Connell Wagner Pty Ltd
ABN 54 005 139 873
116 Military Road
Neutral Bay
New South Wales 2089 Australia

Telephone: +61 2 9465 5599
Facsimile: +61 2 9465 5598
Email: cwsyd@conwag.com
www.conwag.com

Future Mine Development
Groundwater Impact Assessment
Austar Coal Mine

27 October 2007
Reference 30518-001
Revision 1

Connell Wagner

Document Control

Connell Wagner

Document ID: O:\30518\ENG\REPORT\ACMREPORTFINAL.DOC

Rev No	Date	Revision Details	Typist	Author	Verifier	Approver
0	12 October 2007	Draft for Client comment	IF	IF		
1	27 October 2007	Final	IF	IF	BW	LK

Important Things You Should Know About This Report

A person using Connell Wagner documents or data accepts the risk of:

- Using the documents or data in electronic form without requesting and checking them for accuracy against the original hard copy version.
- Using the documents or data for any purpose not agreed to in writing by Connell Wagner.

Exclusive Benefit and Reliance

- This report has been prepared by Connell Wagner Pty Ltd, at the request of and exclusively for the benefit and reliance of its Client
- This report is not a certification, warranty or guarantee. It is a report scoped in accordance with the Client's instructions, having due regard to the assumptions that Connell Wagner Pty Ltd can be reasonably expected to make in accordance with sound engineering practice and exercising the obligations and the level of skill, care and attention required of it under this contract.

Third Parties

- It is not possible to make a proper assessment of the report without a clear understanding of the terms of engagement under which the report has to be prepared, including the scope of the instructions and directions given to and the assumptions made by the engineer/ scientist who has prepared the report.
- The report is a report scoped in accordance with the instructions given by or on behalf of the Client. The report may not address issues which would need to be addressed with a third party if that party's particular circumstances, requirements and experience with such reports were known and may make assumptions about matters of which a third party is not aware.
- Connell Wagner therefore does not assume responsibility for the use of the report by any third party and the use of the report by any third party is at the risk of that party.

Limits of Investigation and Information

- The report is also based on information provided to Connell Wagner by other parties. The report is provided strictly on the basis that the information that has been provided can be relied on and is accurate, complete and adequate.
- Connell Wagner takes no responsibility and disclaims all liability whatsoever for any loss or damage that the client may suffer resulting from any conclusions based on information provided to Connell Wagner, except to the extent that Connell Wagner expressly indicates in the report that it has verified the information to its satisfaction.

Contents

Figures

Appendix A

Appendix B

Groundwater summary sheets

1. Introduction

The Austar Coal Mine, formerly the Southland Colliery, is located approximately 10 kilometres southwest of Cessnock on the Wollombi Road (Figure 1). The mine is proposing to carry out underground mining activities in the stage 2 and stage 3 areas within the company's existing mining lease area.

Austar is currently extracting coal by longwall top coal caving methods in the Greta Seam in the stage 1 area of the lease. The approval to extract coal by this method was granted in 1996 and the consent modified to allow the introduction of Longwall Top Coal Caving (LTCC) in September 2006 subject to a number of conditions. One condition required the mine to develop a Site Water Management Plan (SWMP) which is designed to ensure that the mining operation does not result in adverse impacts on water quality. The SWMP focuses on strategies to manage and monitor water quality, and outlines a monitoring and reporting schedule. As part of the SWMP, an assessment was required of the potential for any impact of the proposed mining on the groundwater regime in this region.

Preliminary investigations for stages 2 and 3 of the project have highlighted two main aspects of the local groundwater regime which may be impacted. These include:

- the potential impact on any aquifer zones in the overburden; and
- the potential impact on the alluvial aquifer in the valley of Quorrobolong Creek and its tributaries.

In order to assist with future mine planning, Austar has commissioned Connell Wagner to examine these hydrogeological aspects in detail. This assessment draws on available relevant data, and presents a documented evaluation of the likely impact of subsidence on the aquifers. This report presents the findings and the results of the evaluation. Sections 3, 4 and 5 of the report present relevant data and establish the baseline geological and hydrogeological conditions in the vicinity of the future mining area, while Sections 6 to 8 present an evaluation of the potential impacts of the proposed mining. Section 9 focuses on the proposed monitoring measures for stages 2 and 3.

2. Scope of works

The scope of work for this study was outlined in a proposal forwarded to Austar in September 2007 and included the following:

Stage 1 – Characterise the Local Groundwater Regime

- Meet with Austar staff for handover of all information and on-site evaluation of available water balance data – relevant data to be provided;
- Assess and evaluate all of the available geological, alluvial and groundwater data;
- Provide a description of the local hydrogeological regime, based on the available data and the results of previous studies in the region;
- Confirm the extent of all alluvial areas, produce a map showing the extent of the alluvium relevant to the project and the location of the existing water bores, and characterise existing groundwater usage patterns within the Sandy Creek/Cony Creek area with reference to data from the NSW database of groundwater wells and bores;
- Confirm the nature of any aquifers zones in the overburden strata above the proposed mine workings;
- Establish a groundwater monitoring bore in the alluvial area using an existing borehole and instrumentation provided by Connell Wagner.

Stage 2 – Groundwater Impact Assessment

Following the completion of stage 1 an assessment will be made of the likely impact of extraction of future longwall panels on the hydrogeological regime. This assessment will include the following:

- Estimate the likely height of fracturing above the future extraction panels in this area utilising previous experience at the mine and including reference to other studies in the local area;
- Determine the likely impact of future proposed mining on the hydrogeological regime and groundwater utilisation in these areas, based on;
    - the assessment of the current water balance data from stage 1;
    - the nature of the existing hydrogeological regime;
    - the extent of the alluvium and the local topography;
    - the nature of any aquifers in the overburden;
    - the current groundwater usage patterns;
    - a detailed analysis of the geological conditions, and any variations in the stratigraphy over the site;
    - the proposed mine layout, including proposed panel widths, depths of cover and working thickness;
    - the results of subsidence monitoring and predictions of future mine subsidence;
    - the nature and extent of fracturing in the overburden due to longwall extraction; and
    - previous mining experience in the local area.
- Make a qualitative assessment of the likely maximum mine water inflows to the future extraction area;
- Highlight critical locations and make recommendations for any necessary actions to monitor and/or protect groundwater resources within the lease area;

Stage 3 – Report preparation

Once the study is completed, produce a report which will be suitable for submission to the DoP and DPI in support of future mining applications, and will provide the necessary input to the SWMP particularly for stage 2 and 3 of the project. The report will include:

- a summary description of the geological setting and local hydrogeological regime, including the existence and importance of aquifers in the region;
- an assessment the likely impact of the proposed mining on the overburden strata;
- a summary of the assessed impact of the mining on the local hydrogeological regime; and
- a summary of the mine water inflow assessment; and
- recommendations for any actions to monitor and/or protect groundwater resources within the lease area.

3. Geological setting

The geological conditions in the vicinity of Austar Coal Mine are presented in detail in the notes accompanying the Newcastle Coal Geology map (Hawley & Brunton, 1995). A brief summary of the geological setting is presented below.

The mid Permian Age Greta Coal Measures crop out around the Lochinvar Anticline, which is the dominant structural feature in the Cessnock area. Austar Coal Mine Colliery is located on the nose of the anticline, and the strata in this area dip at 2 to 4 degrees to the south-east. The colliery extracts coal from the Greta Seam, which is the main economic coal seam in the Greta Coal Measures.

The Greta seam ranges up to 7 metres thick in the Austar Coal Mine lease area, although the maximum extraction thickness in the former Ellalong and Southland workings was 3.9 metres. The seam is overlain by the Paxton Formation, which comprises a series of interbedded sandstone and siltstone layers up to 20 metres thick. Unconfined compressive strength (UCS) testing carried out on core from several boreholes as part of the investigation for the SMP for longwalls 3 to 5 (SCT, 2006) produced an average UCS of 38 MPa for 26 rock samples from the Paxton Formation. Prior to this, in 1999, testing of seven core samples of the Paxton Formation from borehole SBD 1012, at the site of the # 3 shaft yielded an average UCS of 47 MPa (Rosengren & Associates, 1999).

The Pelton Seam, which is less than 0.5 metre thick, lies at the top of the Paxton Formation and forms the upper limit of the Greta Coal Measures. The Branxton Formation overlies the Greta Coal Measures and extends from the Pelton Seam to the ground surface. Its maximum thickness in this region is of the order of 1300 metres, and it comprises sandstone and conglomerate towards the base, with silty sandstone becoming more common towards the top. The rock is generally strong and massive, with few bedding plane partings. Previous unconfined compressive strength testing for Southland Colliery indicated that the lower 40 metres of the Branxton Formation has an average UCS of 79 MPa, while the lower 200 metres has an average UCS of 56 MPa (Holt Assoc., 1992). Additional testing carried out on core from borehole ADQ 1075 as part of the investigation for the SMP for longwalls 3 to 5 (SCT, 2006) confirmed the high strength of this rock unit. The average UCS of 8 samples of the Branxton Formation taken from this borehole was 59 MPa. Previous UCS testing on 38 samples of (Rosengren & Associates, 1999) Branxton Formation rocks from borehole SBD 1012 produced an average UCS of 47 MPa. These test results are shown on the logs in Appendix A.

The area is crossed by several major fault zones, which radiate around the nose of the anticline, and trend in a south to south-easterly direction. The fault zones that have been intersected in the workings include the Swamp Fault Zone, which crosses the centre of the Austar lease, and the Greenmount Fault Zone, which separates the Ellalong and Bellbird areas. Another major fault zone borders the western side of the lease and is parallel to the main south headings. Most fault zones intersected to date comprise a series of smaller faults with a total throw of up to 10 metres. Many of the smaller faults are discontinuous and may occur as en echelon type structures.

Two additional fault zones have been identified in the area to be extracted in the future. These are the Quorrobolong fault zone, which is located on the western side of the proposed stage 3 longwall panels, and the Abernethy fault zone which forms the eastern boundary of the lease area.

Igneous structures are not common in the workings, although one major dyke structure crosses the Ellalong longwall panels, trending at about 150°. Another major dyke, the Central Dyke, bounds the eastern side of longwalls SL 2 to 4, where it is associated with some water inflows. The main geological structures are shown on Figure 2.

There are several creek valleys that cross the stage 2 and 3 area. These valleys range up to several hundred metres wide, and are filled with recent alluvial and colluvial deposits comprising mostly sand, silt and clay.

4. Previous and proposed mining

Mining has been carried out in the Cessnock area for more than a century There are many abandoned coal mines in the area, most of which are inundated with mine water and are up-dip of the current and proposed future workings. The collieries adjacent to the current workings include the following:

- The Ellalong Colliery forms part of the current Austar Coal mine and most of the water make in the mine is pumped to the Ellalong goaf before it is pumped out of the mine via the No. 2 shaft.
- The West Pelton workings are located to the west of the main south headings and connected to the Austar workings by two dewatering boreholes.
- The East Pelton workings are located to the west of the main south headings and connected to the Austar workings by five dewatering boreholes
- Kalingo (Cessnock No. 1) Colliery is located to the west of the current Austar longwall panels A1 and A2 – seepage from these workings flows to longwalls 13 and A2
- Bellbird Colliery is located to the north of the current Austar longwall panels A1 and A2 – seepage flows to longwall A2;
- Aberdare Central Colliery is located to the east of longwalls SL2 to SL4 – seepage flows to longwalls A1, A2 and SL2 to SL4; and
- Aberdare South and Elrington Collieries are situated to the south of the current workings – these workings may provide possible future seepage to the workings in stage 2 and stage 3 areas.

In addition to these collieries, there are numerous other abandoned collieries in the surrounding area which have an influence on regional groundwater including the Maitland Main, Stanford Main No. 2, Aberdare Extended, Cessnock No. 2, Aberdare, Aberdare East and Abermain No. 2 collieries. The location of these collieries is shown on Figure 2. Stages 2 and 3 involve the extraction of fifteen longwall panels in the Greta Seam over an area of more than 1400 hectares. Details of the proposed mining are summarised below:

	Stage 2	**Stage 3**
Seam	Greta	Greta
Longwall panels	A3 to A5	A6 to A17
Extraction thickness	5.0 to 6.5 m	4.2 to 7.0 m
Depth of cover (over longwall panels)	470 to 545 m	450 to 740 m
Panel length	954 to 1317 m	1514 to 3171 m
Panel Width	227 m	227 m
Solid pillar width	45 m	45 m
Predicted maximum subsidence	1.39 to 2.95 m	1.92 to 3.04 m
Predicted maximum tensile strains	0.7 to 1.2 mm/m	0.8 to 1.2 mm/m
Predicted maximum compressive strains	1.9 to 3.7 mm/m	1.8 to 3.0 mm/m
Predicted maximum tilts	5.8 to 10.9 mm/m	6.7 to 10.0 mm/m
Commencement date	June 2008	April 2011 (A6)

The location and the layout of the proposed longwall panels is shown on Figure 2. The structure contours on the seam are shown on Figure 3, and the depth of cover in the development area is shown on Figure 4.

5. Local hydrogeological regime

In order to determine what impact, if any, the proposed mining will have on the aquifer systems in the vicinity of the stage 2 and 3 areas, it is necessary to establish a model for the local hydrogeological regime. The hydrogeological regime is defined as the occurrence of groundwater and its dynamic interaction with the local geological conditions. Unfortunately, there is little published data on the hydrogeological characteristics of the Newcastle Coalfield strata. The following assessment is based on data gathered for the current investigations, additional data acquired during previous investigations at the mine and other local investigations (Pacific Power International, 1997 and 2002; Forster, 1995; Forster & Enever, 1991; Morton & Kidd, 1980), as well as local experience.

Previous local experience has shown that, there are three potential sources of groundwater that form an integral part of the local hydrogeological regime in this area:

- alluvial aquifers;
- fractured rock aquifers (including coal seam aquifers); and
- abandoned coal mines.

The distribution, characteristics and importance of these water sources are summarised in the following subsections.

5.1 Alluvial aquifers

Potentially, the most important natural groundwater resource in the Newcastle/Cessnock area is found in the alluvial sediments, which cover the low-lying areas, and fill the broad valleys of the creeks that form the tributaries of the Hunter River. 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).

While most of the important, and heavily utilised alluvial deposits are associated with the larger rivers and creeks, some of the smaller tributaries contain alluvial deposits of reasonable importance. One of these is Quorrobolong Creek and its tributaries which flow in a general westerly direction across the Austar lease area. The tributaries that cross the Austar lease, including Sandy Creek and Cony Creek, are second or third order streams, and comprise a series of intermittent creeks, which only flow after consistent or heavy rainfall. These creeks have shallow alluvium-filled valleys ranging in width up to 400 m. They flow ultimately to the west of the Austar lease area into the Wollombi Brook, a tributary of the Hunter River that contains a significant alluvial aquifer.

The groundwater in the alluvium is derived largely from infiltration of rainfall and runoff, although some is derived from lateral infiltration during high flows in the adjacent creeks. Normally, the groundwater discharges into the creeks during periods of low flows. There is also a general, gradual movement of groundwater in a downstream direction within the alluvium, which contributes to the alluvial aquifers further downstream. Due to the very low vertical permeability of the underlying rock strata, there is very little vertical leakage of groundwater from the alluvium, and it is essentially isolated hydraulically from the rest of the hydrogeological regime.

There has been no detailed investigation to determine the nature and depth of the alluvial deposits in the creek valleys within the lease area. The little data that is available indicates that the alluvium in this area is generally clayey, with no major water-bearing zones. Nevertheless, terrain mapping and evaluation has established the extent of the deposits, which cover only a small proportion of the extended lease area (Figure 5). A search of the Department of Water and Energy (DWE) database of water bores indicates that there are no registered bores within the local area that extract water from the alluvial deposits, although there may be some unregistered bores.

Due to the lack of data on the groundwater in the alluvium, a groundwater monitoring site has been established by Austar in an existing borehole in the stage 2 area (AQD 1073A) as part of the current studies. This bore is 7.7 metres deep and is located in the alluvial deposits in Quorrobolong Creek over longwall A4 (see Figure 5 for the location of the bore). The log of the bore (included in Appendix A) indicates that the alluvium is less than 3 metres thick in this area, and the groundwater table was at a depth of 2.7 metres below the ground surface when the bore was drilled. Subsequent measurements have indicated that the groundwater table has risen to a level of 1.6 metres below the surface following heavy rains in June 2007. Recent EC readings in the bore range between 676 to 1760 µS/cm. No EC measurements were taken prior to the June 2007 rainfall event, but it is likely that the water quality would normally be lower than the recent readings.

Although there is limited data on the alluvium, it is possible that there may be occasional water-bearing sand horizons, interbedded with less permeable clay lenses. Due to the variable composition and excessive fines content, its overall permeability is not likely to be high, and yields from any water bores would generally be expected to be low. The limited data available also suggests that the groundwater quality is normally fair, and could be suitable for stock use but not domestic consumption. Consequently, as an aquifer, the alluvium in this area is probably of limited importance. There is negligible utilisation of the alluvial groundwater supported by the fact that there is a lack of registered bores in the area.

Despite this conclusion, there may be pockets or zones of better quality water within the alluvium (possibly in former channel deposits), which are recharged with groundwater during flood events, and contribute some of that water to the local stream system during the period following the flood. These pockets of groundwater may also make a small contribution to the groundwater in the more important alluvial aquifers down stream in Quorrobolong Creek and Wollombi Brook. As a result, the impact of future mining on the alluvium must be assessed, to comply with the draft Guidelines for Management of Stream/Aquifer Systems in Coal Mining Developments (DLWC, 2001).

The only groundwater dependent ecosystem known in the area that relies to some extent on the groundwater in the alluvium is the Swamp Oak Riparian Forest area above the proposed underground mining which is restricted to the creek channels . For this reason, potential impacts on the alluvial aquifer must be determined, as there may be a consequential impact on the dependant ecosystem.

5.2 Fractured rock aquifers

Investigations have shown that the Permian strata overlying the coal measures in the Newcastle Coalfield generally have very low permeabilities ($<10^{-8}$ m/s), however there are occasional layers that have a slightly higher permeability and represent relative aquifers. Since the interstitial permeability of the rock fabric is generally negligible, groundwater occurrence and flow in these water-bearing strata is almost always through the discontinuities in the rock, which can produce a secondary permeability. These aquifer zones are termed **fractured rock aquifers**. They generally comprise 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 fracture, cleat and/or joint patterns (hence the term fractured rock aquifer).

The term “aquifer” is generally applied to any stratum that has a high groundwater carrying capacity, relative to the surrounding soil or rock. It does not necessarily indicate the presence of a significant water resource within the stratum. The term “water-bearing zone” is often more applicable in this context, and is used to describe aquifers where the continuity and permeability of the water bearing stratum has not been established.

Fractured rock aquifers have the potential for high flows, since they are confined aquifers and are at a relatively high pressure. Nevertheless, flows are often 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 hydraulic head. Due to the very low vertical permeability of the Permian strata, there is very little leakage between any water-bearing zones or aquifers. Because of this they may receive very little recharge through infiltration, with most recharge generally coming from the subcrop zone, or through major geological structures which feed water from higher up in the sequence.

The occurrence of fractured rock aquifers in the strata overlying the Austar mine are summarised in the following subsections.

5.2.1 Branxton Formation

Due to the massive nature of the Branxton Formation, it contains few if any major fractured rock aquifers, with only the occasional water-bearing zone being intersected in drill holes. A search of the DWE database of water bores indicates that there is only one registered bore within the stage 2 area which intersected groundwater in the rock strata. This bore is 39.6 metres deep, and is located to the west of longwall A3. The limited data from this bore (GW054676) indicates the alluvium is up to 10 metres thick, but the water bearing zone was located in a shale layer below the alluvium. The bore is low-yielding, and produces a flow of about 1 L/sec of poor quality water (EC = 12,000-16,000 µS/cm). The standing water level in this bore is currently about 1.3 metres below the surface following heavy rainfall, although the groundwater table is normally more than 2 metres deep. The bore is not utilised for agricultural purposes, but is used as a background monitoring bore for the DWE.

A seven metre deep bore, which intersects the soil profile, is located adjacent to the registered bore GW054676. The groundwater in this bore has an EC of 10,000 to 11,000 µS/cm, and the depth to the water table is normally more than 2 metres. However, recent heavy rainfall has reduced the near-surface groundwater EC to about 1600 µS/cm, and raised the water table to within 0.15 metres of the surface.

There are an additional three registered bores within the near vicinity of the stage 3 longwall panels that intersect the Branxton Formation strata. These bores range in depth from 9.1 to 55 metres and all three attempt to tap fractured zones in the upper Branxton Formation. All three bores are low yielding, with individual fractured zones producing 0.3 to 0.6 L/sec. The one bore in which salinity levels were measured had salinity estimate of 10,000 to 14,000 ppm. This generally poor groundwater quality in the Branxton Formation is due largely due to the fact that the rocks were formed in a marine environment, and the long residence time of the groundwater in the strata provides ample opportunity for any salt to be leached from the rocks by the groundwater.

The groundwater works summary sheets for all bores are given in Appendix B, and the location of the bores is marked on Figure 5.

Other investigations by Austar, including exploration boreholes, have indicated that there may be a potential water-bearing zone in the Branxton Formation at a depth of 70 to 100 metres below the surface. A bail-out test carried out in a pilot hole (RB1) during the sinking of the number 4 downcast ventilation shaft supports this. During the test, the bore was bailed to a depth of about 120 metres over a period of 3 hours. Flow into the bore averaged about 1 L/sec, but did not increase with depth below about 70 metres, suggesting that the water bearing stratum was between that level and the standing water level in the bore (53 m). In addition, once the bore was dewatered to a depth of 90 m, water could be heard trickling into the hole, indicating a water-bearing stratum above this level.

Further evidence for the existence of this shallow water-bearing stratum is the data from piezometers installed in borehole AQD 1077, adjacent to longwall A2. The piezometer at a depth of 30 metres measures no head, indicating that the groundwater table is below this level, while the piezometer at a depth of 200 m, shows a piezometric level about 80 m below the ground surface.

It is almost certain that this near-surface water-bearing stratum in the Branxton Formation is not a single stratigraphic horizon. It is likely that the higher permeability zone is formed where the high horizontal stresses are relieved, and some fracturing occurs. It is possible that this stress relief occurs at the base of a massive sandstone unit in which the stress is released due to reduced overburden pressure.

It is important to quantify the permeability of the Branxton Formation, as any groundwater bearing horizons within the zone of interconnected cracking in the overburden strata immediately above a longwall panel will drain into the goaf during extraction of the coal seam, and the permeability of these strata can be used to calculate the predicted rate of inflow to the mine..

Previous experience in the Newcastle Coalfield has shown that the permeability of the strata in the Branxton Formation is normally very low. The sandstone is generally strong and massive with a silica and/or clay matrix. As a result, the interstitial permeability is negligible, and any measured permeability derives from fractures and joints. The limited geotechnical logging that has been undertaken has shown that there are very few open fractures which have the capacity to transmit significant groundwater flow. The exploration borehole (AQD 1075) confirmed this, in which packer testing was conducted at selected test horizons in the Branxton Formation overburden. Of the 7 tests conducted, 3 produced zero permeability, while the remainder had permeabilities ranging from 1.7 x 10^{-8} to 2.6 x 10^{-9} m/sec (SCT, 2006). The non-zero results are plotted on Figure 6.

While these permeability values are very low, the packer testing method used is generally only suited to strata with a permeability of greater than 10^{-7} m/s. A review of the test results has confirmed that several of the tests show evidence of fracture dilation at high pressures. This phenomenon could also be due to leakage past the packers at high pressures. Importantly, the result is that permeabilities may have been overestimated for these tests, and the permeability of the Branxton Formation may be even less than the testing has indicated.

Slightly higher permeabilities were measured in borehole SBD 1012 which is the site of the #3 ventilation shaft. The results in five tests ranged from 1.4 x 10^{-8} to 8.3 x 10^{-8} m/s. These data are also plotted on Figure 6. Again, the test method used was the packer test, which has limitations as discussed above. An airlift test on this bore produced only 0.3 L/sec for the full length of 450 metres (including the Greta Seam), confirming the very low permeability of the strata.

In summary, the permeability of the Branxton Formation strata is generally very low and not likely to provide a viable source of groundwater, or produce large quantities of inflow to the mine. There is evidence to suggest that there may be groundwater-bearing zones in the overburden above the mine at a depth of around 70 to 100 metres below the surface. However, based on the available information, it is concluded that the importance of this groundwater as a water resource is likely to be minimal, since the water quality in these water-bearing zones is poor and the yield low. Despite this, the potential impact of the proposed mining on these zones must be evaluated to fulfil the conditions set for the SWMP, and to demonstrate that the development of the mine complies with the NSW State Groundwater Policy Framework Document (DLWC, 1997).

There are no known groundwater dependent ecosystems of any significance that rely on the groundwater in the Branxton Formation, so that the requirements relating to these systems are not relevant for this development.

5.2.2 Coal measures

Like the Permian strata, the rocks in the Greta Coal Measures also have very low permeabilities ($<10^{-8}$ m/s), with occasional layers that have a slightly higher permeability and represent relative aquifers. As a rule, the coal seams are normally the water-bearing zones in the coal measures due to the presence of cleats and fractures in the rock mass. These too are termed fractured rock aquifers, and occasionally have permeabilities up to two orders of magnitude greater than the surrounding strata. In general though, there are very few important groundwater resources in the coal measure strata. Hitchcock (1995) concludes that the coal measures in the Newcastle Coalfield “have a poor resource potential with low yielding aquifers of high salinity”. This explains why fewer users exploit this resource than other sources.

The permeability of the coal measure strata was measured in one borehole (AQD 1075) using packer testing. This test yielded a permeability of 3.9×10^{-10} m/sec (SCT, 2006) and confirmed the very low permeability of these strata (see Figure 5). There are no known fractured rock aquifers in the Greta Coal Measures above the Greta Seam, and no registered bores have been identified that utilise groundwater from the Greta Coal Measures in this area.

The permeability of the Greta Seam appears to be higher than the other strata in the coal measures and represents a fractured rock aquifer zone. Although its permeability has not been measured in any of the bores in the stage 2 or stage 3 areas, previous testing (Morton & Kidd, 1980) has indicated that the permeability varies significantly with depth. The test results have been plotted on Figure 6 and indicate a permeability ranging from about 0.6 m/day near the ground surface, to 0.01 m/day at a depth of 80 metres. The data suggest a decrease in permeability of approximately one order of magnitude for every 40 or 50 metres of depth. While this conclusion appears robust, the methodology used in this testing is uncertain. Nevertheless, the permeability will certainly decrease with depth as the increasing overburden pressure serves to close any open cleats or fractures in the coal fabric. It is unlikely however that a similarly decreasing rate will occur for much greater depths, and the permeability/depth plot may flatten with depth.

The data indicates that most groundwater reporting to the current mine workings flows from the Greta Seam. However, it is of minimal significance as the seam contains poor quality groundwater, and there is no evidence that it has been exploited to any extent in the vicinity of the project. Nevertheless, the impact of the proposed mining on this aquifer must be evaluated to demonstrate that the development of the mine complies with the NSW State Groundwater Policy Framework Document (DLWC, 1997).

However, as there are no known groundwater dependent ecosystems that rely on the groundwater from the Greta Seam, the assessment requirements relating to these systems are not relevant for this development.

5.3 Abandoned mine workings

The local groundwater regime is heavily influenced by historic mine workings. As discussed in Section 4, there are several abandoned collieries adjacent to the Austar mine which are partially filled with groundwater. In addition to normal groundwater percolation into these workings, they also receive water from several other sources. These main sources measured by volume include the following:

- Return of the brine component of the output from the Reverse Osmosis Plant into the underground workings;
- Diversion of water from surface dams to underground workings during major storm events (governed by automatic control systems);
- Tailings discharge from the CHPP into the underground workings;
- Transfer of water from 2 east underground storage to the Bellbird Colliery workings; and
- Inflow of rainfall/runoff from high intensity or prolonged rainfall events.

The quality of the water contained in the abandoned mine workings is already extremely poor, as evidenced by the groundwater quality data obtained for water entering the mine through the coal barriers between the abandoned mines and the Austar workings. Indicative values from the monitoring database of the quality of the water entering the mine are included in the table below.

Location	pH	EC µS/cm	Fe mg/L
#2 Shaft Pump (Ellalong Goaf)	4.7	18,733	575
West Pelton Goaf	6.8	8,350	52
East Pelton Goaf	3.8	11,960	851
LW13 flank hole (adjacent to Kalingo workings)	3.8	15,382	507
13C/T A1 Panel flank hole (adjacent to Aberdare Central workings)	3.9	11,823	1700

Generally speaking, most rainfall does not infiltrate into the abandoned mine workings, but is held in the soil and/or evaporated/transpired back into the atmosphere. Only during high intensity or prolonged rainfall events does the rainwater percolate through the surface soil profile and into the joint/fracture system in the overburden. Some of this water may then percolate down into the shallow underground workings near the Greta seam outcrop.

In addition, there may also be significant one-off events which contribute to the groundwater in the abandoned mines. For example, during a major rainfall event in June 2007, a large volume of water was diverted via a sinkhole in Black Creek into the Aberdare Central workings during and after the storm event.

The hydraulic head in these collieries is significantly higher (~160m) than the level of the existing Austar workings, and this is responsible for most of the groundwater inflow to the mine.

The water levels in some of these mines are now measured on a regular basis, and the relative heads are given below for the period prior to the June 2007 storm event as well as the post-storm levels, and shown in graphic form in Figure 7.

Colliery	Pre-storm water level (mAHD)	Post-storm peak level (mAHD)
Ellalong #2 shaft	-275	-274
Aberdare Central	-87	-36
Bellbird[1]	-	-54
Elrington	-	-92
Hebburn #2	-85	-85
Kalingo	-110	-74
West Pelton	-137	-137
East Pelton	-157	-156

A number of important points can be noted from the data plotted in Figure 7:

- The data suggests that several of the mines may have a hydraulic connection, as they have a water level around the RL 9900 (-100 m AHD) mark.
- The June 2007 rainfall event had a significant impact on three mines, Kalingo, Aberdare Central and Bellbird.
- The water level in both the Kalingo and Aberdare Central workings was falling slowly prior to the storm, probably due to slow drainage into the current Austar workings.
- The rainfall event had no impact on the level in the East Pelton, West Pelton and Ellalong workings, as these are kept low by pumping and drainage. This is why the water levels in these mines are lower than in the other workings.
- The head in most of the workings is about 160 metres above the level of the adjacent longwall panel A2 in the Austar mine.

This groundwater source will continue to provide the bulk of the groundwater inflow to the Austar workings into the future, and this needs to be taken into account in determining the likely future water inflows.

---

[1] This borehole was drilled by Austar after the June 2007 storm event to enable water levels to be monitored in the Bellbird mine workings.

6. Impact of longwall mining on the overburden

In order to determine the impact of the proposed mining on the aquifers in the future extraction area, there is a need to understand the mechanics of deformation of the overburden strata above a longwall mining operation. These deformations can be broadly classified into two categories: surface and sub-surface deformations. Both types of deformation are described below, and their potential impacts on the hydrogeological system summarised.

6.1 Surface deformations

Surface deformations resulting from coal extraction have been observed and measured on a routine basis at most underground coal mines for many years. In addition to the more obvious impacts on surface structures, these deformations have the potential to impact on shallow unconfined aquifers and surface waters. The deformations most commonly observed include subsidence, surface strains, surface tilts and valley bulging. The potential impacts on local groundwater systems that can result from these phenomena, are described briefly below.

<u>Subsidence (vertical ground surface movement).</u>
The formation of a subsidence trough over a longwall panel can lead to disruption to groundwater flow if the subsidence is of sufficient magnitude, with the potential for discharge of groundwater to the surface water system.

<u>Surface strains (horizontal ground surface movement).</u>
Of the two main types of strain (compressional and tensile), tensile strain is more likely to impact on groundwater systems. For high subsidence values, the tensile strains may be large enough to cause cracks in the ground surface, which may temporarily drain any near-surface unconfined aquifers. Compressional strains at the surface may give rise to ground heaving or shearing. Surface strains may also concentrate at major geological structures, resulting abnormally high ground movements and cracking.

<u>Surface tilting (change in slope of the ground surface).</u>
Where the tilt is sufficiently large and the hydraulic gradient in the aquifer is sufficiently low, mining-induced tilting may either disrupt the groundwater flow, or increase/decrease the discharge in a near surface aquifer.

<u>Valley bulging and valley closure (uplift in valley floors and inward movements of valley sides).</u>
Where valley bulging is significant, it may give rise to cracking in the valley floor, which in turn may temporarily disrupt the flow in shallow aquifers. In such cases, some or all of the flow may be diverted into shallow underground cracks. Generally, the groundwater flow reappears downstream of the area affected by the mining, where there is no cracking. Normally, valley bulging will be more severe in valleys with steep side slopes.

6.2 Sub-surface deformations

In addition to the near-surface deformations described above, sub-surface deformations may also impact on deeper aquifer systems and, to a lesser extent, surface waters. An understanding of this phenomenon is therefore necessary in order to determine the potential for any adverse impact on the local hydrogeology from this source. A discussion of the sub-surface deformation process and its potential impacts follows.

When the void created by extraction of a coal seam becomes sufficiently large, the unsupported roof of the seam fractures and falls into the void. Collapse of the roof continues upwards until the void is filled by broken rock, forming a goaf. This caved material supports the overlying strata, which sag downward. Significant fracturing occurs in the sagging strata immediately overlying the void, but this decreases in intensity higher up in the overburden. Where large areas are extracted, the sagging extends up to the ground surface forming a subsidence trough, and fracturing will occur to some extent through the full overburden height. Importantly, the fractures induced in the sagging strata lower down in the sequence near the goaf may interconnect. If the mine is at a shallow depth below an aquifer, these interconnecting fractures will provide a seepage path between the aquifer and the mine. Where the aquifer is at a greater height above the mine, the interconnected fractures may not reach the aquifer zone, and it will remain intact and relatively unaffected, although the fracturing may result in some temporary impacts.

Many previous studies both in Australia and overseas have examined the mechanics of strata deformation in order to understand the behaviour of the overburden strata above underground mines. Most studies have recognised four separate deformation zones in the overburden strata (Forster & Enever, 1992). Although there is some variation in the definition of these zones between the studies, a general description of each zone has been compiled and is given below.

Caved or Collapsed Zone (Some authors note primary and secondary caved zones.)
This zone comprises loose blocks of rock detached from the roof and occupying the cavity formed by mining. It can also contain large voids. Large increases in bulk permeability occur in this zone.

Fractured or Disturbed Zone
This zone comprises in-situ material lying immediately above the Caved Zone, which has sagged downwards and consequently suffered bending, significant fracturing, joint opening and bed separation. These beds rest on the underlying caved material causing it to compact. The Fractured Zone displays a significant increase in horizontal and vertical permeability, due to the interconnection of the fractures induced in the strata, and as such, the hydrogeological regime in this zone is permanently and completely altered.

Constrained or Aquiclude Zone
The Constrained Zone comprises confined rock strata above the fractured zone that have sagged slightly, but, because they are constrained and the imposed strains are lower than in the Fractured Zone, the degree of fracturing and dislocation of the strata is limited. Some horizontal bed separation or slippage is generally present, as well as discontinuous vertical cracking (usually on the underside of thick strong beds). Increases in horizontal permeability occur but no significant increase in vertical permeability is likely. Because of the occurrence of fracturing and dislocation in this zone, there may be some minor or temporary alteration to the hydrogeological regime.

Surface Zone
The surface zone comprises unconfined strata at the ground surface, in which the surface deformations occur (see Section 6.1 above). Vertical permeability will increase in this zone, and the hydrogeological regime will show some changes.

These zones are shown diagrammatically in Figure 8.

The thickness of each of the deformation zones listed above is influenced by many factors. The most significant of these is the size of the mine opening. As this opening widens, the degree of deformation in the overburden strata increases. Initially, caving occurs in the roof strata, followed by formation of the fractured zone above the caved material. At greater extraction widths, the extent of the fractured zone increases and deformations at the ground surface become apparent. The maximum degree of deformation occurs when the mine opening reaches its critical width. Previous studies indicate that this critical width is about 1.4 times the depth of cover (Holla, 1991). For extraction widths greater than the critical width (supercritical extraction), there is no increase in the vertical extent of the deformation zones. Studies have shown, that for any given coal seam extraction width and orientation, the extent of each of the strata deformation zones in the overburden is dependent on the seam extraction height, depth of cover and the physical properties of the overburden strata (Forster, 1995).

If there are only minimal quantities of groundwater contained in the overburden strata, then the strata disturbance and increased permeabilities described above will have little impact on mining activities or the groundwater regime. It is only when mining is planned under extensive aquifers (or surface water bodies), that the nature and extent of the strata deformation zones must be considered.

It is evident that the caved and fractured zones would normally experience an increase in vertical permeability and would therefore tend to drain groundwater from any aquifers which occur in these zones. However, the constrained zone, since it contains few interconnecting fractures, has the potential to prevent a significant vertical hydraulic connection between the mine and any overlying aquifer. Therefore, provided the initial permeability of the overburden strata is low, and there are no major aquifers within the caved or fractured zones above the mine, then there is limited potential for disruption to the groundwater regime or for groundwater inflows into the mine workings from the upper overburden. This does not mean that there will be no groundwater flow at all between the constrained material and the fractured zone below, just that any flow will be insufficient to cause a significant disruption to the groundwater regime.

6.3 Assessed impact

In order to determine the impact of the proposed future mining on any aquifers in the area, the height of the fractured zone above the proposed mine workings needs to be estimated. This is defined as the height of interconnected fracturing that could transmit water from the strata or alluvium to the mine opening. Since there is no quantitative method of estimating this height prior to mining, it must be established based on previous experience, incorporating 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, bedding and depth of cover.

Previous studies in the Newcastle Coal Measures (ECNSW, 1987, Forster & Enever, 1992) have suggested that the fractured zone extends to a height of between 20 and 33 times the coal extraction thickness above supercritical extraction areas. These findings have not been tested in the Cessnock area, but it is noted that there are some differences in the composition of the overburden above the Greta Seam compared to the Newcastle Coal Measures.

Several other field studies have been carried out at various locations to investigate the extent of the overburden deformation zones above underground coal mines, and in particular to determine the height of the fractured zone. Using either piezometric or microseismic monitoring during mining, these studies have measured a height for the fractured zone of between 40 and 120 m (or 18 to 39 times the extraction thickness), over a range in cover depths of 80 to 500 metres, and seam heights of 1.9 to 3.2 m (ECNSW, 1987; Forster & Enever, 1992; Seedsman & Kerr, 2001; Kelly et al, 1998). These case studies are summarised in Table 2 below.

Table 1 – Fractured Zone Heights above Various Coal Seams

Colliery	Panel No.	Seam	Extraction thickness (m)	Depth of cover (m)	Fractured zone height (m)	Investigation method
Cooranbong	North B	Gt Northern	3.2	80	58	piezometric
Appin	LW 28	Bulli	2.3	500	90	microseismic
Wyee	LW 11	Fassifern	1.9	180	40	piezometric
Wyee	3D Panel	Gt Northern	1.9	185	63	piezometric
Gordonstone	LW 103	German Ck	3.0	235	120	microseismic
Bellambi West	LW 514	Bulli	2.7	400	90	microseismic

In addition to these case studies, Li (2005) cites several additional case studies of mining beneath water bodies, where no measurements were made of the fractured zone height, but the lack of a hydraulic connection gives an indication of the upper limit of the fractured zone. These case studies are listed in Table 2 below.

Table 2 – Mining under water bodies (Li, 2005)

Case	Panel No.	Panel width (m)	Extraction thickness (m)	Depth of Cover (m)	Separation from water body (m)	Water body	Hydraulic connection ?
1	4 to 8	205	2.5 – 4.0	110-220	Similar to DoC	alluvium	No
2	9 & 9A	200 & 210	3.3	60-90	Similar to DoC	alluvium	Yes
3	20	225	3.4	110	Similar to DoC	alluvium	No
4	27 & 28	165	4.8	125-160	Similar to DoC	alluvium	No
5	4 to 6	260	2.4 – 2.5	150-170	Similar to DoC	tailings dam	No
6	17 to 23	130 – 150	3.2	150-180	Similar to DoC	tidal lake	No
7	1 to 4	110	2.6	325	85	alluvium	Yes
8	1 to 4	110	2.6	335	185	alluvium	No

It is evident from all of the above data that the fractured zone generally does not extend any more than about 120 metres above the mine opening. Nevertheless, since none of the above case studies are located in the Greta Coal Measures, the data must be used with caution when endeavouring to estimate the height of fracturing in other strata including the Branxton Formation.

The Branxton Formation is similar in some respects to the coal measure strata in that it contains massive sandstone units, which are similar in strength to the massive conglomerate layers in the Newcastle Coal Measures, and have few natural defects. The main difference however, is that the Branxton Formation does not contain any fine grained strata, which, in the Newcastle

Coal Measures, serve to limit the height of the fractured zone. This is important because the massive units concentrate strains on vertical fractures, whereas softer fine grained rocks can absorb strain by shearing along bedding planes. This can limit the height and continuity of vertical fractures.

This aspect must be considered, along with any other points of difference. The main differences are that the proposed extraction thickness in the Greta Seam is considerably greater than for any of the cases noted above, and the depth of cover much greater. Both of these aspects may serve to increase the fractured zone height. Nevertheless, there are other aspects that should assist in limiting the fractured zone height, including the following:

- The proposed longwall panels are of sub-critical width, so that the full fractured zone height will not be developed;
- Because not all of the top section of the coal seam is recovered, the effective extraction height is significantly less than the full seam height; and
- The massive sandstone bands in the overburden will have some spanning capability, so that the full subsidence (and hence the full fracture height) will not be developed.

Since the relative influence of all of these factors is difficult to determine, a conservative position has been taken, and the upper bound Newcastle Coal Measure ratio has been used to produce an estimate the fractured zone height. Assuming a fractured zone height/extraction thickness ratio of 33 produces a fractured zone height of the order of 165 to 231 metres (with an extraction thickness of 5.0 to 7metres). In reality, the effective extraction thickness for a 7 metre thick seam is of the order of 5.04 metres, so that the fractured zone heights estimated above are almost certainly overestimated.

There is no direct data available to verify this estimate, although data from piezometers installed in borehole AQD 1077 adjacent to longwall A2 suggests that the estimate is reasonable. This borehole has seven piezometers installed at various heights in the overburden above the Greta Seam, and one installed below the seam. Although four of the piezometers have now failed, the data collected prior to their failure is useful in demonstrating the likely height of fracturing in the area. Figure 9 shows plots of the pressure head measured in the piezometers since they were installed. The important aspect of this graph to note is that piezometers 3, 4, 5 and 6 (installed at heights of 12, 49, 76 and 126 metres above the seam respectively) all show a declining pressure trend, while piezometers 7 and 8 (installed at heights of 236 and 406 metres above the seam) show no significant change over time. Piezometer 8 at a depth of 30 metres measures no head, indicating that the groundwater table is below this level, while the piezometer 7 at a depth of 200 m, shows a piezometric level about 80 m below the ground surface.

While the data is not conclusive, a possible explanation for the observed behaviour is that the strata containing the lower piezometers (3 to 6) is draining gradually into some adjacent goaf, via the fractured zone, while the upper piezometers are unaffected, since they are located above the fractured zone. If this interpretation of the data is valid, then the fractures zone extends to a height somewhere between 126 and 236 metres above the seam. This range contains the estimated fractured zone height of 165 to 231 metres nominated above. Even if this interpretation is flawed, the data indicate that the upper two piezometers are unaffected by the adjacent mining. The data also suggest that there is a relatively impermeable layer somewhere between piezometers 6 and 7, as there appears to be no hydraulic connection between these two points, whereas the lower piezometers show similar pressure changes.

Another possible interpretation of the data is that the lower strata are simply destressing with the passage of longwall A1, and the strata are not necessarily connected to the fractured zone. If this is the case, then the fractured zone will be less than that estimated above.

Assessment: ***Based on the available data, a conservative figure of about 231 metres should be assumed for the fracture zone height above the stage 2 and 3 longwall panels. As a result, the fractured zone is likely to be restricted to the upper part of the Greta Coal Measures and the lower part of the Branxton Formation. Although strata fracturing and hydrogeological changes will be experienced in the Branxton strata above this zone, these changes will not be significant and/or permanent.***

Assessment: ***It is assessed that large scale surface cracking will be unlikely over the longwall panels, given the low level of tensile strain predicted to occur. It is also assessed that, due to the width of the creek valleys and the relatively flat slopes on either side, that no impacts from valley bulging effects will be observed.***

7. Impact of longwall mining on the aquifers

7.1 Impact of mining on local aquifers

The review of the hydrogeological regime in Section 5 identified the following potential water-bearing horizons in the local area:

- alluvium in the valleys of Quorrobolong Creek, Cony Creek and Sandy Creek;
- water-bearing horizons in the Branxton Formation within 100 metres of the ground surface; and
- the Greta Seam.

It is therefore necessary to examine the potential impact of mining in greater detail, and determine how the expected overburden deformations described above will affect these aquifers. This will allow an understanding of the reasons for any impact or lack of impact, so that monitoring systems can be put in place to check that the conclusions are valid.

7.1.1 Alluvium

The current investigation has revealed the existence of a potential alluvial aquifer in the alluvium in the valley of Quorrobolong Creek , Cony Creek and Sandy Creek. Although the aquifer is of limited extent and importance (and is not currently utilised) in the area, it probably supplies water to the creek during dry periods, and feeds the much more extensive and important aquifer further downstream in Wollombi Brook. For this reason, the impact of the mining on this aquifer needs to be assessed, not only within the development area, but from a catchment-wide perspective.

The proposed mining has the potential to impact on this aquifer in three ways:

- groundwater in the aquifer could drain vertically through mining-induced cracks in the overburden into the mine workings;
- discontinuous surface cracking caused by subsidence or valley bulging could temporarily divert water from the aquifer; and
- changes in ground level caused by mine subsidence could disrupt flow in the aquifer.

An analysis of the likely height of fracturing above the proposed longwalls (Section 6.3) suggests that the interconnected fracturing (fractured zone) is likely to extend to a height of about 165 to 231 metres above the roof of the seam. As a result, the fracturing is unlikely to reach the ground surface beneath the creek valley, since the depth of cover ranges from 470 to 700 metres beneath the alluvium. This leaves a minimum constrained zone thickness of at least 240 metres. Consequently, the extraction should not result in any drainage of groundwater from the alluvial aquifer into the goaf.

Since the predicted tensile strains are not large, it is unlikely that surface cracking will be observed, and any cracks that do occur will generally be limited to areas where rock is near the ground surface. If cracks do form, it is likely that they will be insignificant, since the clay layer at the base of the alluvium is more likely to deform plastically under tensile strain, rather than form cracks. In any event, any cracking should only have a temporary minor impact, since the rising groundwater table caused by surface subsidence will counteract any adverse effect. Since the constrained zone prevents water loss from the alluvial aquifer, there is no nett loss of water in the alluvial aquifer. Consequently, the long-term impact of any surface cracking on the aquifer is likely to be negligible.

A similar negligible impact is also expected from valley bulging effects. Predictions indicate that the degree of bulging will be less than 200 mm, and closure will be less than 100 mm (MSEC, 2007). This level of displacement will be insufficient to cause any significant cracking that will impact on the alluvium.

Assuming this is the case, then any impact on the alluvial aquifer will be limited to the changes in elevation caused by the subsidence effects at the surface. It is predicted that the mining will subside the ground surface by an estimated 1.4 metres over the stage 2 area and 1.9 metres over the stage 3 area with a maximum upperbound limit of 3.0m for both of the areas.This has the potential to lead to a re-adjustment of the groundwater level over the longwalls. The predictions also indicate the subsidence profile across the site will not reflect the pillars to any great degree, so that the differential subsidence within the subsided area will generally be less than 200 mm. Changes of this magnitude will have a negligible impact on the aquifer.

Nevertheless, the aquifer in the centre of the subsidence trough will subside relative to the aquifer over the pillar, so that the hydraulic gradients in the aquifer will change.. A realistic estimate of the potential impact this may have is the average gradient change from the barrier pillar to the zone of maximum subsidence over the longwall panels, which is of the order of only 0.2% for the stage 3 longwalls and less than this for the stage 2 longwalls. As a result, the water levels in the aquifer over the pillar and in the subsidence trough over the panels should be virtually unaffected by the surface subsidence.

It is theoretically possible during this process, that a small volume of groundwater may be released into the creek channel, resulting in the potential for short-term changes in flow rates and water quality in the creeks. However, due to the very small gradient changes expected, these temporary changes, if they occur, will be undetectable.

Overall, the resultant impact on the groundwater system should be negligible, since there are no users of this groundwater resource in the development area. Any future users of alluvial groundwater in the development area are also unlikely to be adversely affected. In practice however, it is unlikely that any users would exploit the aquifer in the future due to the likely poor yields and poor quality that has been recorded..

Assessment: ***The likely overall impact of the proposed extraction on the alluvial aquifer is assessed to be minimal, since the fractured zone above the mine is not expected to reach the ground surface and hence vertical drainage should not occur. In addition, fracturing from valley bulging is not predicted. The impact will be limited to minimal changes in hydraulic gradient in the aquifer zones, which should have a negligible impact. In the current context, the risk of the loss of the resource is considered acceptable, due to its relatively minor importance in this area, and the very low probability of an adverse outcome.***

Even though no adverse impact is expected, a monitoring program should be implemented to confirm this assessment. This will also give useful data relevant to future longwall extraction beneath alluvial deposits in the area. A suggested monitoring program is outlined in Section 9.

7.1.2 Branxton Formation

As indicated in Section 5.2.1 above, no significant fractured rock aquifer zones are currently known in the Branxton Formation, although there are indications of a discontinuous water-bearing horizon at a depth of 70 to 100 metres below the ground surface. There is no evidence of any registered bores currently utilising the groundwater from this horizon, probably because the groundwater quality and yield from this water-bearing zone are generally poor.

Nevertheless, the impact of mining on this zone is assessed in case there are some locations within the development area where this aquifer could be exploited.

In Section 6 above, it was inferred (conservatively) that the fractured zone above the longwall panels could extend to a height of 231 metres above the Greta Seam. Any aquifer zones that do exist within the fractured zone in the development area will probably be significantly affected due to the extensive fracturing expected in the overburden strata within the fractured zone. The known water-bearing horizon at a depth of 100 m will be located at least 150 metres above the top of the fractured zone in the stage 2 area. The separation will probably be even greater in the stage 3 area. Because of this, there will be no vertical drainage of the aquifer into the mine, and it should be unaffected by the longwall mining. While the formation of a goaf at depth will increase the vertical hydraulic gradient in the overburden, the vertical permeability of the strata is sufficiently low that any increase in vertical percolation of groundwater will be negligible relative to the flow in the aquifer.

Assessment: ***It is assessed that any water-bearing zones which occur within the fractured zone above the Greta Seam will most likely drain into the mine opening during extraction of the longwalls (no such zones are currently known). It is concluded that the impact of the proposed mining on the water-bearing zone at a depth of 70 to 100 metres will be negligible since it is located well above the zone of interconnected fracturing. In the current context, the risk of the loss of the resource is considered acceptable, since it contains poor quality groundwater, is low yielding, and has limited potential for future exploitation.***

Even though no adverse impact is expected, a monitoring program could be implemented to confirm this assessment. This will also give useful data relevant to future longwall extraction in the area. A suggested monitoring program is outlined in Section 9.

7.1.3 Greta Seam

Coal extraction in the Greta Seam has been carried out for more than a century in the vicinity of the Austar Coal Mine. This prolonged period of extraction has served to drain the groundwater from the seam over a large area. This process is slowly reversing as most of the former mines gradually fill with water over time.

Since the Greta Seam will be totally extracted in the proposed future development at Austar, any groundwater remaining in the seam in this area will be drained into the mine. As a result, the hydraulic head in the seam will be gradually drawn down in the area surrounding the mine, except along the northern and western sides of the development area, where the abandoned mine workings contain a reservoir of groundwater. Along these sides, the drawdown will be limited as the seam will be recharged by water in the old workings.

Since the incremental drawdown in the seam caused by the extraction of longwall panels will be minimal, and there are no known users of this groundwater resource, due to the depth, poor quality and low yield, any impact on this resource will be negligible.

Assessment: ***Extraction of the Greta Seam will drain groundwater from the seam into the mine and lower the hydraulic head in the seam in the area to the south of the development. Since the incremental drawdown will be minimal, the groundwater quality is poor, the seam is very deep, and there are no known users of the resource, the impact is judged to be negligible.***

7.2 Regional impact

As well as the local impact of the mining on the aquifer systems, it is necessary to evaluate any regional consequences. Any impact on the alluvial aquifer will generally be restricted to the area over the subsidence troughs, however there will be minimal change in the hydraulic gradient in the aquifer around the edge of the subsidence troughs, which may take a short time to stabilise after the mining has been completed (see Section 7.1.1 above). This process should effectively re-establish the hydraulic gradient in the downstream direction (both upstream and downstream of the subsidence trough), and the flow into and out of the system will ultimately be similar to the pre-mining flow. Consequently, the impact on the aquifer and any groundwater users further downstream will be negligible overall.

While the risk of adverse consequences is assessed to be extremely low, any unexpected changes in the alluvial aquifer system in this area will still have a negligible affect on the important alluvial aquifers further downstream, as this area forms a very small proportion of the total catchment area for these aquifers, and an even smaller proportion of the total groundwater volume in the system.

Since the water-bearing zone in the Branxton Formation is unlikely to suffer any significant long-lasting impacts due to the mining in the development area, the regional consequences on this aquifer outside the development area are judged to be negligible. The hydraulic head in the lower part of the Branxton Formation will be drawn down within the immediate vicinity of the mine, but this will have no discernable regional impact as there is no known groundwater resources in this part of the formation.

In Section 7.1.3, it was determined that the groundwater in the Greta Seam would continue to drain into the workings. It therefore needs to be established that this will not have any wide-ranging impacts on a regional scale. Searches have shown that there are no domestic, industrial or agricultural users of the groundwater resource in the Greta Seam in the area surrounding the Austar Coal Mine, probably due to its depth, poor quality and relatively low yield. Consequently, there will be no immediate impact from the mining, but the long-term impacts must also be assessed.

It has already been concluded that the drawdown in the coal seam aquifer is significant in the vicinity of the mine and extraction of longwalls in the stage 2 and 3 area will probably drain the groundwater from the seam on the southern side of the area at a low rate of less than 0.4 ML/day (see section 8.2.3). This is not seen as significant, since the drawdown will be only temporary, and the groundwater in the seam makes no contribution to local stream flow or any other surface water resource. In addition, the seam is being recharged on the northern side of the area from the groundwater in the old mine workings. Therefore any impact on this water source from the extraction of longwalls in stages 2 and 3 will be negligible on a regional scale. The groundwater regime will re-establish former levels after mining.

Once mining is completed, and pumping from the pit ceases, the strata will re-pressurise as the mine fills with water. Previous experience in the numerous other pits in the area has shown that the pre-mining hydrogeological conditions will eventually re-establish following mining. Based on these facts, it is concluded that the incremental impact on the regional hydrogeological regime at Austar due to the extraction of longwalls in stages 2 and 3 will be minimal.

Assessment: ***The impact of the proposed future extraction at the Austar Coal Mine on the alluvial aquifer system on a catchment-wide basis should be negligible, while incremental impact on the regional hydrogeological regime in the overburden strata will also be negligible.***

8. Potential future mine water inflows

The previous sections of this report have demonstrated that the risk of any adverse impact on the main aquifers in the future development area is negligible. Consequently, any inflows to the mine will be from sources that have no environmental significance. Nevertheless, the potential for mine water inflows must be estimated, both for mining operational reasons and to determine future water management requirements.

Currently most of the groundwater entering the Austar mine originates from the water in the adjacent abandoned mine workings. Without this contribution to the mine water inflows, the groundwater inflow would be minimal, and in line with most other mines in the Newcastle Coalfield, which are generally reasonably dry.

In general terms, it is expected that inflow to the stages 2 and 3 areas will be less in relative terms than the inflow to the current workings since:

- The depth of cover is greater and the permeability of the overburden and the Greta Seam will be lower by one to two orders of magnitude; and
- The major structures in the area diverge, so that there are likely to be fewer structures that will transmit water to the workings.

Although groundwater inflows to the mine are not likely to be the source of any significant problems or adverse environmental outcomes, it will be of assistance for future mine planning if some estimate of the potential future mine water inflows is known. Normally, to assess the magnitude of mine water inflows with any accuracy requires the use of a three dimensional numerical model. However, in this instance, numerical modelling is not warranted due to the difficulty in modelling complex water flow along dykes and faults. It was considered that the best method of providing useful inflow estimates was to employ a semi-quantitative assessment methodology, utilising empirical methods and the available water balance data from the current mining operation. This is considered to be valid due to the relatively consistent properties of the overburden strata across the area. The large volume of available water balance data, along with valid extrapolation and engineering judgement should provide the best assessment in these circumstances.

The inflow assessment comprised two aspects:

- estimating realistic permeabilities for the rock strata; and
- using these estimates to determine the mine water inflows.

8.1 Permeability estimates

In order to determine the likely future water inflow to the mine, it is necessary to have a reasonable estimate of the permeability of the strata that will produce the groundwater. Although some testing has been carried out on these strata, a more accurate estimate of the permeability is more likely to be obtained from the current mine water monitoring data.

Since the Greta Seam produces most of the water in the current workings, an accurate estimate of the permeability of this seam is most important. Some indication of the permeability of the Greta coal can be gained from the water inflow measurements in the current workings. Gateroads for the A2 panel have been driven across the northern side of the lease area adjacent to the inundated former workings in the Kalingo, Bellbird and Aberdare Central collieries. The relatively high head of water in the former workings gives rise to inflows into the A2 panel of the order of 1.3 ML/day. Of this amount, approximately 0.3 ML/day comes from the flanking boreholes.

Assuming that steady state conditions prevail, the permeability of the Greta Seam can be calculated from the Darcy equation using the inflow measurements as follows:

$Q = k\ i\ a$ .... Equation 1

Where:

Q = total inflow volume to the A2 panel (m^3/day)
k = permeability (m/day)
i = hydraulic gradient between the former workings and the A2 panel
a = area of coal seam exposed in the A2 panel (m^2)

The following assumptions have been made to validate this method in the current circumstances:

- All groundwater flow through the coal seam enters the mine workings;
- The full coal seam height transmits groundwater;
- The is a constant hydraulic head in each of the surrounding collieries;
- The coal seam has a homogeneous permeability; and
- Steady state conditions have been reached.

Using this method produces an estimated permeability of 0.12 m/day, using an inflow rate is 1.3 ML/day, or 0.9 m/day if the inflow rate is assumed to be 1 ML/day. In reality, the actual permeability will be somewhere between these two estimates. For a depth of 400 metres, these permeability values appear to be excessive when compared to the permeabilities measured previously (see Figure 5). The likely reason for the higher than expected permeability is that there is additional inflow to the workings through structures associated with the Swamp Fault zone or Central Dyke, both of which are adjacent to the workings.

Nevertheless, the estimated permeability represents the upper bound permeability for the coal seam. This permeability will need to be reduced to allow for the greater depth of the seam in the stages 2 and 3 areas. For the purposes of the inflow calculations, the Greta Seam permeability in stages 2 and 3, is assumed to decrease from 0.1 m/day at 400 metres depth of cover to 0.001 m/day at 700 metres depth.

In Section 7 it was concluded that the fractured zone would extend into the lower part of the Branxton Formation, for a distance of up to 215 metres above the Great Seam. Although there are no known aquifer zones in this part of the sequence, it is still important to know the permeability of the strata so that inflow volumes can be calculated.

As indicated in Section 5.2.1 above, measurements of the Branxton Formation permeability in this area to date have relied on packer testing, which has limitations when measuring very low permeabilities. Although these tests indicate that the permeability of the Branxton Formation is very low, it is likely to be even lower than these measurements suggest, and similar to the permeability of the Narrabeen Group, which is generally about two orders of magnitude lower than the permeability quoted above. Permeability testing using very accurate production testing methodology has been carried out on the Narrabeen Group strata for another coal mine on the Central Coast. These data are plotted on Figure 6, along with the permeability test results from borehole AQD 1075. Both sets of results indicate a general reduction in permeability of one order of magnitude for every 140 metres increase in depth. It is also important to note that both sets of results have outliers representing higher permeability zones (in relative terms), which are probably due to the presence of a greater number of fractures or joints.

A better indication of the permeability of the Branxton Formation can be obtained from the measured inflows to the existing mine workings. Using the available data, it is possible to estimate the inflow to the former Ellalong goaf area from the overburden strata. This is done by using the water balance method where:

$$\text{Volume pumped from Ellalong goaf at Shaft \#2} + \text{Change in volume in the Ellalong goaf} = \text{Volume pumped into goaf} + \text{Inflow from surrounding strata into goaf}$$

Since there may be some errors in the estimation and measurements of the pumped inflows to the goaf, the water balance can be established over a long period of time, so that any inadvertent errors will have a minimal impact on the overall water balance, and any random errors in the measurement will be eliminated. Since both the change in water stored in the goaf and the inflow to the goaf are difficult if not impossible to measure, it is necessary to determine the water balance between two dates when the water level in the goaf is the same. The change in water volume in the goaf will then be zero and can be eliminated from the equation, leaving the inflow from the strata to the goaf as the only unknown. We can then solve for this unknown as follows:

$$\text{Inflow from surrounding strata into goaf} = \text{Volume pumped from Ellalong goaf at Shaft \#2} - \text{Volume pumped into goaf}$$

For the period 9 September 2006 to 31 May 2007 the inflow from the strata to the goaf was determined from the above equation to be 9.85 ML or 0.037 ML/day. Obviously, the accuracy of this estimate is affected by the accuracy of the inputs, which may have some limitations. Nevertheless, the relatively small calculated inflow from the strata gives a good indication of the very low permeability of the overburden strata. It is also important to note that some of the inflow will be from the Greta Seam, even though the seam will be largely dewatered in the vicinity of the mine. Because of this, the inflow from the overlying strata will most likely be even less than the calculated volume.

It is possible to estimate the permeability of the Branxton Formation strata from the measured inflow, although the following assumptions must be made:

- a steady state groundwater regime exists in the vicinity of the Ellalong workings;
- the goaf drains the strata for a height of 200 metres above the extracted seam; and
- all of the inflow is from the overburden strata.

These assumptions should in general produce an upper bound permeability estimate.

The permeability can be calculated from the following formula, which has been modified from the Goodman formula for steady state inflow to a shaft or tunnel (Goodman et al, 1965).

$$Q/L = \frac{k \pi H_o}{2.3 \operatorname{Log}(4H_o/D)} \qquad \text{... Equation 2}$$

Where:

Q = total inflow volume (m^3/day)
k = permeability (m/day)
D = height of the goaf (m)
H_o = initial hydrostatic head (m)
L = perimeter of the extracted area (m)

This yields a mean permeability for the Branxton strata in the Ellalong goaf of 1.89 x 10^{-10} m/s. This permeability has been plotted on Figure 6 along with the permeability test data for comparison, and it is evident that the calculated value is lower than the measured data, but is probably more representative of the overall strata permeability.

For the purposes of the inflow calculations and for simplicity, a permeability of 0.00002 m/day (2.32 x 10^{-10} m/s) will be used for the Branxton Formation strata.

8.2 Inflow estimate

Inflow to the future mine workings is likely to come from four sources:

- inflow through the Greta Seam into the headings from the abandoned mine workings along the northern side of the development area;
- seam water from the Greta Seam during driving of gate roads for each longwall panel;
- inflow from the overburden strata in the fractured zone in the overburden; and
- inflow from major geological structures including the Swamp Fault, Central Dyke, Quorrobolong Fault Zone and Abernethy Fault Zone.

While it is possible to estimate the approximate flow rates from the first three sources listed above, the impact of the structural zones on the total inflow must remain a matter of speculation until these sources are further investigated. Nevertheless, an attempt has been made to quantify the future inflows into the workings using the available empirical methods, which are likely to produce more realistic inflow estimates than 3D numerical modelling due to the presence of the structural zones.

8.2.1 Stage 2 inflows

Stage 2 includes longwalls A3 to A5, which are located to the south of the current workings. Due to the increased distance of these panels to the water-filled abandoned mine workings, the inflows to these panels should be significantly less than for the current panels. Inflows were calculated by dividing estimating inflows to the various parts of the area, including the 200 mains, panel gate roads, longwall goaf and Central Dyke.

The inflows to the 200 mains should be insignificant in the stage 2 area, as the coal seam in this area has been dewatered following the extraction of the adjacent SL2 longwall panel. Since the goaf of this panel is drained at the southern corner, there is very little hydraulic head on the seam. A nominal 0.2 ML/day is assumed for the inflows to these headings. This assessment assumes that the SL2 panel is dewatered prior to the mining of the 200 mains as intended. If this is not the case, than additional inflows will be experienced in these workings.

The mining of the LW A3 maingate will produce some inflows, as this will be driven in virgin coal approximately 300 metres south of the 200 mains. Walton, 1983, provided a formula for estimating the transient inflow into a tunnel fully penetrating a porous aquifer as follows:

When $t \leq L_T / E_T$

$$Q = 4E_T[S_yTm^2/2 + STH_o/4]^{0.5} \times t^{0.5} \quad \text{....... Equation 3}$$

When $t > L_T / E_T$

$$Q = 4E_T[S_yTm^2/12 + STH_o/4]^{0.5} \times [t^{0.5} - (t - L_T/E_T)^{0.5}] \quad \text{....... Equation 4}$$

Where:

Q = total inflow volume (m^3/day)
E_T = excavation rate (m/day)
S_y = aquifer specific yield
T = aquifer transmissivity (m^2/day)
S = aquifer storage coefficient
m = aquifer thickness (m)
H_o = initial hydrostatic head (m)
T = time after commencement of tunnel (days)
L_T = total length of tunnel (m)

Using this formula yielded a peak inflow to the A3 maingate of 0.23 ML/day. This inflow reduces significantly once the excavation is completed, but since excavation will have commenced on the longwall A4 maingate, inflow to these headings will replace inflows to the A3 maingate. Since the 100 mains will be excavated at a slower rate than the longwall gate roads, they will produce considerably less groundwater. An amount of 0.1 ML/day is estimated for these mains.

Inflow to the longwall A3 goaf was estimated by using the same method as above, but assuming that the Branxton strata in the fractured zone represent the aquifer that is fully penetrated. This methodology produces a maximum inflow of 0.36 ML/day during the passage of longwall A3. This inflow rate will decrease rapidly after the completion of the longwall. Since longwall A3 is in relatively virgin territory, and subsequent longwall panels are shorter than A3, the total inflow rate to the stage 2 area goaf will most likely decline slowly after the completion of this longwall to about 0.2 ML/day. On completion of the three longwall panels, the inflow from the goaf will decline to about 0.04 ML/day over time.

The only other potential source of groundwater inflow will be from the Central Dyke to the east of the three longwall panels. This is a major structure, which is recharged with groundwater from the inundated Aberdare Central workings to the north. As part of the mine management system to safeguard against the potential for inrush during mining, dewatering holes were installed in the barrier between longwall panels SL2 to SL4 and the Central Dyke. The dyke was also directly explored by an inseam borehole and by continuous miner and was not a source of high water flow rates. These exploratory works are just north of A3 panel. Theinrush protection boreholes were not grouted and act as drainage holes that run sub-parallel to the dyke. They are still open and draining groundwater into the SL2 goaf, from where it is siphoned off and pumped to the 10 c/t fishtank. Since these holes cannot now be sealed, this constant drainage may serve to dewater the dyke structure further to the south in the vicinity of longwalls A3 to A5.

Nevertheless, it is uncertain whether the dyke will be a major source of groundwater in the stage 2 longwalls, all of which will start adjacent to the dyke structure. Consequently, the worst case situation was adopted, and it has been assumed that the dyke is fully charged with groundwater. Given this assumption, equation 1 was used to estimate the inflows to the panels during extraction. This produced an estimate of 0.4 ML/day, however, if the dyke is fully charged, it is likely that drainage holes will be drilled into it from the workings to reduce any excess hydrostatic pressures, and this could increase this value.

The total inflows during extraction of the stage 2 longwall panels are summarised below.

Inflow location	Estimated maximum inflow (ML/day)
200 mains	0.2
100 mains	0.1
longwall maingates	0.23
goaf	0.36 to 0.2
Central Dyke	0.4
Total	1.13 to 1.29

This estimate does not take into account that these longwalls are located in a wedge between the Central Dyke and the Swamp Fault. It is possible that in this area, there is a much greater degree of fracturing and jointing in the strata, which would increase the permeabilities of both the coal seam and the overburden strata, and may produce greater inflows than those predicted. Since previous mining has been carried out between these two major structures without significant additional inflow, it is assessed on the balance of probability that any additional inflow due to increases in permeability will not be significant.

These estimates assume that no major dewatering of the fault zone will be required. This assumption is based on the fact that the Bellbird mains cross the fault and keep it dewatered, as well as previous mining experience adjacent to the fault. If this assumption proves false, then there will be additional inflows not accounted for in these figures. Once extraction of longwall A5 is complete, all the inflows will report to the goaf formed by the extraction of the three panels, so that ongoing dewatering will not be necessary until the goaf fills to the 200 mains. Based on an assumed void volume of 2.6 million cubic metres, the goaf should take about 6.4 years to fill. This time will be reduced if inflows to the stage 1 area are allowed to flow to the stage 2 goaf, rather than being pumped to the Ellalong goaf.

8.2.2 Longwall A6 inflows

For the purposes of this report, longwall A6 has been separated from stage 3 of the development, as it is located in a separate structural regime. The same approach to determining inflows was taken as for the stage 2 longwalls, with the inflows being calculated by estimating separate inflows to the various parts of the area, including the 200 mains, longwall gate roads and the longwall goaf.

The inflow to the 200 mains will increase as the roadways approach the abandoned Aberdare Central workings. The Walton formulas (equations 3 and 4) were used to determine the estimated maximum inflow of 0.19 ML/day.

Longwall A6 is located to the east of longwalls A3 to A5, and is situated between the Central Dyke and the Quorrobolong Fault zone. Inflows to longwall A6 will be extremely difficult to predict, due to the presence of these major structures, and the possibility that the strata between the structures may be more fractured than normal. It is possible that the structures have a hydraulic connection to the former Aberdare Central colliery, and are charged with groundwater. In this case inflows to LW A6 will be significant. Alternatively, if the structures are not charged with groundwater, then the inflows may be less than normal, as there will be a limited volume of groundwater in the area between the structures, assuming that they form a barrier to groundwater flow.

It is likely that the Central Dyke, if it is charged with groundwater, will be drained locally by longwall panels A3 to A5, which are located on the western side of the dyke, if this is the case, then mining in the 201 panel (A6 tailgate) will produce a maximum groundwater inflow of the order of 0.35 ML/day, which will reduce as the panel moves further to the south. Mining in the

202 panel (A6 maingate) will not increase the level of inflow beyond this level, as the seam will be largely depressurised during mining of the 201 panel due to the probable isolation of the seam between the two structures. Similarly, extraction of the longwall panel is unlikely to increase the inflows significantly, as any water-bearing zones above the panel will have a limited extent between the two structures. In addition, inflows to the goaf will not report to the face, but will flow to the southern end of the extracted panel.

The total estimated additional inflows during extraction of longwall A6 are summarised below.

Inflow location	Estimated maximum inflow (ML/day)
200 mains	0.19
A6 gateroads	0.35
Total	0.54

The above calculations assume that longwall A6 is hydrologically isolated between the two major structures. This appears to be a valid assumption based on previous experience. Nevertheless, inflows could be significantly greater than that estimated above should any dewatering holes be considered necessary to reduce the hydrostatic pressure associated with either of the flanking structures.

Once extraction of longwall 6 is complete, all the inflows to the panel will report to the A6 goaf, so that ongoing dewatering will not be necessary until the goaf fills to the 200 mains. Based on an assumed void volume of 1.65 million cubic metres, the goaf should take about 8.4 years to fill.

8.2.3 Stage 3 inflows

Stage 3 will include 13 longwall panels with a depth of cover up to 740 metres. The increased depth of cover should result in a decrease in the permeability of the strata, and a decrease in the relative water inflows. Like the current workings, the largest proportion of the water inflow to the mine in stage 3 will occur along the northern side, adjacent to the abandoned mine workings. The same approach to determining inflows was taken as for the stage 2 longwalls, with the inflows being calculated by estimating separate inflows to the various parts of the area, including the 300 mains, panel gate roads, longwall goaf as well as flow from the abandoned workings and the Abernethy Fault.

The 300 mains trend in an approximate south easterly direction to the east of, and sub-parallel to, the Quorrobolong fault zone, which may have a significant influence on the inflows to the stage 3 area. Little is known of the nature of the fault zone, including its groundwater carrying capability or whether it will provide a good hydraulic connection to the old Aberdare Central workings. If a good connection exists, then the fault zone could supply a constant source of water to the 300 mains through the Greta Seam. Nevertheless, it is assumed that this will not be the case, due to the distance of the fault from the workings and the increasing depth of the seam towards the south, which will serve to close any open fracture that could carry groundwater. In addition, the throw on the fault of the order of 10 metres should restrict any lateral flow in the coal seam across the fault.

As a result, the maximum inflow to the 300 mains will most likely occur towards the northern end of the panel due to the assumed higher permeability of the seam in this area. It is estimated, using the Walton formulas (equations 3 and 4), that the inflow to the mains should be of the order of 0.1 ML/day. This relatively low flow is due to the very slow rate of development of these headings.

The longwall A7 tailgate roadways will be driven along the northern side of the stage 3 area parallel to the abandoned Aberdare Central workings. Since these workings are currently inundated to a level of RL 9960 (300 metres above the tailgate), and the horizontal separation between the workings is approximately 200 metres, this panel should experience some groundwater inflows. Using equation 1, and taking account of the varying distance between the workings, the estimated flow into the longwall A7 tailgate could be of the order of 0.91 ML/day.

The mining of the longwall A8 maingate roadways and subsequent panels will produce lesser inflows than the A7 tailgate, since there is no constant source of groundwater in the seam to the south. As a result, the seam will be progressively dewatered with each successive longwall panel. The inflows to the gate roads have been estimated using the Walton formulas (equations 3 and 4), and the results indicated that the maximum inflow to the longwall A7 maingate will be approximately 0.36 ML/day. Although the gate roads in subsequent panels are longer, the permeability of the seam will decrease as the depth of cover increases, so that the maximum inflow from the gate roads is likely to be from the initial longwall panels. Once the mining in subsequent maingates commences, inflow to the new maingate will replace inflow to the previously mined gate roads, and will probably be no more than the 0.36 ML/day estimated for the A7 maingate.

Inflows to the goaf from the Branxton Formation have been calculated using the same method as above. This indicated that the inflow to the longwall A7 goaf would be of the order of 0.18 ML/day, which would increase to 0.24 ML/day after longwall A10 and 0.26 ML/day after longwall A17.

The impact of water stored in the Aberdare Central workings has been taken into account in the estimates for the longwall A7 tailgate above, but the Aberdare South workings, located further east may also contribute to groundwater inflows. The degree to which these workings will impact on the conditions in the stage 3 area will depend largely on the nature of the Abernethy fault zone, and whether it forms a barrier to groundwater flow from the north, or whether it contains highly fractured rock which form a conduit for groundwater from the water-filled Aberdare Central workings to the northwest.

Assuming that the fault does not form a barrier to groundwater flow, the additional groundwater inflows will be experienced at the eastern end of longwalls A7 to A10 as a result of the groundwater stored in the Aberdare South workings. This inflow has been determined to be of the order of 0.05 ML/day, due to the distance of the workings from the longwall panels. If however the Abernethy Fault zone is fully charged with groundwater from the Aberdare Central workings, then the inflows will be significantly greater, especially if any drainage bores are required to reduce the hydrostatic pressure along the fault. In this case, the additional inflows to longwalls A7 to A10 may be of the order of 0.7 ML/day.

There is unlikely to be any significant inflows from the Aberdare South workings in the longwall panels south of longwall A10, but the inflow volume into these subsequent panels will depend on the nature of the Abernethy Fault zone. If the fault zone is not fully charged with groundwater, then any additional inflows are likely to be negligible. However, if the fault zone provides a conduit for groundwater from the abandoned workings, then additional inflows will be experienced, even though the fault will be dewatered to some extent by the inflow to panels A7 to A10. In these circumstances, the additional inflows may be of the order of 0.13 ML/day.

The total estimated inflows during extraction of the stage 3 longwall panels are summarised below.

Inflow location	Estimated maximum inflow (ML/day)
300 mains	0.11
A7 tailgate	0.91
longwall maingates	0.36
longwall goaf	0.18 to 0.26
Aberdare South workings	0.05 to 0.7
Abernethy Fault	0.13
Total	1.74 to 2.47

These estimates assume that no major dewatering of the fault zones will be required. If this is not the case, then there will be additional inflows not accounted for in these figures.

Once extraction of all longwall panels in this area is complete, all the inflows will report to the goaf. If the mine is closed following the extraction of longwall 17, all of the inflows from the entire mine will eventually report to the stage 3 goaf. The goaf will provide a significant storage volume, which is estimated to be of the order of 23 million cubic metres. If all of the current and future inflows report to the stage 3 goaf, it is estimated that the goaf will fill to the level of the Bellbird mains in approximately nine years. Since the inflows to the stage 3 area will decrease as the workings fill with water and the differential head decreases, the time to fill the workings will most likely be much more than nine years, and may be up to 15 years.

9. Recommended monitoring and verification

Although this study has concluded that the importance of the groundwater resources in the area is minimal and the risk to these resources from the mining is negligible, a monitoring program should be established to confirm the study results. Verification of the results will also be required to allow the effectiveness of the program to be assessed and any remedial measures to be undertaken.

9.1 Monitoring

The groundwater monitoring program is based on the premise that the height of interconnected fracturing above the coal seam is not known with any certainty, but should not be high enough to intersect either the alluvial aquifer or the shallow water-bearing zone in the Branxton Formation, which is more than 300 metres above the seam. Due to the lack of any significant aquifers in the lower overburden, the height of fracturing is therefore considered to be unimportant and largely academic in this case. Consequently, multi-level piezometers, which have been used in other localities, are not necessary to monitor the height of fracturing, particularly given their high cost and demonstrated propensity to fail at an early stage in the monitoring process.

The strategy that should be adopted is to monitor the groundwater levels in both the alluvial aquifer and the shallow water-bearing zone (70 metres to 100 metres below ground surface) for any changes. Ongoing analysis of the data will be carried out to determine if the changes are due to longwall extraction. If the changes are determined to be mining-related, the verification review process will examine the cause and suggest possible contingency measures (see Section 9.2 below).

The monitoring program should include the following:

Stage 2 area

- Continue to monitor the groundwater levels in bore AQD 1073A on a continuous basis to give an indication of the impact of longwall mining on the groundwater level in the alluvium. EC readings should be taken in the bore every three months.

- Establish a groundwater monitoring bore to check for any drawdown in the near-surface water-bearing zone in the Branxton Formation in the vicinity of the stage 2 extraction area. The groundwater level should be monitored continuously in this bore and EC readings should be taken every three months.

- Monitor daily rainfall in the vicinity of the site so that the timing of any groundwater level fluctuations can be compared with the occurrence of rainfall events.

- Obtain ongoing monitoring results from the DWE for groundwater well GW054676 and the adjacent shallow bore.

- Review the results of the above monitoring at three monthly intervals and report results at the completion of each longwall panel.

Stage 3 area

- Establish two shallow groundwater monitoring bores in the alluvial area (one over longwall A6 and one over longwall A16), and monitor the groundwater levels on a continuous basis to give an indication of the impact of longwall mining on the groundwater in the alluvium. EC readings should be taken in these bores every three months.

- Establish two groundwater monitoring bores to check for any drawdown in the near-surface water-bearing zone in the Branxton Formation in the vicinity of the stage 3 extraction area. The groundwater level should be monitored continuously in these bores. EC readings should be taken in the bores every three months.

- Monitor daily rainfall in the vicinity of the site so that the timing of any groundwater level fluctuations can be compared with the occurrence of rainfall events.
- Review the results of the above monitoring at three monthly intervals and report results at the completion of each longwall panel.

The suggested locations of the proposed groundwater holes are shown in Figure 5. The location of these bores is subject to landowner approval, and may also be altered to take advantage of proposed exploration bores. The monitoring bores can be established in these exploration bores by grouting the base of the hole to a depth to be determined, once the standing water level is established.

This monitoring program should be included in the Site Water Management Plan.

9.2 Verification

During the current study, every effort has been made to evaluate the potential impact of mining accurately and, where uncertainty exists, adopt an appropriate level of conservatism. The level of mining experience in this area gives confidence that the predictions are as accurate as conditions allow. Nevertheless, there will always be a minimal risk of an adverse outcome, no matter how intensive the investigation and evaluation has been. In order to confirm that the outcomes are as predicted, it is necessary to have a verification strategy so that the monitoring results are properly evaluated and any remedial measures implemented if necessary.

The verification program involves a detailed review of all available data at specific times to assess whether the data indicate any condition or occurrence that differs from the predicted conditions. Any unexplained condition will be investigated and, if possible, the cause of the anomaly determined.

The data available for the verification review will include:

- Data from groundwater monitoring bores
- Subsidence data
- Extensometer data
- Mine water balance data
- Shaft water level data
- Surface water data

The verification reviews have been timed so that if the review indicates the occurrence of unexpected behaviour, any necessary remedial measures can be carried out in a timely manner. This will also allow sufficient time for any required modifications to future operations to be implemented. A verification review will take place at the following milestones:

- At the completion of longwall A2
- At the completion of longwall A5
- At the completion of longwall A6
- At the completion of longwall A11
- At the completion of longwall A17

Each verification review will examine the available data from the period since the previous review, and will include the following aspects:

- Assess the likely height of fracturing in the area under review (if possible);
- Assess the condition of the aquifers in the area under review;
- Determine the sources of groundwater inflow to the mine and their relative volumes;
- Determine whether the assessed conditions differ in any way to the conditions predicted;
- Determine whether the variant conditions indicate a potentially adverse outcome, or will have an adverse impact on the main aquifers;
- Identify any necessary remedial measures that will mitigate the identified impact or prevent it from occurring (these measures will be drawn from methods that have proven successful in the past);
- Identify any necessary modifications to future operations or operational constraints that will assist in limiting future adverse impacts.

10. References

DLWC, 1997, *NSW State Groundwater Policy Framework Document*, Department of Land and Water Conservation, August 1997.

DLWC, 2001, *Draft Guidelines for Management of Stream/Aquifer Systems in Coal Mining Developments – Hunter Region*, Department of Land and Water Conservation, August 2001

Forster, IR, & Enever, J. 1991, *Hydrogeological Response of Overburden Strata to Underground Mining - Central Coast New South Wales*, Office of Energy Report, 1991.

Forster, IR, 1995, *Impact of Underground Mining on the Hydrogeological Regime, Central Coast NSW*, in Engineering Geology of the Newcastle-Gosford Region, eds Sloan, S. W. and Allman, M. A., AGS, pp 156 – 168, February 1995

GeoTerra, 2006, *Longwall Panels A1 and A2, Surface Water and Groundwater Assessment, Ellalong NSW*, GeoTerra P/L, Report No. AUS1-R1F, April 2006.

Goodman, RE, Moye, DG, van Schalkwyk, A, Javandel, I, 1965, *Groundwater inflows during tunnel driving*, Engineering Geology 2, No. 1, 39 – 56.

Hawley, SP & Brunton, JS, 1995, *Newcastle Coalfield – Notes to Accompany the Newcastle Coalfield Geology Map*, Department of Mineral Resources, Report No. GS1995/256, September 1995.

Hitchcock, 1995, *Hydrogeology of the Newcastle-Gosford Region*, in Engineering Geology of the Newcastle-Gosford Region, eds Sloan, S. W. and Allman, M. A., AGS, pp 156 – 168, February 1995

Holla, L, 1991, *Mining Subsidence in New South Wales, 3. Surface Subsidence Prediction in the Western Coalfield*, L Holla, Department of Minerals and Energy, January 1991.

Holt Assoc., 1992, *Geotechnical Assessment of Strata Conditions at Proposed Bellbird South Colliery for Southland Coal P/L*, GE Holt & Associates Report, February 1992.

Li, 2005, *Managing potential impacts of underground coal mining on surface and subsurface water bodies*, in AusIMM Subsidence Workshop, University of Wollongong, September 2005

Morton, WH and Kidd, CH, 1980, *Prediction, Control and Disposal of Groundwater in Coal Mines*, in Proc. of First National Seminar on Environmental Controls for Coal Mining, ed. J.C. Hannan, University of Sydney, November 1980.

MSEC, 2007, *The prediction of subsidence parameters and the assessment of mine subsidence impacts on natural features and surface infrastructure resulting from the extraction of proposed Austar longwalls A3 to A5 in support of a SMP Application*, Mine Subsidence Engineering Consultants, Report No. MSEC275, February 2007

Pacific Power International, 1997, *Cooranbong Colliery Life Extension Project, Overburden Groundwater Study*, Report No. GEO 100, March 1997

Pacific Power International, 2002, *Southland Colliery Groundwater Inflow Study*, PPI Report No. GEO 183, August 2002.

Rosengren & Associates, 1999*, No 3 Ventilation Shaft Geotechnical Review,* Kevin Rosengren & Associates Pty. Ltd, September 24, 1999

SCT, 2006, *Geotechnical Characterisation of Southern Mining Area (Based on Boreholes AQD 1072, AQD 1073, AQD 1074 & AQD 1075)*, SCT Report No. ACM3120, December 2006

Walton, WC, 1983, *The use of analytical groundwater models in mining monitoring*, Groundwater Monitoring Review, Winter 1983.