwater usage patterns within the continued underground mining area;
- Estimate the likely height of fracturing above the future extraction panels in the continued underground mining area;
- Determine the likely impact of future proposed mining on the hydrogeological regime and groundwater utilisation in the continued underground mining area – highlight critical locations;
- Make recommendations for any additional actions to monitor and/or protect groundwater resources within the continued underground mining area;
- Utilise the result of the study to make an assessment of the potential hydrogeological impact on a regional scale; and
- Produce a report detailing the outcomes of the assessment.

The current investigation was designed by Aurecon to address these aspects. The scope of the study did not include an examination of the impact of the mining on the surface water hydrology, including the stream channels, dams and flood plains. Surface water will be assessed by others.

3. Local geology and hydrogeology

3.1 Geology

The near surface strata in the continued underground mining area belong to the Permian Age Newcastle Coal Measures. The major influencing structure in this region is the Macquarie Syncline, which trends in a NNW-SSE direction, and bisects the West Wallsend lease to the east of the continued underground mining area. In the this area, the strata dip to the east at an angle of about 2° to 4°, consistent with their location on the western limb of the Macquarie Syncline.

The Newcastle Coal Measures are thickest in the east, and thin significantly towards the west, due largely to a decrease in the quantity of sediment. The maximum total thickness of these coal measures decreases from about 420 metres in the centre of the Macquarie Syncline to a minimum of about 50 metres in the west. In the continued underground mining area the total thickness of Newcastle Coal Measure strata ranges from about 80 to 200 metres. The local stratigraphic sequence in the area is summarised in Table 1.

In the West Wallsend area, the Newcastle Coal Measures comprise four major formations (Moon Island Beach, Boolaroo, Adamstown, Lambton) separated by prominent tuff bands. The upper three formations (Moon Island Beach, Boolaroo and Adamstown) contain conglomerate and sandstone bands with interbedded shale, siltstone, tuffaceous claystone bands and high ash coal seams. The coal seam of particular relevance to this study is the West Borehole Seam, which belongs to the basal Lambton Formation, and will be extracted in the continued underground mining area. The Nobbys Tuff overlies the West Borehole Seam and forms a distinctive marker horizon over most of the Newcastle region, although in the northern part of the application area, the tuff thins to near-zero thickness.

The Adamstown Formation, which overlies the Nobbys Tuff, makes up the bulk of the overburden above the West Borehole Seam in the continued underground mining area, where it is up to 100 metres thick. This formation contains several coal seams (Australasian, Montrose, Wave Hill, Fern Valley and Victoria Tunnel) that are generally of poor quality. The lower part of the Adamstown formation over most of the application area comprises a thick, coarse-grained sedimentary sequence, in excess of 30 metres thick. The upper part of the Adamstown Formation is finer grained, and comprises interbedded sandstone, siltstone and shale. The coal seams also occur in this part of the Formation in this area. The majority of these seams converge to form two bands, 10 to 15 metres thick (containing dirty coal and carbonaceous mudstone, with interbedded tuff layers). The Warners Bay Tuff, which lies above the Adamstown Formation, is up to 7 metres thick.

The overlying Boolaroo Formation ranges from 35 to 70 metres thick, and is exposed on the flanks of the ridges. It comprises interbedded sandstone, siltstone and shale, with minor conglomerate bands and thin coal seams (mostly splits of the Pilot Seam). In the continued underground mining area, the overlying Awaba Tuff, and the uppermost formation, the Moon Island Beach Formation, both have a limited extent and crop out only on the ridge tops.

Several major dykes have been identified in the existing West Wallsend Colliery workings and in the Newstan Colliery workings to the south. These dykes are near-vertical and generally trend in a NNW-SSE direction. Since this structural trend direction is relatively consistent throughout the Newcastle Coalfield, any major dykes in the continued underground mining area would most likely be intersected in the South West 4 Headings south of longwall 30. Occasional faults cross the West Wallsend Colliery lease and also trend approximately in a NNW-SSE direction similar to the dykes. A major NNW-SSE trending structural zone crosses the centre of the lease area and separates the northern and eastern domains from the western and southern domains.

Joints in the coarse-grained sediments are generally tight and widely spaced where the rock is exposed at the surface and underground. Jointing in the fine-grained sediments is closer spaced, although when the rock is fresh, these joints are normally tight and clean. Joints have a similar strike direction to the faults (NW-SE), and most tend to be near vertical or steeply dipping to the southwest.

There are several creek valleys that cross the continued underground mining area. These valleys range up to one hundred metres wide, and are filled with recent alluvial deposits comprising mostly sand, silt and clay. These are discussed further in Section 3.2.1.

Table 1 - Stratigraphic Sequence *

GROUP	FORMATION	COAL SEAMS	THICKNESS
NEWCASTLE COAL MEASURES	MOON ISLAND BEACH	Vales Point Wallarah Great Northern	
	AWABA TUFF		
	BOOLAROO	Fassifern Upper Pilot Lower Pilot Hartley Hill	60 - 75 m
	WARNERS BAY TUFF		up to 7 m
	ADAMSTOWN	Australasian Montrose Wave Hill Fern Valley Victoria Tunnel	65 - 100 m
	NOBBYS TUFF		0 – 3 m
Base of Coal Measures	LAMBTON	Nobbys, Dudley } Young Wallsend Yard, Borehole } Borehole/Yard } West Borehole Seam	
	WARATAH SANDSTONE		

* Based on revised Newcastle Coal Measures stratigraphy ratified in June 1992 by the Standing Committee on Coalfield Geology of NSW (Hawley & Brunton, 1995).

3.2 Hydrogeology

An understanding of the local hydrogeological regime in the continued underground mining area is necessary in order to determine if there is likely to be any impact from the future mining. The hydrogeological regime in the West Wallsend lease area has been examined in several previous studies (Pacific Power International, 2002, Connell Wagner PPI, 2003 and Connell Wagner PPI, 2004, Connell Wagner, 2006). The following assessment is based on the results of those investigations, and several other studies, which have examined the permeability and hydrogeological properties of the strata in the Newcastle Coalfield.

Previous experience has shown that, there are three potential sources of groundwater that have been exploited in the Lake Macquarie area:

- alluvial aquifers;
- the near-surface weathered rock aquifer; and
- fractured rock aquifers (including coal seam aquifers).

The occurrence and properties of these aquifers are summarised in this section.

3.2.1 Alluvial aquifers

Potentially, the most important groundwater resource in the Newcastle/Lake Macquarie area is found in the alluvial sediments, which cover the low-lying areas adjacent to the lake system, and fill the broad valleys of the creeks that flow into the lake. In the Lake Macquarie area, numerous bores and wells draw water from these sediments, which usually comprise a fine-grained surface layer underlain by sand and gravel deposits. Flows from these wells mostly range from 0.1 to 9 L/s, and water quality is generally reasonable (Hitchcock, 1995).

The West Wallsend lease covers two major catchment areas. These are the Cockle Creek catchment (and its tributaries including Burkes Creek and Diega Creek) and the catchment of Palmers Creek (including Ryhope Creek and Central Creek). The Cockle Creek catchment covers an area of about 8000 hectares and drains into the northern end of Lake Macquarie. To the east of the West Wallsend lease near Lake Macquarie, Cockle Creek is a perennial stream with a broad floodplain and significant alluvial aquifer. However, within the lease area, the upper reaches of Cockle Creek comprise a series of ephemeral channels, which only flow after consistent rainfall. Although stream flows in the lease area are intermittent, the creek beds are contained in broad, flat valleys, which are filled with alluvial deposits.

The Cockle Creek catchment is flanked to the south by the Palmers Creek catchment, which underlies a small portion of the lease area to the south. The valley of Palmers Creek comprises a broad alluvial terrace which contains one major aquifer. The groundwater in this aquifer is exploited in several bores and is utilised for stock and domestic purposes. This aquifer is outside the continued underground mining area, and the mine plan has been altered so that there is a barrier of several hundred metres between the workings and the aquifer.

Alluvial sediments within the continued underground mining area are extremely limited in extent, although more extensive areas lie in lower catchment areas to the east and south of the project area (Figure 2).

During previous investigations at West Wallsend, a program of auger drilling was undertaken to determine the nature of the alluvial deposits in Cockle Creek, and check for any alluvial aquifers. More recently, a second augering program was also carried out in the alluvium in Palmers Creek and Ryhope Creek. Since both of these investigations are relevant to the current study, the results will be used in the following assessment of the hydrogeological conditions in the continued underground mining area.

The investigation program in Cockle Creek included the drilling of seven auger holes, which were drilled to the base of the alluvium above Longwalls 27 and 28 (Figure 8). The auger drilling indicated that the alluvium is up to 15 metres thick in the valley of Cockle Creek in the centre of the lease area, and comprises mostly clayey sand and sandy clay with occasional clean sand and gravelly bands. No single major aquifer was identified in the deposits, however the alluvium contains a series of water-bearing sand horizons, interbedded with less permeable clay lenses. Groundwater inflows to the boreholes generally occurred during drilling when one of these sand horizons was intersected. Because of the variable composition and excessive fines content in the alluvium, its overall permeability is not likely to be high, and yields from any water bores would generally be expected to be low.

Sampling and testing of the groundwater in the bores indicated that generally it did not meet the standard for good quality drinking water for human consumption (TDS <500 mg/L). Most of the groundwater in the alluvium fell into the slightly brackish category, although subsequent monitoring of the boreholes indicated significant variations in water quality, with much lower TDS contents after major rainfall events.

The investigations concluded that the alluvium in Cockle Creek in the lease area does not contain a significant aquifer, and that the alluvial groundwater resource in this area is of minor significance, due to its variable quality, and limited volume.

In the Palmers Creek catchment, the investigation of the alluvium was carried out in an area that was to be undermined in the southern domain. This area is now within the southern domain, so that the results are still relevant to the current study. The investigation included a series of nine shallow hand augered bores to a maximum depth of 5.3 metres. Two of these bores were located in the valley of Palmers Creek and seven in the alluvium in Ryhope Creek, a tributary of Palmers Creek. The results confirmed that the alluvium in Ryhope Creek is relatively thin but is similar to that intersected in Cockle Creek. It comprises mostly clayey sand and sandy clay with occasional gravelly bands. No single major aquifer was identified in the deposits, however the alluvium contains occasional water-bearing sand horizons, interbedded with less permeable clay lenses.

The investigation in Palmers Creek intersected alluvial material to depth of 5 metres, where refusal was reached in a gravelly band. While no major alluvial aquifer was located, water bearing sand and gravel zones were intersected, including the gravel layer at the base of the bores. These zones are probably fed from the major aquifer zone which is known to exist in the much thicker alluvial deposits, to the south of the main Palmers Creek channel at this location.

In summary, the continuous underground mining area includes alluvium in stream valleys, but does not contain significant aquifers.

3.2.2 Weathered rock aquifer

The lack of groundwater flow in the coal measure strata is due to the extremely low primary permeability of the rock material. As a result, most groundwater flow through the overburden strata is due to secondary or fracture permeability (through interconnecting defects such as joints and bedding).

Fracture permeability is most common in the weathered zone and in near surface strata where joints and fractures are likely to be open. This can form a near surface unconfined aquifer, termed the **weathered rock aquifer**, which may be intersected above the bedrock throughout the area. The weathered rock layer is generally of the order of 10 metres deep throughout the region, and hence the aquifer, where it occurs, is limited to this zone. The permeability and groundwater quality in the aquifer are both variable, due primarily to the variable properties of the parent rock from which the weathered rock layer is derived. However, where conditions permit, the aquifer can be exploited in shallow wells of large diameter to increase yields. Generally however, the occurrence of an aquifer in the weathered rock layer is patchy.

Occasionally, flow from this aquifer is significant, and may emerge at the ground surface in the form of a spring. Groundwater flow rates from these springs are usually intermittent, and depend on the recent climatic conditions, while the water quality is poor to good. There are no known springs derived from the weathered rock layer within the continued underground mining area, which confirms that the weathered rock aquifer is generally poorly developed in this area. There are also no known groundwater dependant ecosystems reliant on this aquifer as a water source.

Due to the broad extent and variable nature of the weathered rock aquifer, it is more difficult to characterise than the alluvial aquifer, but there is one known well (4.3 m deep) in the lease area, which taps the weathered rock aquifer near the southern end of longwall 28. This is north of the current continued underground mining area. The well is brick lined and has a diameter of about four metres. The conductivity of the water in the well was measured and found to be 300 μS/cm. Based on established correlations, this equates to a TDS of about 200 mg/L, which represents good quality and is suitable for human consumption, although the well is not currently utilised. Monitoring indicated that the water level and quality in this well was unaffected by the extraction of longwalls 27, 28 and 31, at a depth of cover of about 130 metres.

Apart from this, there are limited specific data on the nature of the aquifer in the lease area. Two previous investigations undertaken at proposed shaft sites at West Wallsend Colliery included water pressure testing to determine the likely inflows to the shafts (Robert Carr Associates, 1998 and Douglas & Partners, 1992). Only two of these tests were carried out in the weathered rock aquifer, and produced permeabilities of 4 and 6 lugeons (one lugeon is approximately equivalent to a permeability of 1×10^{-7} m/s at 20° C). These values represent a reasonably poor permeability, but are typical of the permeability of the weathered rock aquifer in this area. As a result, it is a safe assumption that the characteristics of the weathered rock aquifer in the lease area, where it exists, are probably typical of the aquifer over the rest of the region.

In summary, the evidence indicates that, where the weathered rock aquifer exists in the region, it is of minimal importance, due to its poor yield and continuity. The available data also indicate that this aquifer is largely non-existent or has a minor significance within the continued underground mining area. As a result, the risk of any adverse impacts from the mining will be negligible, and does not require any further evaluation.

3.2.3 Fractured rock aquifers

The groundwater resource in the underlying unweathered strata of the Newcastle Coal Measures is also of minimal importance on a regional scale. Previous geotechnical investigations have confirmed that the Newcastle Coal Measures do not normally contain any significant quantities of groundwater, and the permeability of these rocks is generally less than 10^{-7}m/s (Pacific Power International, 1997). Because of this, most underground mines in Newcastle Coalfield (apart from those mining at very shallow depths) are relatively dry, and rarely experience any major inflow problems. Significant groundwater inflows in underground mines usually only occur when shallow workings intersect faults or jointed zones, which drain water from the overlying weathered rock aquifer into the mine.

The few aquifers that do occur at depth in these strata, are usually **fractured rock aquifers**. These include jointed coal seams and localised jointed or fractured zones, often adjacent to major faults. Fractured rock aquifers occasionally have permeabilities up to two orders of magnitude greater than the surrounding strata, due to their interconnecting cleat and/or joint patterns (hence the term fractured rock aquifer).

These aquifers have the potential for higher flows than the weathered rock aquifer, since they are confined aquifers and are at a higher pressure. Nevertheless, flows are often relatively small in these zones, and water quality is generally poor and suitable only for stock use. They are normally exploited using pumped bores, to utilise the high head in these aquifers. Hitchcock (1995) concludes that the Newcastle Coal Measures "have a poor resource potential with low yielding aquifers of high salinity". This explains why fewer users exploit this resource than other sources.

The existence of water bearing zones in coal seams at West Wallsend Colliery was confirmed by water pressure testing at two shaft sites. Of the twenty successful tests in the overburden strata in these bores, fifteen gave permeabilities of less than 1 lugeon. Of the remaining five, four measured permeabilities in coal seams that ranged from 1 to 14 lugeons. The other test measured a permeability of 2.5 lugeons in fractured rock forming the roof of the West Borehole Seam. These results indicate that, while the permeability in some of the coal seams is greater than in the surrounding rocks, there are no significant aquifer zones, as the maximum permeability of 14 lugeons is not sufficient to produce any significant groundwater flow. Testing of the salinity in the borehole at one of the shaft sites yielded an average TDS value of 1260 mg/L. Water of this quality is not suitable for human consumption, and is suitable only for stock use.

Normally, any groundwater bearing seam in the immediate overburden strata above a longwall panel will drain into the goaf during extraction of the seam. Since very few groundwater inflows have been experienced in the existing West Wallsend workings to date, this confirms that the water-bearing coal seams are an insignificant groundwater source in this area, and there are no major fractured rock aquifers in the overburden strata above the existing workings. Were there any significant aquifer zones in the near roof strata, water inflows to the mine would be common.

Based on previous mining experience at West Wallsend, as well as the results of recent exploratory boreholes carried out for the current project, the conditions in the continued underground mining area are likely to be similar to the rest of the workings, and there is no evidence of the existence of any significant fractured rock aquifers in the near-roof strata. Consequently, the risk of an adverse impact on any fractured rock aquifer is negligible, and requires no further evaluation

3.2.4 Groundwater Dependant Ecosystems

Groundwater dependant ecosystems are biological communities that have their species composition and their natural ecological processes determined by the quantity and quality of groundwater. The NSW Groundwater Quantity Management Policy requires that all significant groundwater dependant ecosystems be identified and protected. In the continued underground mining area, three vegetation communities are considered likely to be dependent on groundwater resources: Alluvial Tall Moist Forest EEC, Swamp Mahogany Paperbark Forest EEC and Riparian Paperbark Peppermint Forest. A freshwater wetland has also been identified within the continued underground mining area. This wetland had been extensively investigated as part of previous studies. The wetland is considered to be fed by surface water and is not considered to be a groundwater-dependant ecosystem (Umwelt 2008).

The continued underground mining area is not expected to result in an adverse impact on groundwater resources, and similarly alluvial aquifers are not expected to be adversely impacted. It is unlikely that the Project will result in a significant negative impact on identified groundwater-dependent ecosystems. Further details on groundwater-dependent ecosystems are presented in the Ecological Assessment (Appendix 6 of the EA).

3.2.5 Volumes of groundwater in the project area

Quantification of groundwater in the alluvial aquifers in the continued underground mining area is difficult, due to:

- The small area affected (Figure 2).
- The lack of groundwater usage data in these areas.
- The absence of continuous aquifer horizons in the alluvial sequence in these areas.

Given the small volume of alluvial sediments affected, and the absence of aquifer-quality strata, the volumes of groundwater in the alluvial sediments are highly likely to be very low.

Nevertheless, the volumes of groundwater in the alluvial sediments are highly likely to be very low, and insignificant compared to the groundwater volumes contained in the major aquifers further downstream.

3.2.6 Permeability of aquifers

Observations of the nature of the alluvial sediments indicate that, overall, permeabilities are likely to be moderate to low. Higher permeability sand and gravel units are present in discontinuous lenses, and appear to be interbedded with lower permeability sand and silt sequences. The available data indicate that the alluvial sediments in the continued underground mining area do not contain any significant aquifers.

Test data from the weathered rock and fractured rock aquifers are summarised in Appendix 1. The data indicate that the strata are generally low permeability, with measured permeabilities typically in the range of 10^{-7} m/s or lower. Very few tests indicated permeabilities of the order of 10^{-5} m/s or better.

4. Proposed future mining

At the time of preparation of this report, extraction in the West Borehole was being carried out in Longwall 36 in the northern domain. Subsequent extraction is to take place in Longwall 37 adjacent to Longwall 36, before extraction commences in the continued underground mining area.

Future coal extraction at West Wallsend Colliery within the continued underground mining area is expected to include up to 13 longwall panels, ranging up to 3579 metres long and 168 metres wide. The proposed future mine plan is shown on Figure 1. For the purposes of this assessment, the future mining in the continued underground mining area has been divided into two separate geographical areas. These areas are:

- Western Domain – comprising 10 longwall panels north of the F3 Freeway mostly in the catchment of Cockle Creek and partly in the catchment of Palmers Creek; and
- Southern Domain – comprising 3 longwall panels south of F3 Freeway in the catchment of Palmers Creek.

Details of the proposed mining in the two areas are summarised in Table 2 below:

Table 2 – Proposed Mining Details

FEATURE ↓	**AREA → LONGWALLS →**	**Western Domain LW 38 to 43, 47 to 50**	**Southern Domain LW 44 to 46**
Seam		West Borehole	West Borehole
No. of Panels to be Extracted		10	3
Working thickness		3.4 to 4.8 metres	4.4 to 5.0 metres
Panel Width		168.6 metres	158.1 to 168.6 metres
Panel Length		784 to 3579 metres	1130 to 1518 metres
Depth of Cover		80 to 390 metres	110 to 184 metres
Chain Pillar Width		30 to 35 metres	30 to 45 metres

Within the continued underground mining area the thickness of the West Borehole Seam ranges up to about 5 to 6 metres, but thins significantly to the west. The proposed extraction height in this seam is 4.8 metres in the southern section of the continued underground mining area, but this will be reduced in the western area where the seam is thinnest.

It should be noted that the mining parameters detailed above, and the proposed mine layout may be altered at any stage prior to or during the future development of the mine due to unforeseen geological, planning or mining factors.

5. Risk assessment and evaluation

The Department of Primary Industries recommends that, in assessing the impacts of subsidence on surface and subsurface features, the risk of an adverse outcome should be assessed. This risk is essentially a product of the probability of an adverse outcome and the consequences of such an event.

Based on the available knowledge of the local hydrogeological regime at the time of the study (summarised in Section 2), the major potential hydrogeological risk associated with the future proposed mining in the lease area was determined to be:

> *Ground surface movements and/or the fracturing of the overburden strata associated with the extraction of the West Borehole Seam has the potential to drain any aquifers in the alluvial deposits, and impact on the amenity of any current or future users of these groundwater sources.*

One of the main principles of the NSW Groundwater Quality Protection Policy is that the scope of works which is required to demonstrate adequate groundwater protection, should be commensurate with the risk the development poses to a groundwater system and the value of the resource. Since the weathered rock aquifer has a negligible importance in the continued underground mining area, and there are no known fractured rock aquifers of any significance, the risk of any adverse impact on these aquifers has not been considered in the subsequent evaluation, and the assessment concentrates on the potential for impacts on the alluvial aquifers.

In order to determine the likely impact of the proposed mining on the groundwater in the alluvium, the following activities were undertaken to assist in the assessment of the potential consequences of the proposed mining:

1. Data relating to the alluvium was gathered from previous field studies;
2. A field reconnaissance program was carried out to confirm the location, extent and nature of the alluvial deposits in the continued underground mining area; and
3. An evaluation was made of the current and future potential groundwater usage in and near the affected area.

In order to determine the likelihood of any adverse consequences occurring, the following activities were undertaken:

1. An estimation was made of the likely height of fracturing above the extracted longwall panels; and
2. Based on ongoing monitoring and data from other sites, a qualitative assessment was made of the likelihood that the proposed mining would have an adverse impact on the local aquifers.

The results of these investigations were used to broadly quantify the risk of an adverse hydrogeological outcome in the continued underground mining area, following which, an assessment was made of the potential for any adverse impacts on a regional scale. This assessment process is summarized in the following sections.

6. Characterisation of alluvial areas

In previous investigations, the extent of alluvium in the lease area was determined by carrying out a field reconnaissance survey in all of the major creek valleys where they cross the lease area. This survey was extended by further field reconnaissance to the southern part of the continued underground mining area, which had not been previously surveyed. As access was not possible to all localities within the area, some interpolation between sites was necessary to map the full extent of the deposits, particularly in the densely vegetated areas. Although in some parts of the area, colluvial deposits merge with the alluvium making it difficult to identify, the extent of the alluvium was determined by observation of topography, examination soil types, and mapping of the creek beds.

No subsurface investigations were carried out as part of this study, as they were not within the scope of works. As a result, the composition of the alluvium and the existence of any alluvial aquifers has been interpreted from previous studies, and in particular from the study in Cockle Creek above longwalls 27 and 28, and in the Ryhope area (Pacific Power International, 2002, Connell Wagner PPI, 2005).

The continued underground mining area covers part of two major catchments that contain alluvium-filled creek valleys: Cockle Creek and Palmers Creek. Within these catchments there are several tributaries in the continued underground mining area. These are (from north to south):

- Cockle Creek
- Diega Creek
- Central Creek
- Ryhope Creek
- Palmers Creek

Diega Creek is a tributary of Cockle Creek, while Central Creek and Ryhope Creek are tributaries of Palmers Creek. The approximate distribution of alluvium mapped in the creek valleys in the two sections of the continued underground mining area is shown on Figure 2, and brief descriptions of the alluvial deposits in each section are given below. The catchment boundaries are also shown on this figure. Topography and alluvial deposits are shown in a generalised cross section (Figure 9). Groundwater flow directions in these alluvial deposits are likely to be down the valleys that contain the sediments (Figure 10).

6.1 Western Domain

The western domain is located in the Sugarloaf State Conservation Area on the north-western side of the F3 Freeway, and covers the upper reaches of the Cockle Creek, Diega Creek and Ryhope Creek catchments. The drainage lines in these areas are first and second order streams that take the form of ephemeral channels, which normally flow only after prolonged or heavy rainfall. To the east and south of the continued underground mining area, these creek valleys contain thick deposits of alluvium, however where they cross the western domain of the continued underground mining area there are no significant alluvial deposits.

Figure 2 indicates that there are large areas of alluvium in Cockle Creek in the northern domain, but in the western domain there are only three small fingers of alluvium in tributaries of Cockle Creek that overlie the proposed Longwall 38. These tributaries are at the upper end of the catchment and have downstream gradients much greater than 3% which is too steep for significant alluvial terraces to form. Consequently, there are almost certainly no alluvial aquifers in the Cockle Creek catchment in this domain.

The situation is similar in Diega Creek, which also has its source in the western domain, where it has two tributaries, Diega Creek and Little Diega Creek. It is evident from Figure 2 that the alluvial deposits in Diega Creek are mostly limited to the area southeast of the F3 Freeway in the eastern domain. In the western domain of the continued underground mining area there are only two small areas of very thin alluvial deposits, at the southern end of Longwalls 38 and 40. Neither of these areas contains a significant alluvial aquifer.

Figure 2 also shows that Ryhope Creek originates on the northern side of the F3 freeway in the Western section of the continued underground mining area, where the depth of cover is shallowest. There is a small finger of very thin alluvium in the creek valley in this area, but it is not undermined by any longwall panels, and is well beyond the end of Longwalls 48 and 49.

6.2 Southern domain

Although this area is smaller than the western domain, the field survey revealed that two alluvium-filled creek valleys cross this area. Diega Creek is the largest and most northerly of the creeks and flows in an easterly direction across the northern end of Longwall 46, where it takes the form of a second order ephemeral channel containing a series of waterholes (Figure 2). Like almost all other creeks in the lease area, the creek only flows after prolonged rainfall. The alluvium in the valley of the creek is up to 80 metres wide where it crosses the site. Nevertheless, it is not expected that there will be any significant aquifers in this alluvium, as the Diega Creek alluvial terrace is much smaller than that in Cockle Creek, which was found to contain no significant aquifers. In addition, a groundwater monitoring borehole (D4) installed just downstream of this area intersected 7 metres of alluvium comprising sandy clay and clayey sand, with no apparent aquifer zones (see Figure 8 for location of groundwater monitoring bores).

The other creek in this area, Central Creek, is a tributary of Palmers Creek and flows towards the southeast. Central Creek contains alluvium up to 100 metres wide at the eastern edge of the continued underground mining area, where it is a second order stream, but it is significantly narrower than this in the first order drainage lines further upstream, where it will be undermined by Longwalls 45 and 46 (Figure 2). It is in a State Conservation Area (SCA), now known as the Sugarloaf SCA. Central Creek flows only after prolonged rainfall, and, while the alluvium at the eastern edge of the continued underground mining area is likely to contain water-bearing zones, it is considered highly unlikely that it will contain an aquifer of any major significance.

Ryhope Creek is located to the south of the continued underground mining area, and will not be undermined by any longwall panels. Hand augering investigations have shown that it contains alluvial deposits, although they do not contain a significant aquifer zone. One auger hole drilled in Ryhope Creek for a monitoring bore (R5) did locate a shallow sand aquifer, which appears to feed an adjacent dam (Figure 8). Ryhope Creek flows into the major alluvium filled valley of Palmers Creek, which forms the southern boundary of the continued underground mining area. It contains extensive alluvial deposits up to 300 metres wide, which include a significant aquifer zone, comprising sand and gravel up to 12 metres thick. None of the longwall panels proposed in this part of the continued underground mining area will undermine this important resource. Longwall 44, which is the nearest panel, is located about 300 metres immediately north of the alluvium.

7. Groundwater usage

7.1 Current usage

Part of the current study was to gain an overall understanding of the extent of existing usage of groundwater in the continued underground mining area. This was achieved primarily with reference to the database groundwater works reports held by the Department Water and Energy (DWE). This database lists details of all registered bores and wells in New South Wales. While it is recognised that many existing bores are not registered, the database does give an indication of the extent of groundwater usage in the state.

The database lists no registered groundwater bores within the area of proposed future coal extraction in the continued underground mining area, which is not surprising, since much of the area is covered by the Sugarloaf SCA. Nevertheless, there are three registered bores in the valley of Diega Creek about two kilometres to the east of the continued underground mining area. These bores have been undermined by previous longwall panels without any reported adverse impact on their yield. Details of the bores are given in Table 3.

Table 3 - Details of Registered Bores in Diega Creek

Reg. No.	Location	GWL (m)	Depth (m)	Water-Bearing Strata	Flow Rate (L/S)	Salinity (mg/L)
27551	Diega Creek	-	2.4	Alluvial sand	-	-
45155	Diega Creek	-	4.3	Sandstone	-	0-500
60852	Diega Creek	-	18.3	-	-	3001-7000

A further three bores are located outside of the southern edge of the continued underground mining area in the valley of Palmers Creek. The details of these bores from the DWE database are given in Table 4 below, and their locations shown on Figure 2.

Table 4 - Details of Registered Bores in Palmers Creek

Reg. No.	Location	GWL (m)	Depth (m)	Water-Bearing Strata	Flow Rate (L/s)	Salinity (mg/L)
64067	Palmers Creek	4	12.8	Sand, gravel	0.4	2000
64025	Palmers Creek	6	12.19	Sandstone, coal	0.9	60
63752	Palmers Creek	6	12.2	Sand, gravel	0.46	20

Bores 64067 and 63752 both appear to exploit the alluvial aquifer in the valley of Palmers Creek, while bore 64025, which is located on the flank of the creek valley, taps a coal aquifer that is probably fed from the alluvium. The water quality in the two bores furthest downstream is very good, and suitable for human consumption. Even though the recorded flow rates from these bores are low, this water represents an important groundwater resource. The water in the remaining bore is of a lesser quality, and suitable only for stock use.

It is unlikely that there are additional, unregistered bores in the continued underground mining area, due to the limited groundwater resources available, and the fact that most of the area is covered by the Sugarloaf SCA. The reconnaissance in the area did not discover any additional bores, other than those noted above. While most farm dams in the area collect surface run-off, some dams which have been excavated into the alluvial deposits, can rely on groundwater for their water supplies. Only one such dam was located during the field reconnaissance. This dam has been dug into the alluvium of Ryhope Creek, in an area that will not be undermined in the continued underground mining area, and is located more than 800 metres from the nearest longwall panel. A second dam is situated at the upper end of Cockle Creek above Longwall 38, but this dam only collects runoff and does not appear to be dependant on groundwater.

7.2 Future usage

As part of the current study, it was necessary to assess the potential for future usage of the groundwater resources in the continued underground mining area.

The results of this assessment have indicated that:

- The current usage of groundwater within the study area is negligible;
- While the groundwater in the alluvium is potentially the most important groundwater resource, it is highly unlikely that the alluvium within the continued underground mining area contains aquifers which would provide a significant groundwater source, with the exception of the aquifer in Palmers Creek (which is located outside the proposed extraction area); and
- The potential for future usage of weathered rock aquifers and fractured rock aquifers is considered to be negligible, due to their generally poor yield, quality and continuity.

While it is theoretically possible that groundwater in the alluvium in the study area may be utilised, the previous study in Cockle Creek indicated that the probability of this could be considered to be very low since:

- The aquifer zones in the alluvium are contained in discontinuous lenses;
- The flow rates from the aquifer zones in the alluvium are unlikely to be economic;
- The water quality in these zones is likely to be poor; and
- Other sources of water are available (surface water and rainwater).

As indicated above, the only alluvial water resource considered to be significant is located in the alluvium in Palmers Creek, which lies outside the southern fringe of the continued underground mining area. Future usage of this water resource is highly likely, due to its good quality and ready availability. Overall however, the potential for future groundwater usage in the continued underground mining area is negligible.

8. Estimation of height of fracturing

In order to determine the impact of the proposed future mining on the groundwater regime in the alluvium, the height of the fractured zone above the proposed mine workings needs to be estimated. The fractured zone is defined as the height of interconnected fracturing that could transmit water from the strata to the mine opening. Since there is no quantitative method of estimating this height, it must be established based on previous experience in the local area, incorporating empirical methodology along with a qualitative evaluation of local geological and mining conditions. This is not a simple task; since the height of the fractured zone is dependant on many variables including seam thickness, rock type, rock strength and deformation properties, jointing and bedding, geological structures and depth of cover.

8.1 Predictions

Previous studies in this region (ECNSW, 1987, Forster & Enever, 1992) have suggested that interconnected fracturing may extend to a height of between 20 and 33 times the coal extraction thickness above supercritical extraction areas. Since the strength properties of the rocks throughout this region are relatively uniform, it should be expected that the height of the significant fracturing in the continued underground mining area would be similar to elsewhere in the region. However, estimating the height of fracturing is not merely a process of determining the working seam thickness and then multiplying by a suitable factor. The exercise requires a full evaluation of all the relevant factors, to determine their influence on the degree of fracturing.

The factor that most influences the height of the fractured zone in this region is the seam extraction height, which is why deformation zone thicknesses are often expressed as a factor of this variable. In the continued underground mining area, the maximum extraction height is 4.8 metres, which is greater than for most other coal seam extraction in this region. Because of this, the height of the fractured zone in this area will be potentially greater than that measured above other mines at a similar depth. However, in order to refine the estimate of the extent of the fractured zone, the evaluation must include an assessment of all the influencing factors.

Next to the extraction height, the most important factor is the rock type and strength of strata in the overburden. Above the proposed mining area, the strata comprise a good mix of interbedded fine and coarse-grained rocks. This is important, since different rock types behave differently when exposed to changes in stress, which occur as the underlying coal seam is extracted. Coarse-grained rocks, which are generally massive or poorly bedded in this area, re-distribute the imposed stresses above the mine by forming vertical fractures, whereas fine-grained rocks tend to be more thinly bedded, and deform by bending and slippage along bedding planes. Consequently, the rocks in the continued underground mining area, by virtue of their variable nature, will tend to inhibit the vertical extension of the zone of interconnected fracturing in the overburden above the mine.

Since the Adamstown Formation, which forms the immediate roof of the seam, has a relatively uniform thickness in the lease area, the height of interconnected fracturing will most likely be reasonably consistent. As a result, it should rise to the same stratigraphic horizon in different parts of the lease area, for similar depths of cover. Based on the analysis of geological data from previous studies in the area (Pacific Power International, 2002), it is evident that the high strength of the strata in the Adamstown Formation will have a significant influence on the height of the fractured zone. These strong strata in the upper part of the formation will act as a beam resting on the caved and fractured material below and serve to limit the subsidence. Since the degree of fracturing in the overburden is directly linked to the degree of subsidence, the height of the fractured zone will be similarly limited. Assuming the subsidence predictions prove reasonably accurate, the fractured zone height will be roughly similar to that above other seams that have produced subsidence of a similar magnitude at a similar depth of cover in this area.

It is therefore assessed that, due primarily to the strength of the strata in the Adamstown Formation, it is highly unlikely that continuous vertical fractures will form through the entire thickness of this unit, except perhaps where it thins to the west. Consequently, the fractured zone will most likely be wholly within the Adamstown Formation.

The exact level of the top of this zone will most likely depend on the position of the numerous tuff layers located in the upper part of the formation. Previous analyses of bore cores indicated that there are up to 100 separate tuff or tuffaceous claystone horizons ranging from 1 mm to more than 3 metres thick in the overburden. Any cracks which penetrate the entire thickness of coarse-grained material in the lower section of the formation should be sealed when they reach the tuff layers, due to plastic deformation or swelling of the reactive clays contained in them. This is even more likely if the cracking results in some groundwater movement. Any one of these tuff layers therefore could form a relatively impermeable horizon that would present a barrier to vertical groundwater movement in the overburden strata, provided that it is located higher than about 65 metres above the roof of the seam.

Because of the variable lithology in the upper part of the Adamstown Formation, predicting the exact height of fracturing is not possible with any certainty. Nevertheless, the fractured zone will most likely extend somewhere into the upper part of the formation. This height is likely to be between 75 and 95 metres above the roof of the seam, depending on the vertical distribution of tuff layers and the extraction height. This is at the lower end of the fractured zone height measured in other areas (20 to 33 times the extraction thickness), but this is due to the presence of the high strength strata above the seam.

The height of fracturing will also vary slightly with depth of cover, since the additional overburden load at greater cover depths may result in greater fracturing in the massive sandstone/conglomerate layer. It is therefore expected that in the western domain, where the depth of cover is shallowest and the extraction height lowest, the height of fracturing will be at the lower end of the estimated range. In addition, the height of interconnected fracturing may be restricted where the tuffaceous claystone bands in the strata above the mine are thicker. It is also possible that the height of fracturing in the vicinity of the major faults may be higher than that predicted, due to the influence of the fault structure.

8.2 Previous experience and monitoring

Previous experience of mining beneath surface water bodies at Wyee Colliery has confirmed the limited extent of interconnected fracturing in the overburden, in conditions similar to those at West Wallsend. At Wyee, several 240 metre wide panels were extracted in the Fassifern Seam beneath the Mannering Creek Ash Dam, in an area where the overlying Great Northern Seam had been previously extracted. The depth of solid rock cover ranged from 140 to 150 metres, and the effective seam thickness was of the order of 4.5 metres. Monitoring showed that there was no indication of any groundwater or surface water inflows to the mine. The conditions at Wyee are similar to those in the continued underground mining area at West Wallsend, and the degree of subsidence at Wyee was significantly greater than that which is expected in the this area (taking into account the subsidence due to both extracted seams).

The data from Wyee indicate conclusively that there is a zone of competent, relatively unfractured rock (aquiclude zone) in the overburden between the Great Northern goaf and the bottom of the ash dam, which prevents drainage of surface water into the mine. This experience was used in assessing the potential for inrush in several panels that were extracted from beneath Lake Macquarie in Wyee Colliery at similar depth of cover. All panels were extracted in dry conditions with no evidence of any lake water entering the workings.

The extensive subaqueous mining experience at Wyee, along with an intensive monitoring program, has provided valuable data which is relevant to other mining in the region. The data gathered was used to predict that there was unlikely to be any impact from the extraction of longwalls 27, 28 and 31 at West Wallsend on the Cockle Creek alluvium. The extraction of these panels was approved subject to an intensive investigation and monitoring program, incorporating seven groundwater observation bores (A1 to A7 – see Figure 8 for locations).

Monitoring of these groundwater observation bores in the Cockle Creek alluvium during the extraction of the longwalls confirmed the existence of an aquiclude zone above the fractured zone at West Wallsend. Although the total depth of cover over these longwall panels is as low as 135 metres (and 120 m to rockhead), there was no indication from the observation bores of any connection between the mine and the alluvium, and the predictions were confirmed. The results of the monitoring are discussed below and summarised in Figure 3. This figure shows the total rainfall budget (in monthly increments) for the site over this period, plotted with the elevation of the groundwater table in the monitoring bores.

The results of monitoring in Cockle Creek indicate a declining groundwater table over the period from July 2002, when monitoring commenced to about June 2006. This decline is due to the lower than average rainfall over the same period, and not due to any mining impact, since the decline commenced well before the start of longwall 27. In the 48 month period between July 2002 and June 2006, below average rainfall was experienced in 40 months, and only 8 months had greater than average rainfall. The total rainfall over the period was 3373 mm compared to a long term average of 3968 mm. Figure 3 indicates an increasing rainfall deficit trend, which is consistent with the declining groundwater levels measured in the observation bores (CWPPI, 2004). During this period of below average rainfall, longwalls 27, 28 and 31 were extracted beneath the alluvium in Cockle Creek. Since June 2006, above average rainfall has eliminated the rainfall deficit, and the groundwater levels have risen again.

Based on the data in Figure 3, there is very little evidence of any impact from the mining in the graph of the groundwater levels. The passage of Longwall 27 appears to have no major impact, although the slight rise in groundwater depth in February 2003 in A3 and A4 (which are over the centre of Longwall 27) is probably the result of subsidence over this panel. The fluctuations in A7 are inexplicable, since this bore is furthest from Longwall 27. The anomalous reading for A3 in June 2003 is reported to be due to leakage of surface water into the borehole. There is a general rise in groundwater levels in this month due to the above average rainfall in the previous two months, although some of the rise may be due to residual subsidence over Longwall 27.

The impact of the passage of longwall 28 is not easy to detect from the data as no groundwater readings were taken in October and November 2003, when the longwall was passing underneath. Nevertheless, the readings in December show the post-mining groundwater levels are generally lower than September 2003 in most bores (Figure 3). This is due to the continuing rainfall deficit over that period. The rise in A6 (over the centre of Longwall 28) in December 2003 is probably due to formation of the subsidence trough. The groundwater levels generally continued to decline in the first half of 2004, in response to the continuing drought conditions. Bores A6 and A7 both showed a slight rise over this period, as the water level over longwall 28 stabilised.

As with the first two longwalls, the groundwater level data shows almost no impact from the extraction of longwall 31, which is at a depth of 130 metres beneath the alluvium. The rise in groundwater levels in most bores in the first half of 2005 is due to slightly above average rainfall for this period, while the return to declining groundwater levels after June 2005 is again due to a period of below average rainfall. Borehole A7, which is closest to longwall 31 shows groundwater movements which are responding to climatic conditions, with no evidence of mining induced impacts. The slow decline in level in A4 during this period is not explained by any mining activity, since longwall 31 is more than 300 metres to the west of this bore. This movement may be due to stabilising gradients in the alluvium, although this is the only borehole in which this behaviour is evident. The sudden drop and subsequent recovery in the groundwater level in A6 in January 2005 is possibly due to a reading error, as its behaviour is otherwise normal.

It is important to note that any disruption to the groundwater levels attributable to the mining during this period was temporary and generally limited to a period of a few months at most. In most holes, the groundwater table returned to levels consistent with that which would be expected, given the climatic conditions. The major influence on groundwater levels during the first part of the monitoring period was the prevailing drought conditions. This effect has also been noted in groundwater bores on other monitoring projects.

Since June 2006, the above average rainfall has produced a significant rise in groundwater levels to near pre-drought conditions. The post-mining groundwater gradient across the two longwalls is similar to the pre-mining gradient (1% downstream), indicating that the groundwater regime has fully recovered. The groundwater mound around the large dam east of Longwall 27 is still in evidence, as indicated by the elevated water levels in A1 and A2, relative to the rest of the bores. At no time was there total loss of groundwater from any bore, which would indicate significant drainage to the mine. This suggests that the disruption is probably mostly due to the changes in ground level induced by the mining, rather than any subsurface cracking. This is consistent with the predictions that the fractured zone above the goaf would only extend to a height of 95 metres above the seam level, which at this location is about 125 metres below rockhead under the alluvium.

Monitoring of the salinity in the boreholes showed quite large variations in the salinity, with salinity decreasing markedly in some bores following heavy rainfall. As expected, the bores that showed the most variation were A3, A4 and A7, all of which had poor quality water initially. This confirms the limited extent and permeability of the aquifer in these bores.

In addition to longwalls 27, 28 and 31, there have been numerous longwall panels extracted beneath alluvial deposits at the West Wallsend Colliery to date, with no long-term adverse impacts evident on the groundwater regime. This gives a good indication that the likely height of fracturing above these workings is within the predicted range. In particular, there have been at least ten panels extracted from beneath the Cockle Creek alluvium and ten panels from beneath Diega Creek. In both of these creek valleys there have been minor temporary hydrogeological impacts observed, but the long-term hydrogeological regime in the alluvium in both creeks appears to be unaffected (despite media reports to the contrary which have focussed on Diega Creek). In addition to this mining, Newstan Colliery has extracted longwall panels beneath the alluvium in Palmers Creek adjacent to the West Wallsend lease area, with no apparent impacts on the important aquifer in this alluvium.

In summary, the previous mining experience in the region, as well as the results of available monitoring, support the predictions of the likely height of the zone of interconnected fracturing above the mine.

9. Assessment of local impacts from future mining

Although the past mining experience at West Wallsend Colliery provides very good evidence that there will be no future impacts on the local hydrogeology, an assessment of the potential risk of an adverse outcome has been made for completeness and to satisfy the statutory requirements.

The risk to the groundwater regime is essentially a product of the probability of an adverse outcome and the consequences of such an event. These aspects are examined in detail in the subsections below.

9.1 Probability of an adverse outcome

The investigations have indicated that the main hydrogeological risk associated with the proposed extraction of longwalls in the future continued underground mining area at West Wallsend Colliery is:

- Ground surface movements and the fracturing of the overburden strata associated with the extraction of the West Borehole Seam has the potential to drain any aquifers in the near-surface alluvial deposits, and impact on the amenity of any current or future users of this groundwater source.

The probability that future mining will have an adverse impact, and drain or partially drain the aquifers in the alluvial deposits, depends on two factors;

- the depth of cover between the mine and the base of the alluvium; and
- the height of interconnected fracturing above the mine opening.

Contours showing the depth of cover over the two sections of the continued underground mining area is shown in Figure 4. This Figure indicates that there is a large range in the depth of cover over the area. The depth of cover in the different catchments above the proposed longwall panels is summarised in Table 5 below.

Table 5 – Depth of Cover over Longwall Panels

District	Catchment	Range in Depth of Cover	Depth of Cover beneath Alluvial Areas*
Western Domain	Diega Creek	78 to 310 metres	110 to 135 metres
	Cockle Creek	102 to 390 metres	106 to 140 metres
	Ryhope Creek	85 to 250 metres	no alluvium undermined
Southern Domain	Diega Creek	135 to 174 metres	136 to 160 metres
	Central Creek	110 to 184 metres	118 to 160 metres

* represents depth of cover to the ground surface

The depth of cover values shown in Table 5 represent the depth of cover to the ground surface. The thickness of solid rock cover would be less than these values beneath the alluvium. Nevertheless, for the purposes of this study, it will be assumed that the depth of solid rock cover beneath the alluvium is approximately 10 metres less than the total depth of cover.

In order to determine the impact of the proposed future mining on the groundwater regime, the height of the fractured zone above the proposed mine workings needs to be taken into account. The assessment of the likely fracture zone height (see Section 8 above) concluded that the height of interconnected fracturing above the extracted panels in the West Borehole Seam would range from 75 to 95 metres. It was noted that the height of fracturing will vary slightly with depth of cover, since the additional overburden load at greater cover depths may result in greater fracturing in the massive sandstone/conglomerate layer above the mine opening. It was also considered possible that the height of fracturing in the vicinity of any major faults may be higher than that predicted, due to the influence of the fault structure.

Based on this evaluation and the results of the monitoring in the Cockle Creek alluvium, the depth of cover in the continued underground mining area has been divided into sub-areas representing very high, high, medium or low probability of any impact on water resources in the surface alluvial aquifers, if they are undermined. These probability categories each have a range which takes into account the uncertainty in estimating the height of fracturing in the overburden. They also represent a conservative approach, since the Medium probability category (adverse impact possible) covers the depth range in which previous testing at Cockle Creek (at a depth of cover of 125 m) has shown no adverse impacts. In addition, at the higher end (105 m) of the High probability category (adverse impact probable), it is conceivable that no impacts will be detected, since there is a 10 metre barrier above the maximum predicted height of fracturing (95 m).

This conservatism has been deemed necessary, due to the uncertainty in estimating the height of fracturing.

The nominal probability categories are defined in the table below.

Table 6 – Probability Categories (Groundwater Resource Impact – if undermined)

Total Depth of Cover (D)*	Likely Impact on Aquifers	Probability Category
D < 75 metres	Adverse impact almost certain	Very High Probability
75 metres < D < 105 metres	Adverse impact probable	High Probability
105 metres < D < 135 metres	Adverse impact possible	Medium Probability
D > 135 metres	Adverse impact unlikely	Low Probability

* The depths of cover include an assumed 10 metres of alluvium.

In order to determine the overall impact of the proposed future mining on the aquifers, it was necessary to identify the zones where the alluvium overlaps areas with expected Very High, High and Medium potential for an adverse impact. This was achieved by overlaying the depth of cover contours over the map of the areal extent of the alluvium in the continued underground mining area. This then indicates any critical areas where the coal seam is at shallow depth beneath the alluvium. Any extraction beneath these critical areas has the potential to give rise to adverse impacts. Figures 5, 6 and 7 show the results of this process.

This exercise revealed that there are some areas in Ryhope Creek to the south of the continued underground mining area with a High and Very High probability of an adverse impact. While these areas will not be directly undermined by the proposed longwall panels, they are within a few hundred metres of the edge of the panels. There are also several very small zones within the continued underground mining area where the probability of an adverse impact on the alluvium due to mining is considered to be Medium because of the limited depth of cover to the mine workings. The vulnerable alluvial areas in the medium probability category are located in Cockle

Creek, Diega Creek and Central Creek. These are highlighted in Section 9.3 below, together with an assessment of the risk of adverse consequences.

9.2 Consequences

The current study has shown that there are some relatively small alluvial areas overlying future longwall panels, where the probability of an adverse outcome from the extraction of the panels is considered to be Medium. Nevertheless, the magnitude of the risk will depend on the consequences of the adverse outcome. Determining these consequences generally requires a detailed assessment of the groundwater regime (usually including a drilling program) in the affected area to determine the importance of the groundwater resource. While this has not been undertaken to date, the field reconnaissance in the continued underground mining area did give a broad indication of the likely importance of the aquifers in the alluvium. In addition, the installation of the groundwater monitoring bores has confirmed the nature of the near-surface alluvial material. This has provided sufficient detail for the current assessment.

The field reconnaissance also indicated that all of the alluvial areas in the continued underground mining area are very limited in extent and located in first and second order drainage lines at the upper end of the creek catchments. The occurrence of significant alluvial aquifers in such areas is virtually unknown. As a result, a more detailed investigation of the nature of the alluvium in these areas is unwarranted, as experience indicates that the likelihood of a significant aquifer in these deposits is negligible.

In determining the potential consequences of mining under these areas, several aspects were identified as being significant, including the following:

- previous investigations (including the installation of groundwater monitoring bores) have shown that the alluvium in the continued underground mining area consists mostly of clayey sand and sandy clay with occasional clean sand and gravelly bands, with no major aquifer zones;
- there are no known users of the alluvial groundwater in the continued underground mining area, and no significant likelihood that there will be any future utilisation of the alluvial groundwater in the area; and
- the contribution of the alluvial groundwater in the continued underground mining area to the groundwater flow in the alluvial aquifers further downstream is negligible.

It was therefore concluded that any alluvial aquifers in the continued underground mining area, will be of minor importance, so that the consequences of an adverse outcome will obviously be less than would be the case for extraction under a major aquifer. This assessment was based on the location of the alluvial deposits and previous experience in the lease area.

9.3 Risk evaluation

In the subsections below, the probability and consequences of an adverse impact from the proposed mining are assessed for the alluvium in each creek valley. This allows an assessment of the relative risks to the alluvial groundwater regime in each area. To assist in the evaluation of the hydrogeological risks, a risk matrix was formulated to categorise the risks. This matrix is reproduced in Table 7. Since the alluvial areas identified as having a Medium or Low probability of an adverse impact contain only minor aquifers, the assessed risk falls mostly into the LOW or VERY LOW RISK category in the risk matrix.

Table 7 – Risk Matrix

Probability Category*	Impact on Aquifers	CONSEQUENCES	
		Major Aquifer	**Minor Aquifer**
Very High Probability	Adverse impact almost certain	VERY HIGH RISK	HIGH RISK
High Probability	Adverse impact probable	HIGH RISK	MEDIUM RISK
Medium Probability	Adverse impact possible	MEDIUM RISK	LOW RISK
Low Probability	Adverse impact unlikely	LOW RISK	VERY LOW RISK

Note: risks not covered in the above risk matrix are deemed to be NEGLIGIBLE
* see Table 6 for definitions of the probability categories

Cockle Creek

The two small fingers of Cockle Creek alluvium which overlie the continued underground mining area both fall into the Medium probability category for an adverse outcome (Figure 5). These areas will be undermined by Longwall 38. A previous study in this area (Pacific Power International, 2002) indicated that the Cockle Creek alluvium further east over Longwalls 27 and 28 comprised mostly clayey sand and sandy clay with occasional clean sand and gravelly bands, and no major aquifer zones. Longwall 38 crosses the alluvium at the western extremity of the Cockle Creek alluvial deposit, where it is much thinner than over Longwalls 27 and 28. It is therefore highly unlikely that it contains a significant aquifer. In addition, the contribution of this area to the groundwater in the alluvial aquifer further to the east is negligible. As a result, it is considered likely that there will be no adverse impacts on either the groundwater regime in this catchment or the potential for future groundwater usage. The risk is rated as LOW.

Diega Creek

Diega Creek is similar to Cockle Creek in that only one small area of alluvium overlying the continued underground mining area is considered to have a Medium probability of being affected by future mining (Figure 6). This area is located on the boundary between the western and southern domains, at the southern end of Longwall 40. The remainder of the alluvium is considered to have a low probability of any impact occurring, including an area which crosses the northern end of Longwall 46, and a small finger at the head of Little Diega Creek which is underlain by the southern end of Longwall 38.

Previous investigations (Connell Wagner PPI, 2004) indicate that it is highly unlikely that this alluvium contains any significant aquifer, due to its narrow width and distance upstream from the lake. Since the alluvial area at risk is at the upstream end of the catchment, the probability that it contains a significant aquifer at this location is even lower, and its contribution to the groundwater in the aquifer further downstream would be negligible. Consequently, the overall impact of future mining on the groundwater regime and the potential for future groundwater usage in the Diega Creek catchment is likely to be negligible. The risk is therefore rated as LOW for the alluvium over Longwall 40, and VERY LOW for the alluvium over Longwalls 38 and 46.

Central Creek

The upper reaches of Central Creek contain alluvium which overlie the continued underground mining area and will be undermined by Longwalls 45 and 46. Only a small portion of this alluvium (over Longwall 46) falls into the Medium probability category of being affected by future mining, while the remainder falls into the low probability category (Figure 6). Previous experience (Connell Wagner PPI, 2004) indicates that, as for Diega Creek, it is highly unlikely that this alluvium contains any significant aquifer zones, due to its narrow width and distance upstream from the lake. Consequently, the overall impact of future mining on the groundwater regime and the potential for future groundwater usage in the Central Creek catchment is likely to be negligible. In addition, the contribution of the Central Creek groundwater to the Palmers Creek aquifer is insignificant. As a result, it is considered likely that there will be no adverse impacts on either the groundwater regime in this catchment or the potential for future groundwater usage, and the overall risk is rated as LOW to VERY LOW.

Ryhope Creek

None of the longwall panels underlies the alluvium in Ryhope Creek which flows into Palmers Creek (Figure 7) and hence, the potential for any adverse consequences on the alluvium is rated as negligible.

It is noted however, that in the upper catchment of Ryhope Creek, the minimum depth of cover is shallow (< 90 metres). At this depth of cover, there is a slight possibility that a direct hydraulic connection will be formed between the ground surface and the mine opening. Since the alluvium will not be undermined, the chance of a direct connection between the alluvium and the mine is considered to be negligible, however, some of the runoff which would normally have flowed down the creek may be diverted underground before it reaches the alluvium. The likelihood of this having an impact on groundwater in the alluvium further downstream is extremely low, as there will still be adequate runoff from other parts of the catchment to replenish the groundwater in the alluvium following rainfall events.

Nevertheless, this risk will need to be addressed in the risk management plan for the site, since the alluvium downstream in Ryhope Creek is a source of water for at least one groundwater user. As a result, the precautionary principle has been adopted, and the risk has been elevated to LOW from NEGLIGIBLE, which would have been the rating if this consequence had not been taken into account.

While the potential risks imposed by future mining on the groundwater regime are largely negligible, further action to control these risks has been considered, taking into account the consequences of any mining-induced impact on the aquifers. Recommendations are given in Section 10.

Palmers Creek

Although none of the longwall panels is located beneath the alluvium of either Palmers Creek, the southern end of Longwall 44 is located about 300 metres to the north of the main alluvial deposit (Figure 7). Previous investigations (Connell Wagner PPI, 2005) have shown that the main aquifer in the Palmers Creek alluvium is located to the south of the creek channel. This is approximately 500 metres from the end of Longwall 44, which is unlikely to cause any impact on the alluvial material. As a result, it is considered that there will be no adverse impact from the extraction in the proposed longwall on the groundwater in the Palmers Creek alluvium. Nevertheless, since the nearest operating groundwater bore is 500 metres from the southern end of longwall 45, the precautionary principle should apply and the assessed risk to this groundwater resource has been elevated from NEGLIGIBLE to LOW.

It was also noted above that there is a possibility of some alteration to the flow in Ryhope Creek, which flows into Palmers Creek. This will have a negligible impact on the hydrological conditions in Palmers Creek, as the affected area in Ryhope Creek forms a negligible proportion of the Palmers Creek catchment.

10. Risk management

In Section 9 of this report, a qualitative assessment was made of the risks associated with longwall mining beneath several small alluvial areas within the continued underground mining area. This assessment took into account the potential consequences if the alluvial groundwater was affected by mining, and the probabilities of an adverse outcome for the affected areas.

Having established the relative risks, it is necessary to formulate risk management options to evaluate and control the risks. This may involve reducing the risk, where the risk is identified as being unacceptable. Actions to reduce the risk may include mitigation measures or longwall panel relocation. Where the risks are tolerable, risk management may include monitoring with remedial measures as necessary.

To assist in this process, a matrix of risk management actions was formulated to address the assessed risks and minimise the potential impacts of longwall mining in the continued underground mining area. This matrix is presented in Table 8 below.

Table 8 – Risk Management Actions

Probability Category	**Impact on Aquifers**	**RISK MANAGEMENT ACTIONS**	
		Major Aquifer	**Minor Aquifer**
Very High Probability	Adverse impact almost certain	VERY HIGH RISK Intensive investigations required. Relocation of longwall panel desirable.	HIGH RISK Detailed investigations required. Mitigation and remediation measures required. Intensive monitoring necessary.
High Probability	Adverse impact probable	HIGH RISK Detailed investigations required. Mitigation and remediation measures required. Intensive monitoring necessary.	MEDIUM RISK Limited investigations required. Remediation measures may be required. Monitoring necessary.
Medium Probability	Adverse impact possible	MEDIUM RISK Limited investigations required. Remediation measures may be required. Monitoring necessary.	LOW RISK No investigations required. Consider monitoring.
Low Probability	Adverse impact unlikely	LOW RISK No investigations required. Consider monitoring.	VERY LOW RISK No actions necessary.

This risk matrix was used to determine the need for any mitigation or monitoring measures in the alluvial areas that will be undermined. Since the assessed risks for alluvial areas above the longwall panels mostly fall into the LOW or VERY LOW RISK category in the risk matrix, major risk reduction measures are not required.

Although the assessed risks are low, monitoring is still recommended for some areas to confirm the conclusions of the study and check for any unexpected adverse impacts. The monitoring program established to address the perceived risks in each of the catchment areas is outlined in the following section.

11. Monitoring and mitigation measures

The following monitoring and mitigation measures are based on the risk management matrix given in Section 10, and are designed to manage the perceived risks to the groundwater resources in the two major catchments in the continued underground mining area.

Cockle Creek (LOW risk)

Previous monitoring in Cockle Creek has shown that the extraction of longwalls 27, 28 and 31 at depths of cover of the order of 125 metres (Medium probability category) produced negligible impacts on the alluvial groundwater. This monitoring is still being carried out and it is recommended that it be discontinued. No additional monitoring or mitigation measures are recommended in respect of the alluvial aquifer, since:

- there are only two small areas of alluvium that will be undermined in the continued underground mining area by Longwall 38 at a similar depth to the area already undermined;
- it is likely that neither of these alluvial areas contain a significant alluvial aquifer; and
- both areas are considered to have only a Medium probability of being impacted by mining.

Central Creek (LOW to VERY LOW risk)

The situation is similar for the Central Creek alluvium, where the area with a Medium probability of an adverse outcome is also very small. No actions are currently recommended in respect of the alluvial aquifer, since:

- there is only one area of alluvium that will be undermined in the continued underground mining area by Longwalls 45 and 46;
- it is considered unlikely that this alluvium contains a significant alluvial aquifer; and
- this area is considered to have only a Medium to Low probability of being impacted by mining.

Diega Creek (LOW to VERY LOW risk)

The Diega Creek alluvium in the continued underground mining area is also in the LOW to VERY LOW risk categories, and should be similarly unaffected by the proposed extraction, since:

- there are only two small areas of alluvium that will be undermined in the continued underground mining area by Longwalls 38, 40 and 46;
- it is considered highly unlikely that this alluvium contains a significant alluvial aquifer; and
- this area is considered to have only a moderate probability of being impacted by mining.

However, Diega Creek has been undermined extensively further to the east, and concerns have been raised in the past by local residents over the impact of mining on the creek. This led to the installation of three groundwater bores in the creek downstream of the continued underground mining area, and ongoing monitoring of these bores appears to indicate that there has been no adverse effects on the groundwater from previous mining. However, because of the previous mining history, two monitoring bores (D4 and D5) have been constructed in the Diega Creek alluvium to confirm the conclusions of this study, and assist in allaying the concerns of local residents. The locations of the monitoring bores are shown in Figure 8.

Ryhope Creek (LOW)

The alluvium in Ryhope Creek will not be undermined by any longwall panels, and it contains no major aquifer of significance. Nevertheless, it is deemed to be worthy of further consideration, since:

- it flows into Palmers Creek, which contains a major alluvial aquifer;
- although the alluvium will not be undermined, it is near several proposed longwall panels on the southern side of the lease, where the depth of cover to the coal seam is as low as 85 metres;
- there is a slight possibility that the flow in the creek may be impacted by mining at shallow depths of cover in the western domain further upstream;
- a local nursery utilizes groundwater from the alluvium in the creek.

Although it is considered highly unlikely that there will be any significant impacts on the groundwater in the alluvium, the factors noted above dictate that some monitoring be undertaken as a precaution. Consequently, three monitoring bores have been installed in the creek to monitor the groundwater in the alluvium (R1, R5 and Q2). One of these (R5) has been established near the groundwater-fed dam utilised by the Ryhope Nursery. The locations of the monitoring bores are shown in Figure 8.

If the monitoring indicates any adverse impact on the groundwater in the alluvial area downstream, remedial measures may be required to assist in restoring the flow in the creek from upstream. The necessary measures would most likely comprise grouting of any cracks in the drainage line, so that the normal flow regime is restored.

Palmers Creek (LOW risk)

Like Ryhope Creek, Palmers Creek will not be undermined by any future longwall panels, the nearest of which will be located more than 300 metres to the north. Nevertheless, because of the importance of the alluvial aquifer in the creek and the shallow depth of cover, one monitoring site has been established for ongoing monitoring. This site is the registered bore that is closest to the proposed mine workings (No. 64025). The location of the monitoring bore (labelled P3) is shown in Figure 8.

12. Assessment of regional impact

Although the risk assessment process has concluded that the risk of any adverse impacts to the local hydrogeological regime in the continued underground mining area are NEGLIGIBLE to LOW, for completeness, it is also necessary to examine the risks on a regional scale. Therefore, the results of the study were used to determine any potential risks to the regional hydrogeologic regime. The two regional risk factors identified during this process are as follows:

1. Any mining-related loss of groundwater from aquifers in the near-surface alluvial deposits may impact on the groundwater supplies and users of this resource further downstream.
2. Any mining-related loss of groundwater from coal seam aquifers in the overburden above the West Borehole Seam may impact on the groundwater supplies in the coal seams and users of this resource in other parts of the basin.

Only a brief assessment was required to determine that both of these risks are NEGLIGIBLE. The factors that support this assessment are set out below.

1. Alluvial aquifers

   The regional risk to the alluvial aquifers is deemed to be NEGLIGIBLE since:

   - The alluvial areas that will be undermined are located in first and second order drainage lines at the upper reaches of the Cockle Creek and Palmers Creek catchments, and contain relatively low volumes of groundwater;
   - No major aquifer zones were identified in the alluvial areas that are to be undermined in the continued underground mining area;
   - The probability of any adverse impacts on any alluvial aquifers in the continued underground mining area (if they exist) was determined to be low to negligible; and
   - The total area of alluvium in the continued underground mining area relative to the total area of alluvium in the two catchments is very small.

2. Coal seam aquifers:

   The regional risk to the coal seam aquifers is deemed to be NEGLIGIBLE since:

   - Coal seam aquifers in this region do not provide an important source of groundwater due to their poor quality and yield, and are only utilised intermittently;
   - No significant coal seam aquifers have been identified in the overburden above the West Borehole Seam in the continued underground mining area;
   - There has already been significant coal extraction in the West Borehole Seam in this region, which would have depleted any groundwater resource in that seam and the overlying coal seams if any resource existed in the first place;
   - The affected seams subcrop immediately to the west of the continued underground mining area so that there is minimal for drainage of groundwater resources up-dip; and
   - The continued underground mining area covers a relatively small area when compared to the total coal basin, so that any additional regional impact would be negligible.

Water usage in the project area is regulated by the Hunter Unregulated and Alluvial Water Sources Sharing Plan 2009. This is a “macro” sharing plan that applies to various water sources in a number of catchments and different types of aquifers. The plan is broken into a number of extraction management units. The sections of the West Wallsend Colliery Continuing Operations Project that impact alluvial water resources fall within the North Lake Macquarie unit; western parts of project fall within the Wallis Creek unit.

Relevant parts of the plan include:

- The plan allows for no new growth in water entitlements, and annual extraction limits are typically set at the current extraction limits.
- Extraction of water from alluvial or other aquifers is subject to the provisions of the plan.

The Continued Operations Project does not propose to extract any groundwater from alluvial aquifers, and it is not planned to increase dewatering from current levels. Consequently the mining activities to be undertaken will be consistent with the requirements of the Hunter Unregulated and Alluvial Water Sources Sharing Plan 2009.

13. References

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Appendix

Groundwater and Permeability Data

There is little published data on the hydrogeological characteristics of the Newcastle Coal Measure strata. The following assessment is based on previous investigations and experience in the area, including Newstan Colliery life extension project overburden groundwater study by Ian Forster 2002 (Pacific Power).

6.3.1 General

Potentially, the most important groundwater resource in the Newcastle/Lake Macquarie area is the alluvium which covers the low-lying areas adjacent to the lake system and fills the broad valleys of the creeks which flow into the lake. Numerous bores and wells draw water from these sediments, which usually comprise a fine grained surface layer underlain by sand and gravel deposits. Flows from these wells mostly range from 0.1 to 9 L/s, and water quality is generally reasonable. (Reference 4).

The groundwater resource in the underlying Newcastle Coal Measures is less important on a regional scale. Fewer bores exploit this resource, since the permeability of these rocks is generally very low. Those bores that do extract water from these strata usually intersect localised jointed or fractured zones, or coal seams, but flows are usually comparatively small. Water quality in these zones is poor and suitable only for stock use. Reference 4 concludes that the Newcastle Coal Measures "have a poor resource potential with low yielding aquifers of high salinity". Previous geotechnical investigations have confirmed that the Newcastle Coal Measures do not normally contain any significant quantities of groundwater, and their permeabilities are low ($<10^{-7}$m/s). (Reference 11)

Because of the extremely low primary permeability of the rock material, most groundwater flow through the overburden strata is due to secondary or fracture permeability (through interconnecting defects such as joints as bedding). Fracture permeability is most common in the weathered zone and in near surface strata where joints and fractures are likely to be open. This forms a near surface unconfined aquifer which covers most of the bedrock throughout the area. Occasionally, flow through this zone emerges at the ground surface in the form of a spring. Groundwater flow from these springs is usually variable, and depends on the recent climatic conditions, while the quality is poor to reasonable.

Coal seams, with their interconnecting cleat and joint patterns, are also often found to be confined "aquifers" with permeabilities up to two orders of magnitude greater than the surrounding strata. Despite this, most underground coal mines in Newcastle Coalfield (apart from those mining at very shallow depths) are relatively dry, and rarely experience any major inflow problems. Significant groundwater inflows in underground mines usually only occur when shallow workings intersect faults or jointed zones, which drain water from the overlying surface aquifer into the mine.

6.3.2 Previous Studies

Several previous studies have examined the permeability and groundwater properties of the strata in the vicinity of the project area. These studies provide data which are relevant to the current study, and confirm the general regional hydrogeological conditions outlined in the previous section. The relevant data are summarised below and are utilised in the assessment.

Study 1

As part of the Eraring coal investigation, a study (Reference 12) was conducted in 1979 to investigate the potential problems associated with the alluvium in the proposed open cut area. The study included drilling of investigation bores in the valley of Jigadee Creek and Lords Creek, immediately downstream of the current extension area. These boreholes located alluvium up to 15 metres thick (in buried creek channels), but averaging about 9 metres across the broad flat valleys. The study found that:

- the alluvium is variable, mainly comprising clay and fine grained silty to clayey sand with buried channels of cleaner, medium to coarse grained sand and thin layers of fine gravel marking the former stream locations;

- the estimated transmissivity of the soil material intersected in the boreholes ranged from 0 to 106 m^2/day with a median value of 6.3 m^2/day.

Study 2

In 1980 a groundwater study was carried out in the proposed Eraring Open Cut area, which lies immediately south of the extension area. (Reference 5). This study included water pressure testing of twenty-four boreholes. Significant results from the study are as follows:

a) Of 75 tests on Teralba Conglomerate, 80% gave a permeability of less than 10^{-7} m/s. The highest permeability measured in the Teralba Conglomerate as $2x10^{-5}$ m/s where an irregular open joint was intersected.

b) In August 1979, it was reported that a drift in the Myuna Colliery intersected a water-bearing joint in the Teralba Conglomerate at a depth of about 135 metres. Initial water inflow rates were of the order of 290 L/min but had more than halved by the end of that month.

c) Of eighteen permeability tests carried out on the Great Northern Seam, seven had a permeability of less than 10^{-7} m/s. Three tests showed high leakage rates indicating a permeability of 10^{-5} m/s.

d) From groundwater inflow data at Awaba Colliery, the author estimates the vertical permeability of the strata above that mine to be about $1.7x10^{-8}$ m/sec. This mine is a wet mine by Central Coast standards and, due to its shallow depth of cover and subsidence cracking, experiences increases in groundwater seepage following rainfall events.

Study 3

In the early 1980's detailed groundwater investigations were carried out during the development of the Cooranbong Colliery (Reference 6). Significant outcomes from that work are summarised below:

a) Water pressure testing discovered that the permeability of the overburden strata above the Great Northern Seam was very low (<10^{-7} m/s). Only two tests (out of 80) measured a high permeability. In both tests, the high permeability was due to open joints or fractures in the near surface strata. Out of twenty six tests carried out in the Great Northern Seam, four yielded high permeability results. This high permeability was attributed to jointing and fracturing at the top and bottom of the seam. The remainder of the tests gave low permeability results with an average less than 10^{-7} m/s. Tests in the Fassifern seam returned about 10% with high permeabilities. These were also attributed to jointing in the coal seam.

The overall conclusion drawn from the testing was that the bulk permeability of the strata was low with occasional high permeability zones associated with joints, fracture zones or faults.

b) Fluctuations in the groundwater level in the near surface weathered rock aquifer due to climatic variations ranged up to 7.8 metres but were generally of the order of 1 to 3 metres.

c) Evidence from the study suggests that both the Great Northern Seam and Fassifern Seam are effectively aquifers relative to the overlying strata. Drainage of groundwater into the mine workings from the Great Northern Seam impacted on the piezometric pressure in the seam up to 1.6 km away.

d) Measurements of water levels were taken in three boreholes over total extraction areas (where the total depth of cover was between 70 and 75 metres), to give an indication of the impact of mining on the near surface aquifer. Two of the boreholes were drilled to a depth of approximately 55 metres above the Great Northern Seam, while one was drilled to within 41 metres of the seam. Water level measurements in the two shallow holes did not register any significant fluctuations during undermining, however in the deeper borehole, the water level dropped 15 metres during pillar extraction. This deeper borehole eventually collapsed below a depth of 18 metres due to strata movement caused by mining. The conclusion drawn from this data is that disturbance of the strata and drainage of any aquifer could be expected for a height of at least 20 times the extraction thickness above the workings.

e) During the early stages of development work for the Cooranbong Colliery, significant water inflows were experienced, especially in the northern belt drift. Over a period of approximately three months from mid-May 1980, 70ML of water was pumped from the drift, and in March 1981, groundwater flow into the drift averaged 400L/min. Workings in other parts of the mine did not encounter such wet conditions, and the inflows were essentially the result of drainage from the near surface aquifer.

f) Drainage of groundwater from the Great Northern Seam during mining resulted in the underlying Fassifern Seam having a high hydrostatic head relative to the Great Northern Seam. This pressure differential results in an upward hydraulic gradient which can cause slight heaving in the weak claystone floor of the Great Northern Seam. This hydrostatic uplift from below may cause fracturing and bed separation in the claystone, followed by ingress of water and subsequent swelling of the expansive clay minerals in the claystone. This provides a plausible explanation of the severe floor heave problems experienced in the Great Northern workings in many areas.

g) Evidence gathered during the study showed that major faults and dykes can act as barriers to horizontal groundwater flow in the coal seams.

h) The investigation was able to demonstrate that the drying up of a local farmer’s well was not the result of nearby mining but was caused by climatic conditions.

Study 4

Australian Groundwater Consultants, in 1988, prepared a report for Cooranbong Colliery detailing results of a study which had the objective of examining the means of prediction and control of groundwater inflows into the mine. (Reference 7). Some of the findings of the study which are relevant to the current investigation are as follows:

a) Inspections of the mine revealed a total lack of primary porosity, with inflow seepage restricted to structural features such as joints, cleats, fracture and fault planes and some bedding planes.

b) Groundwater inflows and/or accumulations in the workings were associated with areas of stored groundwater, including nearby goafed areas, unmined coal updip, abandoned workings updip, depressions in the seam floor, and newly breached fault zones or dykes.

c) Dykes and faults, when intersected in the workings, usually produced moderate groundwater inflows, which reduced over time to minor seepage flows of nuisance value only.

Study 5

In 1990, a detailed study, funded jointly by Pacific Power and the State Energy Research Development and Demonstration Fund, was conducted at Wyee Colliery. (Reference 8). The aim of the study was to determine the impact of total extraction mining on the groundwater regime in the overburden strata.

Packer testing carried out during the study indicated that the overburden rocks above the Great Northern Seam had a very low natural permeability of less than 10^{-8} m/s, except for the upper 25 metres of the strata which had a permeability of between 10^{-7} and 10^{-8} m/s. This slightly higher permeability at the surface confirmed the existence of a near surface weathered rock aquifer.

The study also included a series of measurements of the piezometric pressures at discreet horizons in boreholes, located over a 350m wide area of totally extracted Great Northern workings, where the depth of cover was about 180 metres. At Wyee Colliery, this testing, which was carried out before and after mining, indicated that the coal extraction resulted in drainage of groundwater from the overburden strata to a height above the workings of 21 to 33 times the seam thickness. This indicated that the fractured zone in the strata extended to a height above the workings of 21 to 33 times the seam thickness. Similarly, post-mining testing carried out in a borehole above the Cooranbong Colliery workings confirmed that the fractured zone extended to a height of 21 times the seam thickness above the mine.

Study 6

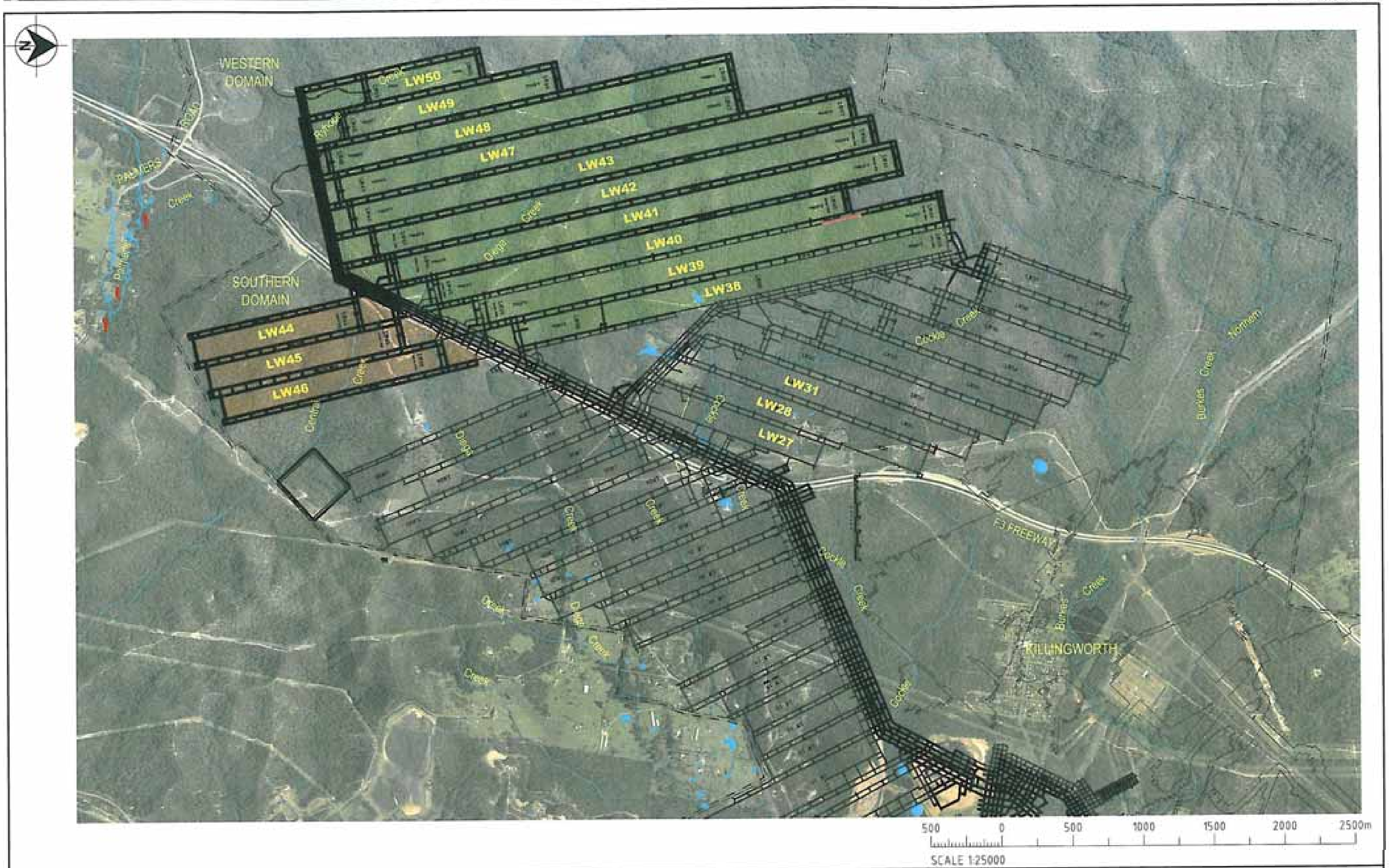
In 1991 Cooranbong Colliery commissioned a study (Reference 9) on the potential for groundwater inflows into the proposed longwalls 5, 6 and 7 beneath Jigadee Creek, where the depth of cover to the base of the alluvium ranged from 50 to 70 metres. It was estimated that the fractured zone above the proposed longwalls would extend to between 50 and 80 metres above the seam with the proposed mining layout, and hence it was possible that the fractured zone would reach the rockhead beneath the alluvium. Nevertheless, it was concluded that, even with 40m of rock cover there was a “low probability that extensive through-going zones or high permeability will occur”. This conclusion was never tested, due to changes in the mine plans.

The study also determined that the alluvium in Jigadee Creek is up to 14.7 metres thick. The composition of the alluvium was found to be variable, with the upper 5 to 8 metres comprising clay and clayey sand. This layer is generally underlain by clean, medium to coarse grained sand beds with some gravel layers. The permeability of the sand and gravel layers was estimated to be between 10^{-3} and 10^{-5} m/sec. The water table measured in boreholes was generally near surface.

Study 7

In 1997, a groundwater investigation was carried out as part of the Cooranbong Colliery Life Extension Project. This study included accurate measurement of the permeability of the Wallarah/Great Northern Seam and the overburden strata. Two tests on the Wallarah/Great Northern Seam gave permeabilities of 2.2×10^{-9} and 7.4×10^{-6} m/s, while seven tests on the overburden strata gave permeabilities in the range 3.1×10^{-9} to 1.9×10^{-11} m/s.

Figures



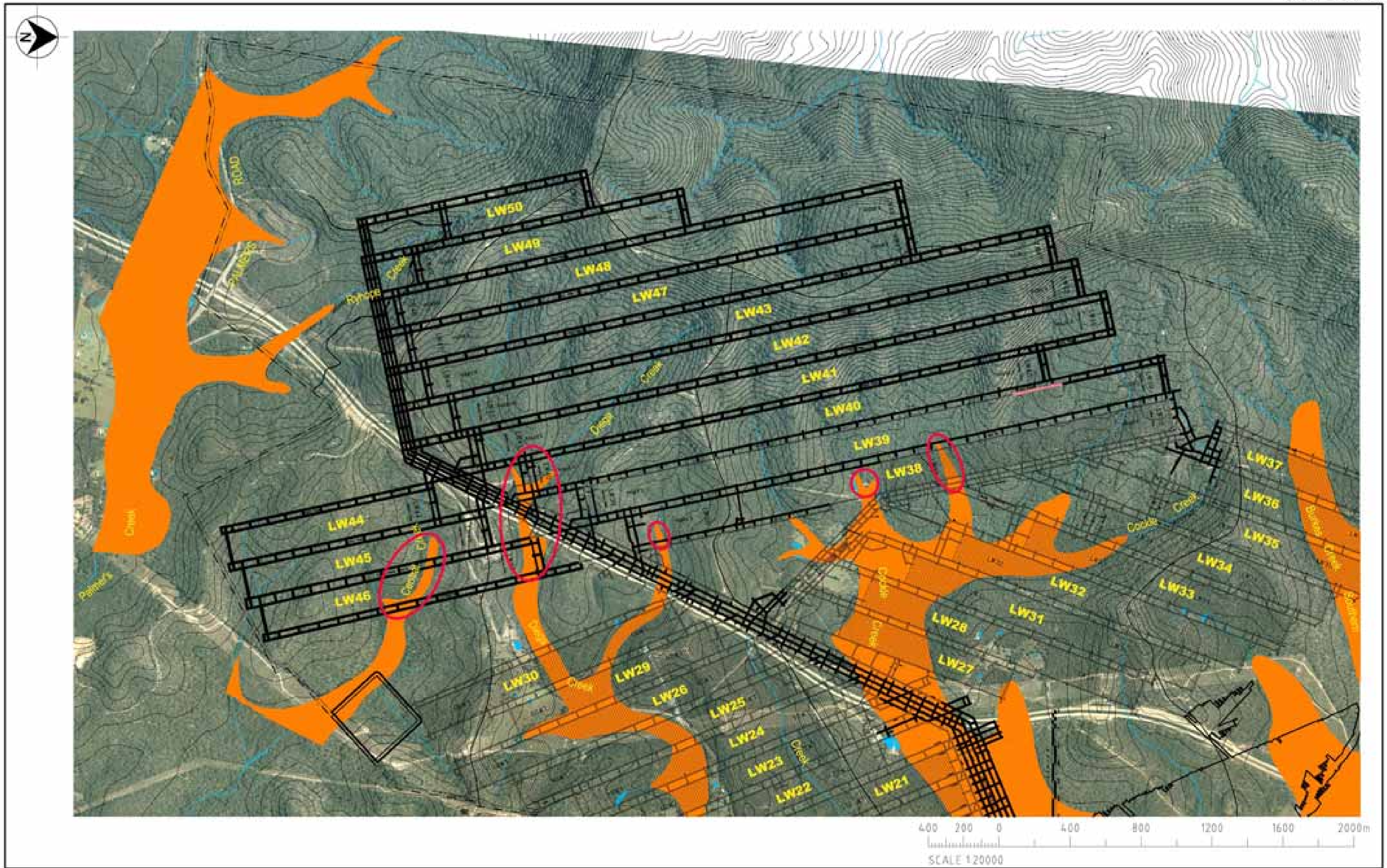
WEST WALLSEND COLLIERY
CONTINUING OPERATION PROJECT
LOCATION PLAN

Indicates Western Domain

Indicates Southern Domain

FIGURE No. 01

aurecon



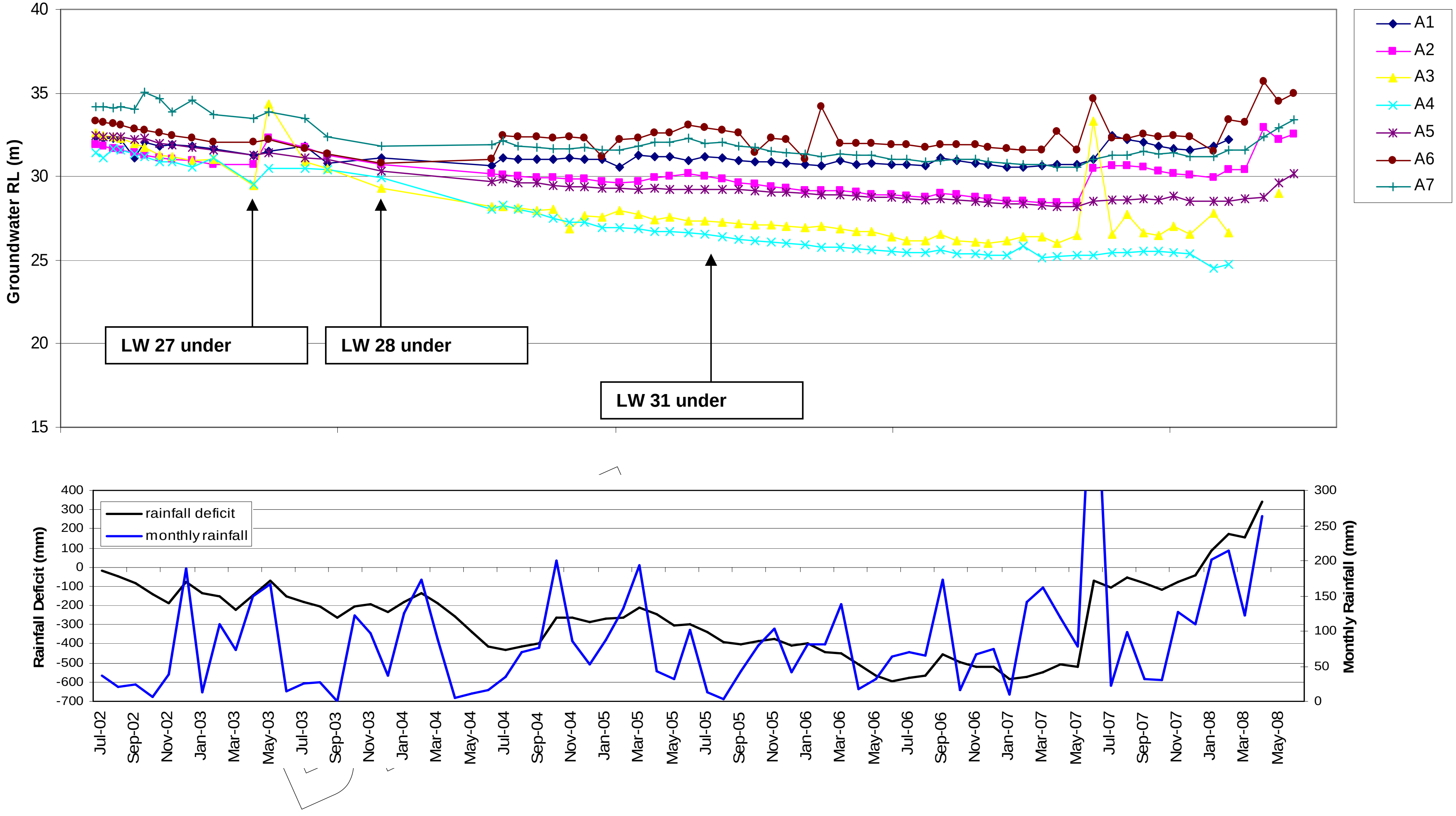
WEST WALLSEND COLLIERY
CONTINUING OPERATION PROJECT
LOCATION OF ALLUVIAL AREAS

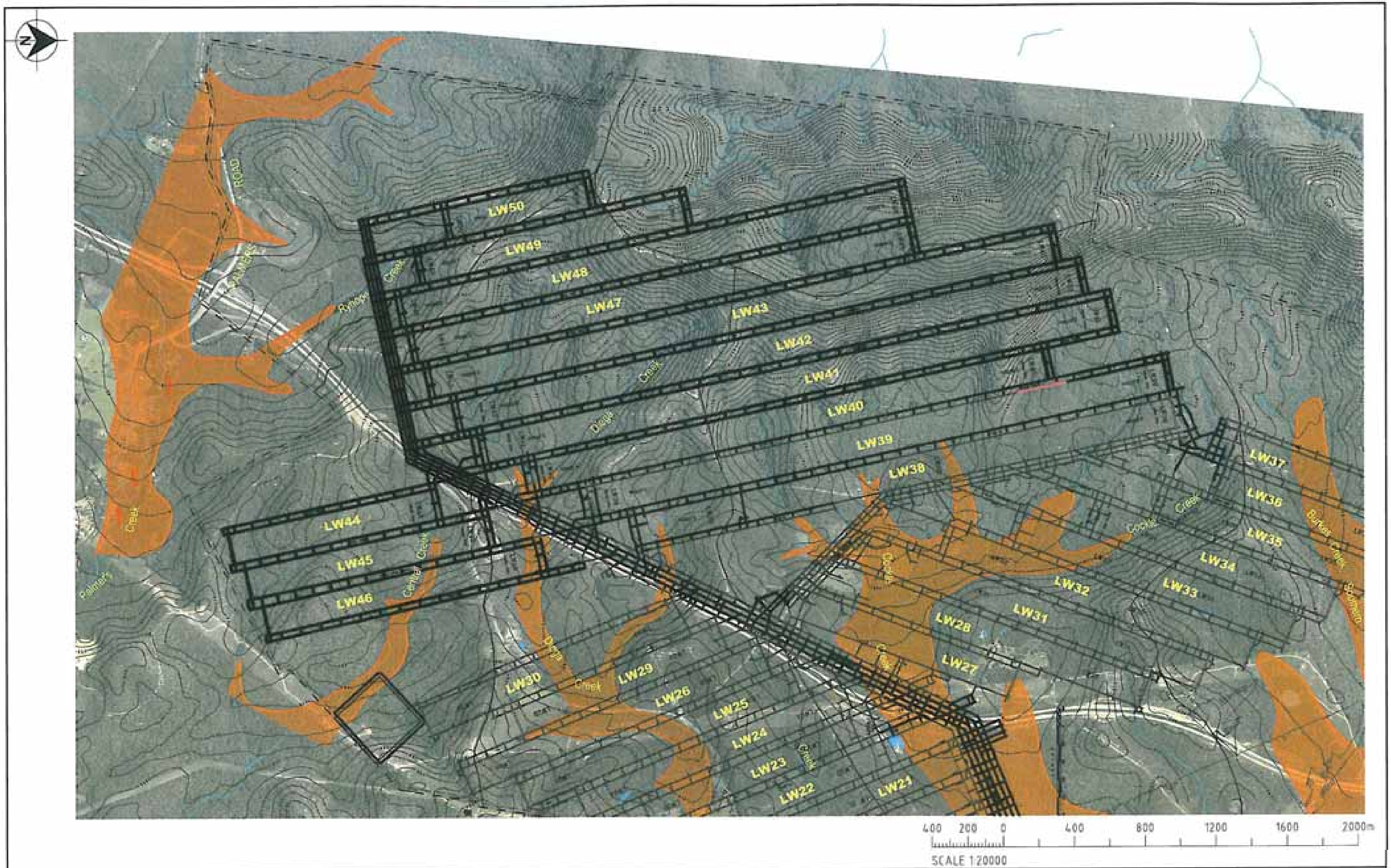
Indicates Alluvial Area

Alluvial Area Overlying Continuing Operations Project

FIGURE No. 02

FIGURE 3 - LW 27 and 28 - Groundwater Levels

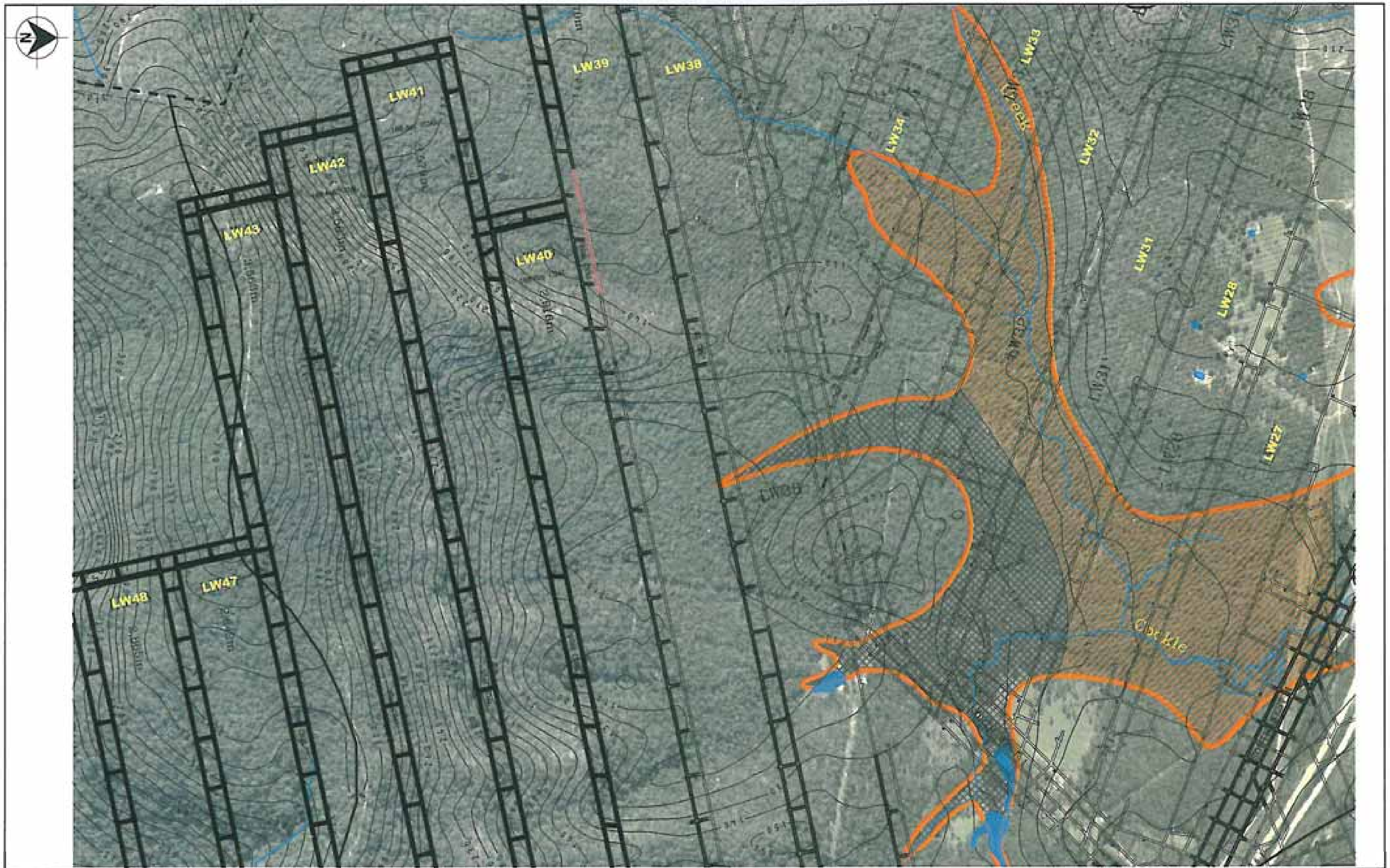




WEST WALLSEND COLLIERY
CONTINUING OPERATION PROJECT
DEPTH OF COVER

Indicates Alluvial Area

FIGURE No. 04



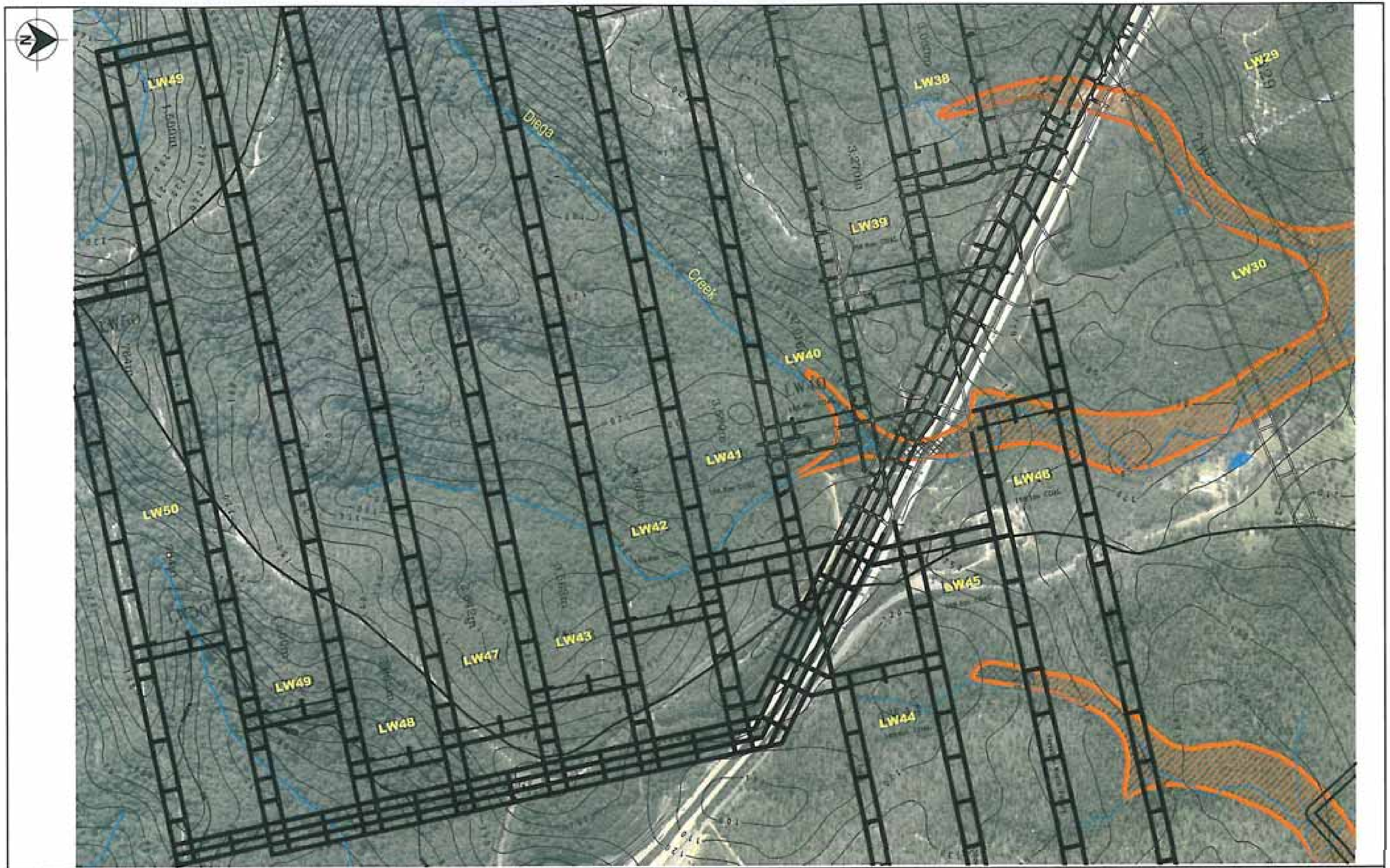
WEST WALLSEND COLLIERY
CONTINUING OPERATION PROJECT
PROBABILITY OF AN ADVERSE IMPACT - SHEET 1 OF 3

Low
Medium
Very High
High

Note: Contours show depth of cover

100 100 0 100 200 300 400 500 600 700 800m
SCALE 1:12500

FIGURE No. 05



WEST WALLSEND COLLIERY
CONTINUING OPERATION PROJECT
PROBABILITY OF AN ADVERSE IMPACT - SHEET 2 OF 3

Low
Medium
Very High
High

Note: Contours show depth of cover

100 100 0 100 200 300 400 500 600 700 800m
SCALE 1:12500

FIGURE No. 06

aurecon

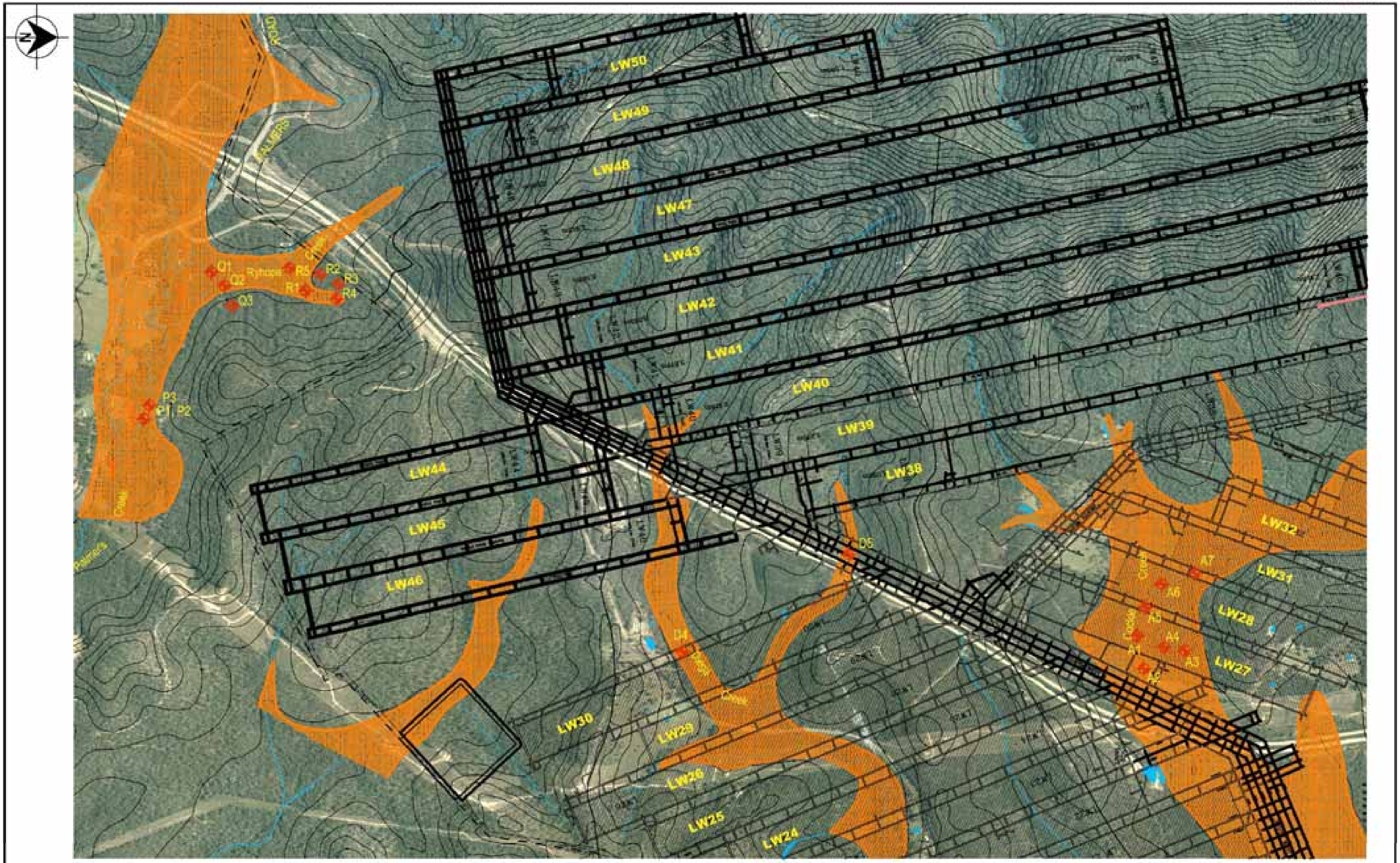
WEST WALLSEND COLLIERY
CONTINUING OPERATION PROJECT
PROBABILITY OF AN ADVERSE IMPACT - SHEET 3 OF 3

Low
Medium
Very High
High

Note: Contours show depth of cover

SCALE 1:12500

FIGURE No. 07



WEST WALLSEND COLLIERY
CONTINUING OPERATION PROJECT
LOCATION OF GROUNDWATER MONITORING BORES/AUGER HOLES

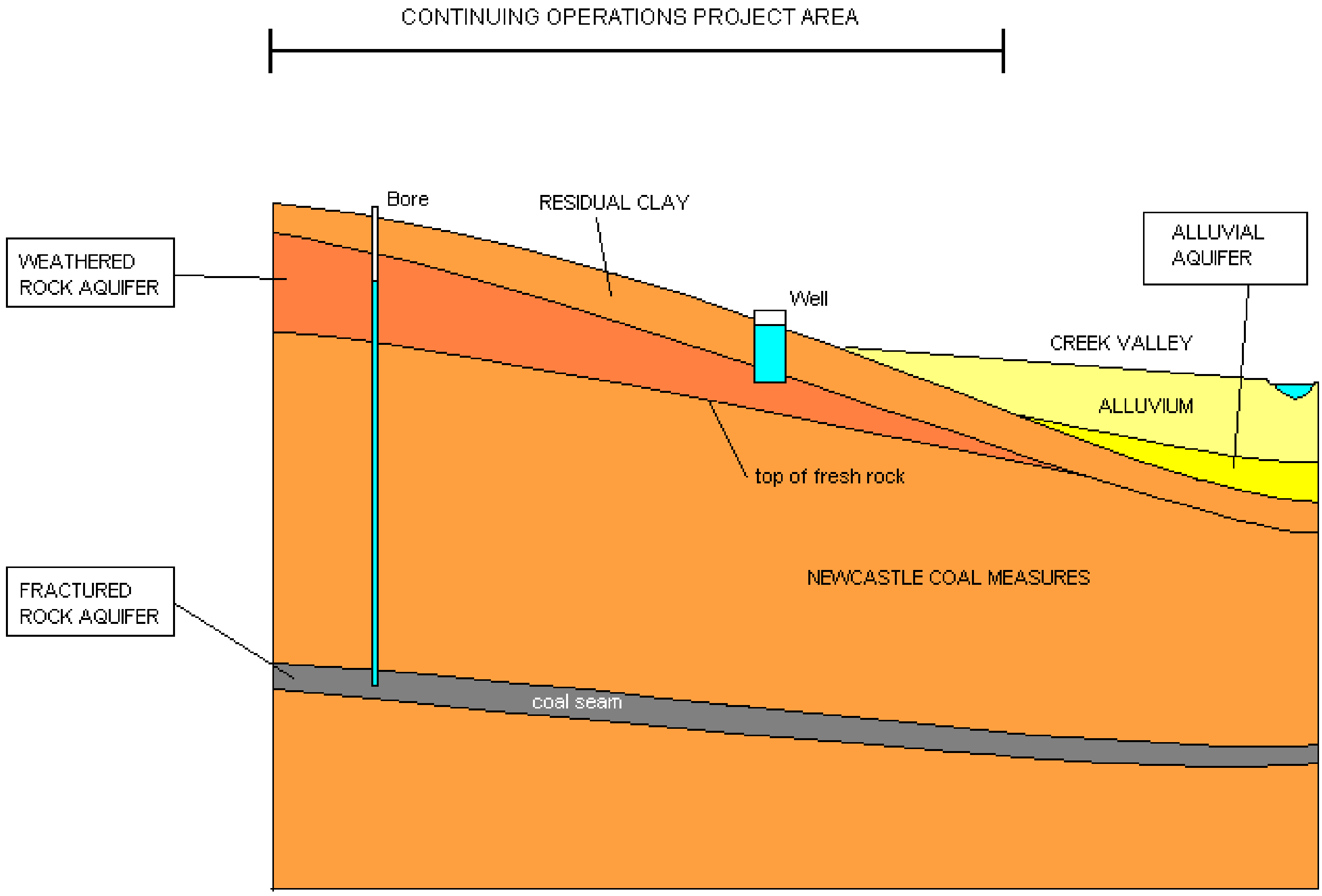
Indicates Alluvial Area

D4 Location of auger hole/ groundwater monitoring borehole

100 0 200 400 600 800m 1000m

SCALE 1:15000

FIGURE No. 08



SCHEMATIC CROSS SECTION

FIGURE No.09

WEST WALLSEND COLLIERY
CONTINUING OPERATION PROJECT
GROUNDWATER FLOW DIRECTIONS

Indicates Alluvial Area

Groundwater Flow Direction

FIGURE No. 10