Illawarra Coal

Appin Area 9

Appin Area 9 Longwalls 901 to 904 Extraction Plan
Annex C - Water Management Plan, 2 September 2014

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ATTACHMENT B – ASSESSMENT OF SURFACE WATER FLOW AND QUALITY EFFECTS APPIN COLLIERY LONGWALLS 901 TO 904 (ECOENGINEERS, 2012)

Review History

Revision	Description of Changes	Date	Approved
A	New Document	5 October 2011	GB
B	Revised Draft	10 November 2011	GB
C	Final – Updated with PAC Approval Conditions	18 January 2012	GB
D	Final – Updated with new Mine Plan	1 May 2012	GB
E	Final – Updated with Agency Comments	31 October 2013	GB
F	Final – Updated with Additional Agency Comments	2 September 2014	GB

Persons involved in the development of this document include:

Name	Title	Company
Daniel Thompson	Environmental Planner	Cardno
Danyil Skora	Senior Environmental Planner	Cardno
Gary Brassington	Manager Approvals (Mining)	BHP Billiton Illawarra Coal

1 INTRODUCTION

1.1 PROJECT BACKGROUND

BHP Billiton Illawarra Coal (BHPBIC) operates the Bulli Seam Operations (BSO) (Appin and West Cliff Collieries) extracting hard coking coal used for steel production.

On 22 December 2011 the Planning and Assessment Commission (PAC), under delegation of the Minister for Planning, approved BSO project (MP 08_0150) under Part 3A of the *Environmental Planning and Assessment Act 1979* (EP&A Act) to continue mining operations until 31 December 2041.

This Water Management Plan (WMP) supports the Longwall 901 to 904 Extraction Plan (EP) for Appin Area 9 (AA9). The relationship between this WMP and the other components of the Extraction Plan is shown in Figure 1 of the Extraction Plan.

1.2 SCOPE

The WMP has been prepared in accordance with the BSO Approval *Condition 5 (h), Schedule 3* as follows:

> *5. The Proponent shall prepare and implement an Extraction Plan for first and second workings within each longwall mining domain to the satisfaction of the Director-General. Each extraction plan must:...*
>
> *(h) include a <u>Water Management Plan</u>, which has been prepared in consultation with OEH , SCA and (NOW), which provides for the management of the potential impacts and/or environmental consequences of the proposed second workings on watercourses and aquifers, including:*
>
> - *surface and groundwater impact assessment criteria, including trigger levels for investigating any potentially adverse impacts on water resources or water quality;*
> - *a program to monitor and report stream flows and assess any changes resulting from subsidence impacts;*
> - *a program to monitor and report ground water inflows to underground workings; and*
> - *a program to predict, manage and monitor impacts on groundwater bores on privately owned land.*

The Study Area for the Extraction Plan (refer to **Figure 1**) is defined in accordance with MSEC (2012) as *the surface area predicted to be affected by the proposed mining of Longwalls 901 to 904 and encompasses the areas bounded by the following limits:-*

- *A 35^{o} Angle of Draw line from the maximum depth of cover, which equates to a horizontal distance varying between 345 m and 510 m around the limits of the proposed extraction areas proposed for Longwalls 901 to 904, and*
- *The predicted limit of vertical subsidence, taken as the 20 mm subsidence contour, resulting from the extraction of the proposed Longwalls 901 to 904.*

Additionally, features potentially sensitive to far field movements, which includes horizontal, valley closure and upsidence movements that may be outside the 20 mm subsidence zone or 35^{o} Angle of Draw line have been assessed. The Study Area for the groundwater component also includes the area of potential groundwater drawdown as a result of the extraction of Longwalls 901 to 904 in the Douglas Park area.

1.3 OBJECTIVES

The objectives of this WMP are to identify at risk surface water and groundwater features and characteristics within the Longwalls 901 to 904 Study Area and to manage the potential impacts and/or environmental consequences of the proposed workings on watercourses and aquifers. Specific focus will be on the Nepean River, as well as other smaller watercourses.

1.4 DISTRIBUTION

This WMP will be developed in consultation with the Office of Environment and Heritage (OEH), NSW Office of Water (NoW) and other relevant stakeholders. The finalised WMP will be distributed to:

- Department of Planning and Environment (DoPE)
- OEH, (formerly DECCW)
- NoW
- Sydney Catchment Authority (SCA)
- Department of Trade and Investment (DTI – formally DRE)

BHPBIC will make the WMP and other relevant documentation publicly available on the BHPBIC website (*Condition 11, Schedule 6* of the BSO Approval).

2 STATUTORY REQUIREMENTS

Extraction of coal from Longwalls 901 to 904 will be in accordance with the conditions set out in the BSO Approval, applicable legislation as detailed in **Section 2.2** and the requirements of relevant licenses and permits, including conditions attached to mining leases.

2.1 BSO APPROVAL

Condition 5 (h), Schedule 3 of the BSO Approval (MP08_0150) requires the preparation of a WMP to manage the potential impacts and/or environmental consequences of the proposed second workings on groundwater and surface water features in the Study Area, including the Nepean River (refer **Section 1.2**).

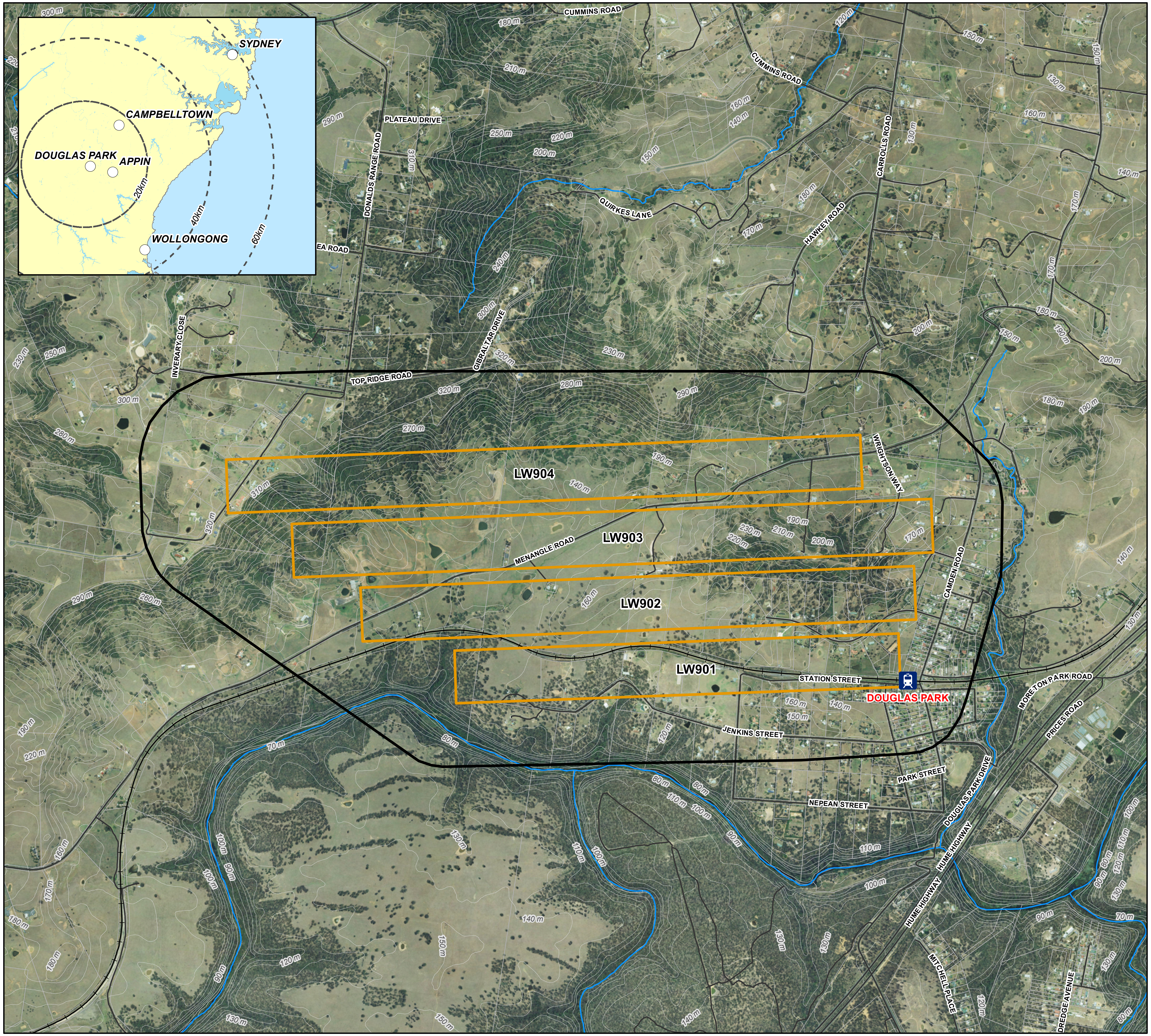
This WMP also addresses the requirements detailed in *Condition 6 Schedule 3, Condition 9 Schedule 3* and *Condition 2, Schedule 6* of the BSO Approval as shown in **Table 2.1**.

Due consideration has been given to all the BSO Approval Conditions in the preparation of this WMP, including those relating to auditing, rehabilitation and environmental management.

2.2 LEGISLATION AND GUIDELINES

This WMP has been developed taking due account of the requirements of the following legislation and associated advisory documents and guidelines including:

- *National Water Quality Management Strategy, Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC & ARMCANZ, 2000).
- *National Water Quality Management Strategy, Australian and New Zealand Guidelines for Water Quality Monitoring and Reporting* (ANZECC & ARMCANZ, 2000).
- *Contamination sites: Draft Guidelines for the Assessment and Management of Groundwater Contamination* (DEC, 2004).
- The *NSW State Groundwater Policy Framework* document (DLWC, 1997).
- The *NSW State Groundwater Quality Protection Policy* (DEC, 1998).
- The *NSW State Groundwater Dependent Ecosystems Policy* (DLWC, 2002).



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Appin Area 9 (LW 901- 904) Study Area

Legend

- Railway Stations (LPI)
- Local Roads (LPI)
- Railway (LPI)
- 10m Contours (LPI)
- Watercourses (LPI)
- Cadastre (LPI)
- AA9 Longwall Layout
- Longwalls 901-904 Study Area

N
W E
S

FIGURE 1

Scale 1:20,000 (at A3)

Kilometres
0 0.25 0.5 0.75 1

Cardno

Map Produced by Cardno Wollongong
Date: 31/10/2013
Coordinate System: GDA 1994 MGA Zone 56
Project: 109012-03
Map: 1801_AppinArea9_LW_StudyArea.mxd 07

Aerial imagery supplied by BHPBIC (2009)

Table 2.1 – Management Plan Requirements

Project Approval Condition	***Relevant WMP Section***
Condition 6, Schedule 3 The Proponent shall ensure that the management plans required under Condition 5 (g)-(l) above include: (a) an assessment of the potential environmental consequences of the Extraction Plan, incorporating any relevant information that has been obtained since this approval; (b) a detailed description of the measures that would be implemented to remediate predicted impacts.	Section 4 Section 7
Condition 9, Schedule 3 The Proponent shall prepare and implement a program to improve its prediction and understanding of subsidence impacts (in particular sub-surface impacts and impacts on groundwater resources), to the satisfaction of the Director-General. This program must be prepared in consultation with DRE and be submitted to the Director-General for approval by 30 September 2012 and must include proposals for: (a) testing (including core testing and in-situ testing) to further define the mechanical, hydrogeological and geochemical properties of rock strata within each longwall domain, including: - testing and validation of assumptions regarding regional continuity of modelled hydraulic properties (including mass porosity and permeability): - identifying hydraulic properties of rock strata close to water-dependant ecosystems; and - identifying the presence and distribution of iron-bearing minerals that might contribute to surface water quality impairment; (b) installation of a regional network of deep pore pressure monitoring bores with vertical arrays of pore pressure transducers to assess and quantify the height and impacts of subsurface fracturing; (c) a census of boreholes which may be impacted by subsidence, the gathering of relevant borehole and groundwater quality data and a regular monitoring program; (d) regular enhancement, calibration and verification of the project's regional groundwater model, and the further development of this model on a mining-domain scale; and (e) regular recalibration of methodologies and models used for subsidence effect and impact prediction, as they are applied within the project area.	Section 4
Condition 2, Schedule 6 The Proponent shall ensure that the management plans required under this approval are prepared in accordance with any relevant guidelines, and include: (a) detailed baseline data;	Section 3

Project Approval Condition	***Relevant WMP Section***
(b) a description of:	Section 2
- the relevant statutory requirements (including any relevant approval, licence or lease conditions);	Section 5
- any relevant limits or performance measures/criteria;	Sections 5 to 8
- the specific performance indicators that are proposed to be used to judge the performance of, or guide the implementation of, the project or any management measures;	Sections 5 to 8
(c) a description of the measures that would be implemented to comply with the relevant statutory, limits, requirements or performance measures/criteria;	
(d) a program to monitor and report on the:	Section 6
- impacts and environmental performance of the project;	
- effectiveness of any management measures (see c above);	Section 8
(e) a contingency plan to manage any predicted impacts and their consequences and to ensure that ongoing impacts reduce to levels below relevant impact assessment criteria as quickly as possible;	
(f) a program to investigate and implement ways to improve the environmental performance of the project over time;	Section 10
(g) a protocol for managing and reporting any:	
- incidents;	Section 9
- complaints;	
- non-compliances with statutory requirements; and	
- exceedances of the impact assessment criteria and/or performance criteria; and	Section 10
(h) a protocol for periodic review of the plan.	

2.4 RELEVANT LEASES AND LICENCES

The following licences or permits may be applicable to BHPBIC's operations in AA9:

- Mining Leases as per Table 2.2.
- Environmental Protection Licence (EPL) 2504, which applies to BSO, including Appin and West Cliff Mines. A copy of the licence can be accessed at the EPA website via the following link http://www.epa.nsw.gov.au/prpoeo/index.htm.
- BSO Mining Operation Plan (MOP) 1/10/2012 to 30/09/2019 (v1).
- All relevant OH&S and HSEC approvals.
- Additional leases, licences and approvals resulting from the BSO Application Approval.

Table 2.2 – Appin Mine Leases, Licences and Other Reference Documents

Mining Lease - Document Number	Issue Date	Expiry Date/ Anniversary Date
CCL 767	29/10/1991	08/07/2029
CL 388	22/1/1992	21/01/2013 Renewal Pending
ML 1382	20/12/1995	19/12/2016
ML 1433	24/7/1998	23/07/2019
ML 1678	26/06/2014	26/06/2035

3 BASELINE ASSESSMENT

Baseline groundwater (Heritage Computing, 2010) and surface water assessments (Gilbert and Associates, 2009) were undertaken in support of the BSO Environmental Assessment (EA). The Study Area for these assessments included the Longwall 901 to 904 Study Area.

Supplementary Assessments for groundwater (GeoTerra (2011)) (refer **Attachment A**) and surface water Ecoengineers (2012) (refer **Attachment B**) were undertaken for the purposes of this Extraction Plan.

3.1 NEPEAN RIVER

The Longwalls 901 to 904 Study Area includes drainage lines, which predominantly flow south to the Nepean River. Within the Study Area the Nepean River has been subdivided into two sections as described by MSEC (2012):

- *Section 1* (upstream of Allens Creek) where flow is controlled by boulder fields and two rockbars and a small weir.
- *Section 2* (downstream of Allens Creek) where the river is a flooded valley controlled by the Douglas Park Causeway.

Water flows in the Nepean River are derived from a number of sources, which include flows from catchment areas, licensed discharges (including Appin West Colliery and Tahmoor Colliery) and runoff from agricultural and urban areas.

Within the Study Area, River flow is predominantly controlled by the Maldon Weir (upstream) and the Douglas Park Weir (downstream). Water levels down river of the Study Area (i.e. down river of Douglas Park Causeway), are regulated by the Menangle Weir, which acts as a dam.

Water flows in the Nepean River:

- Vary greatly and are highly responsive to rain events due to the significant areas of catchment.
- Reach very high levels during sustained storm events, while minimum flow is rarely less than 1.5 ML/day (approx. 5 percentile flow).
- Cease on a small number of occasions, usually only when the rate of pumping out of the River exceeds the rate of inflow under low flow/drought conditions.
- In the section adjacent to the proposed longwalls are likely to be ~15% more than the median flow rate at Maldon Weir, which is 16.5 ML/day, and a little less than the median flow rate at Menangle Weir, which is 34.7 ML/day. Therefore median (50 percentile) flow rate adjacent to the Study Area is about 30 ML/day.

Baseline surface water monitoring for AA9 has been ongoing since October 2008 and provides a comprehensive baseline data set prior to extraction of Longwalls 901 to 904.

Water quality monitoring data for Appin Longwalls 701, 702, 703, 704 and 705 and Tower Longwall 15 also contributes to the baseline and impact monitoring data for the Study Area (as they are located in the same section of the Nepean River, as defined by MSEC (2012). Figure 2 shows the location of the existing water quality monitoring sites. The results of water quality monitoring of the Nepean River and tributaries are shown in **Table 3.1**.

Table 3.1 – Baseline Water Quality Data (October 2008 to September 2010) (Ecoengineers, 2012)

Site	EC (µS/cm)	pH	DO (%)	Total Fe (mg/L)	Total Mn (mg/L)	Ni Filt (mg/L)	Zn Filt (mg/L)
NR120 Upriver	**356.4** (±103.5)	**8.04** (±0.58)	**78.6** (±17.9)	**0.18** (±0.12)	**0.02718** (±0.015)	**0.005** (±0.002)	**0.011** (±0.011)
NR0 Adjacent Area 9	352.4 (±95.8)	**7.71** (±0.35)	**91.2** (±18.8)	**0.19** (±0.18)	**0.02818** (±0.038)	**0.005** (±0.002)	**0.013** (±0.013)
SW3 (NR1)	**361.4** (±88.8)	**7.91** (±0.31)	**85.4** (±21.2)	**0.19** (±0.17)	**0.03418** (±0.036)	**0.006** (±0.002)	**0.010** (±0.011)
SW2 lower Allens Creek	**2043.3** (±1136.2)	**8.65** (±0.34)	**96.2** (±17.7)	**0.77** (±0.88)	**0.05218** (±0.039)	**0.080** (±0.050)	**0.010** (±0.012)
NR2 Downriver Area	**412.0** (±113.0)	**8.17** (±0.34)	**92.2** (±21.9)	**0.30** (±0.27)	**0.03118** (±0.016)	**0.007** (±0.003)	**0.009** (±0.007)
NR3 Lower Harris Creek	**1303.1** (±596.8)	**7.91** (±0.46)	**91.0** (±35.4)	**0.57** (±0.40)	**0.06418** (±0.040)	**0.001** (±<0.001)	**0.014** (±0.016)

Note – all values ± 1 standard variation (stdev) in brackets

Table 3.2 shows the measured daily mean water flows at Maldon Weir (1975 to 2011) and Menangle Weir (1990 to 2009) provided by SCA. Time gauging at Menangle Weir was terminated in December 2009 for a period due to the construction of a fish ladder.

The difference in the water flow rates between Maldon Weir and Menangle Weir is due to the number of sources of additional flow that enter the river and extraction between the weirs. The inflows are from the Cataract River and other drainage lines, licensed discharge flows from Appin Colliery and flows from other catchment areas.

The flow rate at Menangle Weir is considered to be more representative of flows adjacent to Longwalls 901 to 904 than the flow rate at Maldon Weir (Ecoengineers, 2012).

Table 3.2 – Long-term Flow Frequency Records for Maldon Weir and Menangle Weir

Percentile	Maldon Weir flow record (ML/day)	Menangle Weir flow record (ML/day)
60	21.5	43.6
50	16.5	34.7
40	12.8	26.0
30	9.8	18.6
20	7.2	10.9
10	4.5	5.5
Total Days Flow Recorded	**9502**	**6698**

3.2 OTHER SURFACE WATER FEATURES

The larger drainage lines within the Longwalls 901 to 904 Study Area include:

- ***Nepean River Tributary 1*** located directly above the proposed Longwalls 902 to 904.

- ***Harris Creek*** located east of the proposed Longwalls and 400 m from Longwall 903 at its closest point. It is located just outside the Study Area, although Harris Creek could experience valley related movements (MSEC, 2012).

First and second order channels also flow to the Nepean River, and form smaller gullies along the cliffs of the gorge which generally discharge via elevated streams cascading down cliffs after sufficient rain. The majority of rainfall in the smaller catchments would infiltrate into these plateau soils and enter the groundwater system as described in **Section 3.3**.

There are no areas considered flood prone and there are no upland swamps in the Study Area.

A number of earth farm dams are located in the streams and are used as water sources on rural properties. All major streams have dams within their channels and catchment areas.

3.3 GROUNDWATER

The Nepean River is a ‘gaining’ system, where groundwater flows from the plateau under a regional hydraulic gradient to the river. These flows are predominantly horizontal, and determined by a confined flow along discrete layers underlain by fine grained or relatively impermeable strata within the Hawkesbury Sandstone.

Recharge of the groundwater system occurs after rainfall infiltrates into the plateau soil, as well as the underlying Wianamatta Shale and/or Hawkesbury Sandstone. The majority of water discharges from temporary seeps in the cliffs of the Nepean River gorge.

The low permeability of the Bald Hill Claystone acts as an aquatard between the Hawkesbury Sandstone and the Bulgo Sandstone. It has been observed to maintain its low permeability after subsidence and inhibit the movement of water and gas.

Within the Study Area the restricted vertical recharge and predominantly horizontal flow are determined by the:

- Horizontally bedded strata under both sides of the plateau with preferential flow along bedded zones with coarser grain size.
- Claystone/mudstone banding at the base and tops of sedimentary facies, which restrict vertical migration and enhance horizontal flow at the base of the unit.
- Fracture zones enhancing horizontal flow through the strata, and bedding planes and unconformities located immediately above finer grained sediments or iron rich zones.

Twelve NoW registered bores are located within or adjacent to the Longwalls 901 to 904 Study Area along with BHPBIC monitoring piezometers (Figure 2).

NoW registered bores were drilled between 70 m to 240 m below surface, with water obtained primarily from dual porosity sandstone aquifers. GeoTerra (2011) have observed some thin, perched horizon water sections in the Wianamatta Shale (GW104602 at 29.9 m).

Groundwater in the NoW registered bores, where reported, is generally fresh to brackish with salinity (total dissolved solids) between 260mg/l and 2500mg/L.

BHPBIC installed four open standpipe piezometers (NGW series) in 2004 near the Longwalls 901 to 904 Study Area. These were placed in the Hawkesbury Sandstone to 10 m below the base of the Nepean River gorge. BHPBIC installed an additional five vibrating wire piezometer array bores in 2008 (EAW Series) down to 798 m below surface. Four of these moitoring bores are located in the general vicinity of AA9 while the other site is in the adjacent Appin Area 7 domain. Two additional groundwater monitoring sites were installed between the mining area and the Nepean River (S2280 and S2281). These sites have multi level groundwater peizometers and low volume water sampling installations.

NoW data indicates that regionally significant aquifers are generally deeper than 64 m below surface. GeoTerra (2011) supplementary investigations suggest intersections as shallow as 9 m may be present in shallow, perched sandstone aquifers with limited extent.

NoW data also indicates that the deepest aquifer discovered to date was intersected to the east of Longwall 904 (GW104602) at 213 m below surface. GeoTerra (2011) indicate that the majority of aquifer intersections over the Longwalls 901 to 904 Study Area lie at or below the elevation of the Nepean River.

Observations undertaken by GeoTerra (2011) were derived from monitoring over Appin Longwalls 701 to 703 and Tahmoor Colliery, further details regarding these bores and piezometers can be found in **Table 4.4**, the groundwater assessment is provided in **Attachment A**.

4 PREDICTED IMPACTS

In accordance with the findings of the Southern Coalfield Inquiry:

- **Subsidence effects** are defined as the deformation of ground mass such as horizontal and vertical movement, curvature and strains.
- **Subsidence impacts** are the physical changes to the ground that are caused by subsidence effects, such as tensile and sheer cracking and buckling of strata.
- **Environmental consequences** are then identified, for example, as a loss of surface water flows and standing pools.

4.1 SUBSIDENCE EFFECTS

The proposed longwalls are located at a minimum (closest approach) distance of 130 m from the centreline of the Nepean River. **Table 4.1** provides a summary of the maximum predicted values of total subsidence, upsidence and closure along Nepean River, Harris Creek and Tributary 1.

Table 4.1 – Maximum Predicted Subsidence Effects for the Nepean River (MSEC, 2012)

Feature	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Upsidence (mm)	Maximum Predicted Closure (mm)
Nepean River	30	110	200
Nepean River Tributary 1	1175	575	625
Harris Creek	< 20	< 20	< 20

Other drainage lines and surface water features could experience the full range of subsidence effects depending on their specific location in relation to Longwalls 901 to 904. Maximum predictions from MSEC are provided in **Table 4.2**.

Table 4.2 – Maximum Predicted Total Conventional Subsidence Parameters for Other Watercourses Located Directly Above Longwalls 901 to 904 (MSEC, 2012)

Subsidence (mm)	Tilt (mm/m)	Hogging Curvature (km^{-1})	Sagging Curvature (km^{-1})
1200	6.0	0.07	0.12

The maximum predicted subsidence at the private bores and BHPBIC piezometers after completion of Longwalls 901 to 904 as assessed by MSEC (2012) are listed in **Table 4.3**.

Table 4.3 – Maximum Predicted Cumulative Subsidence (MSEC, 2012)

Ref	Northing	Easting	Maximum Predicted Subsidence (mm)
NoW Registered Bores			
GW 34425	6215603	289184	20 – 50[#]
GW 35033	6214961	288045	100 – 200[#]
GW 72249	6215538	288091	1000[#]
GW 100673	6216160	286235	50 - 100[#]
GW 102043	6214659	289777	<20
GW 102584	6216255	289480	<20
GW 102798	6214783	289990	<20
GW 103161	6216499	289511	<20
GW 104068	6214530	289519	<20
GW 104602	6216338	289054	<20[#]
GW 104661	6216470	288973	<20
GW 110671	6216340	288717	20 - 50[#]
BHPBIC Piezometers			
NGW3	1216749.5	275027.4	<20
NGW4	1216826.2	275789.9	<20
NGW5	1216327.4	276124	<20
NGW6	1216680.5	276403.3	<20
EAW5	6218729	289027	<20
EAW7	6217768	291547	<20
EAW9	6216341	287181	20
EAW18	6216904	285466	<20
EAW58	6215342	289803	<20

*# potentially affected by water drawdown as detailed in **Table 4.5**.*

4.2 SUBSIDENCE IMPACTS

MSEC (2012) has identified potential water related subsidence impacts for the Nepean River, Harris Creek and other streams. These impacts include:

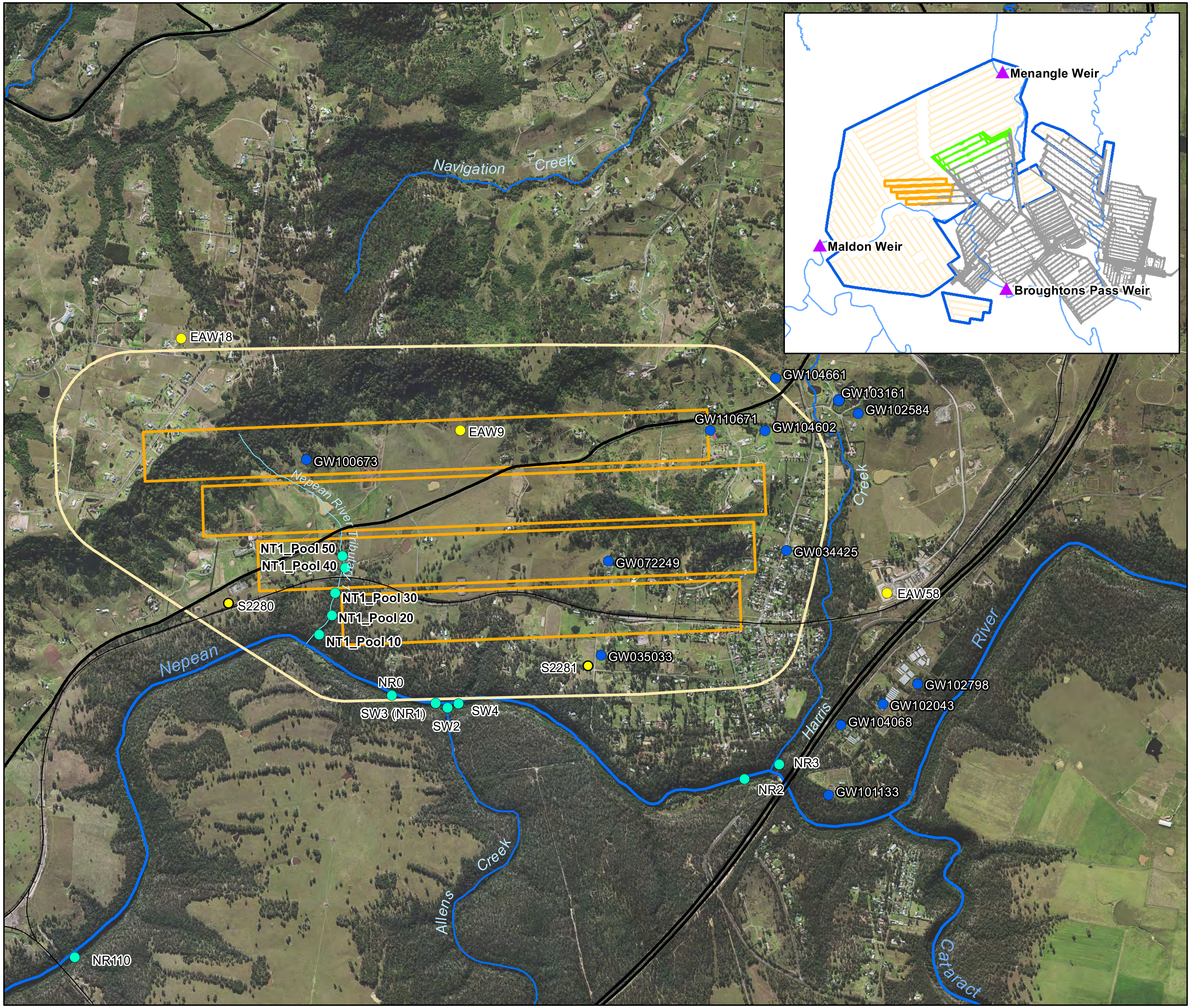
- Surface fracturing, and
- Vertical and horizontal dilation of strata.

Longwall mining can result in the development of fractures in streams. This is most likely to occur in incised and rock bedded streams that have been directly mined beneath. Longwalls 901 to 904 will not be extracted directly beneath the Nepean River.

Some minor fracturing may occur up to approximately 400 m from mined longwalls, however the likelihood of fracturing is low for bedrock located beyond the limit of subsidence.

Mining induced subsidence at these distances is unlikely to result in surface flow diversion or reduction in water quality. It is expected that only minor fracturing may occur in the bed of the Nepean River as a result of the extraction of the proposed Longwalls 901 to 904 (Ecoengineers, 2012).

GeoTerra (2011) have assessed the potential impacts from subsidence on groundwater systems in the Study Area by looking at data from other mines located within the Southern Coalfield that have similar geology (Hawkesbury Sandstone and Wianamatta Shale plateaus with deeply incised gorges), depths of cover (~400 m to 550 m) and mining the Bulli Seam using longwall mining methods.



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Appin Area 9
LW 901-904

Surface & Groundwater Monitoring Locations

Figure 2

Legend
- Surface Water Monitoring Sites
- Groundwater Moitoring
- Private borehole
- Longwalls 901-904 Study Area
- Appin Area 9 Longwall Layout
- Major Roads
- Railway Lines
- Rivers
- Creeks

Inset Legend
- Flow Monitoring Stations
- BSO Approved Mining Area

0 250 500 750 1,000
Meters

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Author: P.Crowe
Approved: G.Brassington

N E S W

Version 2
Horizontal Datum
MGA - Zone 56

Table 4.4 – Bores and Piezometers within the Longwall 901 to 904 Study Area

Borehole Reference	Northing	Easting	Surface Water Level (SWL) (m)	Depth (m)	Year Drilled	Aquifer	Lithology	Yield (L/s)	Total Dissolved Solids (TDS)(mg/L)	Purpose
NoW Registered Boreholes										
GW 34425	6215603	289184	14.60	70.10	1972	9.10 – 10.6 21.3 – 24.3 64.0 - 69.4	Sandstone	0.03 0.04 0.63	n/a	Waste disposal
GW 35033	6214961	288045	54.80	131	1973	17.6 – 17.7 54.8 – 55.1	Sandstone	0.13 0.23	n/a	Stock
GW 72249	6215538	288091	36.60	97.5	1994	76.2 – 76.3 85.3 – 85.5	Sandstone	0.25 1.14	n/a	Domestic / Stock
GW 100673	6216160	286235	49.0	104	1995	71 – 74 84 - 87	Sandstone	0.20 0.40	1200 1400	Stock
GW 101133	6214100	289443	61.0	96	1997	78.5 – 78.8	Sandstone	1.80	1100	Stock / Domestic
GW 102043	6214659	289777	104.0	192	1999	40 – 41 161.5 - 162	Sandstone	0.10 0.20	291 260	Stock / Domestic
GW 102584	6216255	289480	60.0	186	1999	54 - 60 64 - 70 108 -112 144 - 150 177 - 179	Sandstone	0.10 0.10 0.20 0.20 0.9	1370 1190 1300 1300 1300	Domestic / Stock
GW 102798	6214783	289990	n/a	148	1997	95 – 96 103 - 104	Sandstone	0.25 1.00	n/a 700	Domestic / Stock
GW 103161	6216499	289511	25	120	2000	17-18 54 - 56 83 – 84 108 - 110	Shale Sandstone	0.2	1450	Domestic / Stock
GW 104068	6214530	289519	62.0	180	2001	95 – 118 152 – 153 163 - 164	Sandstone	0.52 0.50 0.50	990 1000 1000	Domestic / Stock
GW 104602	6216338	289054	42.0	231	2003	29.9 – 30 161 – 161.5 213 –	Shale Sandstone	0.13 0.75 0.75	2500 n/a n/a	Stock

Borehole Reference	Northing	Easting	Surface Water Level (SWL) (m)	Depth (m)	Year Drilled	Aquifer	Lithology	Yield (L/s)	Total Dissolved Solids (TDS)(mg/L)	Purpose
						213. 5	Sandstone			
GW 104661	6216470	288973	68.0	219	2003	113 - 113.1 154 - 154.1 197 - 197.1 212 - 212.2	Sandstone	1.05	fresh	Domestic / Stock
GW 110671	6216340	288717	82.0	240	2010	72. 0 - 72.2 150.0 -150.3 166 - 166.2 211 – 211.1	Sandstone	0.05 0.10 0.90 0.15	400	Domestic / Stock
BHPBIC PIEZOMETERS										
NGW3	1216749.5	275027.4	77.33*	72.1	2004	n/a	sandstone	n/a	n/a	Monitoring
NGW4	1216826.2	275789.9	68.56*	78.75	2004	n/a	sandstone	n/a	n/a	Monitoring
NGW5	1216327.4	276124	66.71*	66.45	2004	n/a	sandstone	n/a	n/a	Monitoring
NGW6	1216680.5	276403.3	66.33*	66.75	2004	n/a	sandstone	n/a	n/a	Monitoring
EAW5	6218729	289027	various	612	2008	n/a	various	n/a	n/a	Monitoring
EAW7	6217768	291547	various	611	2008	n/a	various	n/a	n/a	Monitoring
EAW9	6216341	287181	various	605	2008	n/a	various	n/a	n/a	Monitoring
EAW18	6216904	285466	various	798	2008	n/a	various	n/a	n/a	Monitoring
EAW58	6215342	289803	various	525	2010	n/a	various	n/a	n/a	Monitoring
S2280	6215278	285757	various	110	2014	n/a	various	n/a	n/a	Monitoring
S2281	6214898	287959	various	110	2014	n/a	various	n/a	n/a	Monitoring

Due to the substantial depths of cover over Longwalls 901 to 904, connective cracking from the mined workings to the surface is not anticipated. Groundwater modelling indicates that there is anticipated to be an eventual recovery of deep groundwater system pressures over many decades following cessation of mining. Water level reductions in the Wianamatta Group perched aquifers may potentially reduce by between 5 m to 10 m.

Based on observations over Appin Longwalls 701 to 703, the sandstone groundwater levels may reduce by up to 10 m. Due to the short term nature of any groundwater level reductions it is concluded that there is unlikely to be a more than negligible impact to groundwater resources in the Hawkesbury Sandstone aquifers resulting from the proposed extraction.

Due to the substantial depths of cover over Longwalls 901 to 904, connective cracking from the mined workings to the surface is not anticipated. Groundwater modelling indicates that there is anticipated to be an eventual recovery of deep groundwater system pressures over many decades following cessation of mining.

4.3 ENVIRONMENTAL CONSEQUENCES

Ecoengineers (2012) and GeoTerra (2011) have identified the following possible water related environmental consequences that may occur due to the extraction of Longwalls 901 to 904 and are discussed in more detail below:

- Gas emissions in the Nepean River and other areas.
- Groundwater outflows and ferruginous springs.
- Sub-bed flow diversions and un-natural pool drainage.
- Impacts to streams and farm dams.
- Reduced groundwater yield.
- Water quality impacts.
- Gas emissions.

4.3.1 Gas Emissions

Based on the gas release zones and related iron stain zones observed at Appin Area 7 Ecoengineers (2012) predict that “minor” emissions into the Nepean River are a likely consequence of the proposed mining of Longwalls 901 to 904.

Dissolved Oxygen (DO) sags due to microbiological consumption of dissolved methane around gas releases have been identified in the Nepean River during the extraction of Longwalls 701 to 703. Within the Longwalls 901 to 904 Study Area (above Allens Creek) the Nepean River contains a large number of boulder fields giving the River a greater re-aeration capacity compared to the flooded section of the River adjacent to Longwalls 701 to 703 (Ecoengineers, 2012).

Therefore, although emissions of strata gas into the Nepean River might give rise to some temporary DO sagging during the mining of Longwalls 901 to 904, such sags are likely to have “negligible” environmental consequences.

Visible iron precipitates could occur in the Nepean River in association with groundwater inflows or gas release sites. Geochemical modeling indicates no adverse effect on water quality is likely to occur from such ‘iron staining’ and it would have “negligible” environmental consequence.

There is potential for strata gas emissions into private bores, and any emissions that may occur are likely to diminish over time. In the event that borehole emissions are identified the area will be made safe and an alternate water supply will be provided, in consultation with the landowner. Mitigation measures would be incorporated into the Property Subsidence Management Plans (PSMPs).

4.3.2 Groundwater Outflows and Ferruginous Springs

The inducement of ferruginous springs due to mining has been occasionally observed in Bulli Seam mining areas especially along margins of outcropping Wianamatta Shale.

Mining of Longwalls 701 and 702 has not led to induction of any detectable ferruginous springs either in the walls of the Nepean River gorge or along adjacent tributaries.

Ecoengineers (2012) therefore consider there is only a low likelihood of ferruginous springs being induced in the walls of the Nepean River gorge adjacent to Longwalls 901 to 904. Should any occur, the high inherent alkalinity and re-aeration capacity of the Nepean River would render their ecological impact to be “negligible”.

4.3.3 Sub-bed Flow Diversions and Pool Drainage

The majority of the controlling stream features in Section 1 of the Nepean River are boulder fields, which are less susceptible to fracturing than rockbars, as they are not vertically confined. Two rockbars have been identified in the Study Area. Rockbar NR-A9-RB01 is located 370 m from the proposed longwalls and, therefore, any fracturing in this location is expected to be isolated and minor in nature. Rockbar NR-A9RB02 is submerged at times of high flow, and therefore does not restrict the surface water at these times.

The potential for diversion of water in Section 2 is very low as the river is flooded and the gradient of the river is very flat. Further, no evidence for sub-bed diversion of River flows or un-natural rates of drainage of pools induced by coal mining ‘upsidence’ has previously been detected in the Nepean River.

Monitoring during extraction of Longwalls 701 to 702 showed no statistically significant difference in River flows at Maldon and Menangle Weirs when compared to pre-mining conditions. The likelihood of any Nepean River upsidence-induced bedrock fracturing causing sub-bed flow is therefore considered to be “negligible” (EcoEngineers, 2012).

If it did occur, bedrock fracturing caused by mining could also increases acid production due to the dissolution of siderite and trace accessory sulfide minerals in the sandstone of the River bed. Any potential reduction in the pH levels in the Nepean River is likely to be neutralised by the natural alkalinity of the Nepean River water, ensuring “negligible” consequences.

Any iron and manganese released should also precipitate and any nickel or zinc would likely undergo speciation (due to the high natural alkalinity in the River) ensuring “negligible” environmental consequences.

4.3.4 Harris Creek

It is considered that there will be “negligible” environmental consequences to Harris Creek from the mining of Longwalls 901 to 904.

Monitoring due to mining in Appin Area 7 has indicated that there is no significant impact on flows in the creek or its contributing flows to the Nepean River (as would be expected in this stream). There has also been no detectable ferruginous and/or saline springs in the Creek.

4.3.5 Other Streams and Drainage Lines

The northern parts of AA9 are drained by the upper reaches of Racecourse Creek (including Apps Gully), Matahill Creek and the headwaters of Navigation Creek. These creeks are neither mined under, nor approached closely by the proposed Longwalls 901 to 904 and are therefore considered likely to experience “negligible” environmental consequences.

Nepean River Tributary 1 is located directly above the proposed Longwalls 901 to 904. The lower reaches of the tributary is fourth order, of which, 120 m is located directly above Longwall 902. The second and third order branches are located above the proposed Longwalls 902 and 903.

Based on previous experience of mining in the Southern Coalfield, it is likely that some fracturing will occur along the drainage lines, particularly those located above or adjacent to the proposed longwalls. It is unlikely, however that there will be any significant net loss of water from the catchment. The predicted mine subsidence movements and, hence, the assessed impacts for the drainage lines are similar to or less than that assessed in the BSO EA.

4.3.6 Farm Dams

Many farm dams have been mined under and monitored by BHPBIC. Only a small number of dams have exhibited impacts with the dam becoming dry following undermining.

It is predicted that the impact on farm dams from mining Longwalls 901 to 904 will be similar, resulting in “minor” to “negligible impacts. Where impacts are observed, these will be repaired and/or alternate water supply provided, in consultation with the landowner.

4.3.7 Reduced Bore Yield

Six NoW registered bores within or near the proposed Longwalls 901 to 904 may be affected by subsidence, where the bores predominantly obtain water from the Hawkesbury Sandstone, rather than the overlying Wianamatta Group shale and sandstones (refer **Table** 4.5).

Table 4.5 – Potentially Affected Water Levels, Yield and Serviceability of Private Bores

Ref	Potential Drawdown (m)	Potential Effect on Yield or Serviceability
GW 34425	<5	Low
GW 35033	<5	Moderate
GW 72249	5 - 10	Elevated
GW 100673	5 - 10	Elevated
GW 104602	<5	Very Low
GW 110671	5 - 10	Moderate - Elevated

With the recommended mitigation measures in place comprising the replacement of water supply for affected landowners impacts to property water supply as a result of the proposed mining of Longwalls 901 to 904 would be negligible.

4.3.8 Groundwater Quality

It is likely that some water quality changes will occur but there is a relatively low level of groundwater resource use in the area. Monitoring of potentially affected bores within AA9 will be conducted in consultation with the owner prior to, during and after development of subsidence at specific bore locations.

If groundwater quality impacts resulting from subsidence are identified, alternate supplies of water will be provided to any affected water user until a similar supply can be re-established with similar water quality characteristics. With these mitigation measures in place it is unlikely that there will be more than negligible impacts to water quality supplies from the proposed mining.

4.3.9 Groundwater Baseflow to the Nepean River

Due to its location at the base of the regional hydrological system no significant changes to baseflow has been observed into the Nepean River as a result of longwall mining in Appin Area 7 or the Tahmoor longwalls. Increased rates of low volume seepage to the river may have been generated, but seepage would be insignificant when compared to the volume of water flowing down the River.

Due to the low levels of strain on the plateau area and limited potential for fracturing of rock, cracking of soil and water diversion, it is unlikely that the proposed mining of Longwalls 901 to 904 will have more than negligible impact to lower order streams, seeps, springs and flow to the Nepean River.

It is anticipated that there will be no permanent reduction in groundwater levels underneath the Nepean River, as once any subsidence induced fractures are filled with water, there is no vertical discharge path through which groundwater can flow out of the system, so there will be no ongoing water flow into any fractured basement of the gorge or riverbed. The small amount of river water diverted to fill any fractures that do occur would be quickly replenished by the large volume of water in the ponded river sections and the large daily flow down the river (minimum of 3 ML/day).

4.3.10 Mine Inflow

Loss of stream flow or substrate groundwater to the Bulli Seam workings has not been observed in any mines in the Southern Coalfield at similar depths of cover that exist at AA9.

The potential for inflow of surface water to mine workings is low. The horizontal permeability of the Hawkesbury Sandstone and mid to upper Bulgo Sandstone above and below the Bald Hill Claystone may be enhanced after subsidence, however no free draining direct vertical hydraulic connection to the Bulli Seam workings is anticipated.

4.4 IMPROVED UNDERSTANDING OF SUBSIDENCE IMPACTS

Condition 9, Schedule 3 of the BSO Approval requires BHPBIC to prepare and implement a program to improve its prediction and understanding of subsidence impacts to the satisfaction of the Director-General. The program will have particular focus on sub-surface impacts and impacts on groundwater resources. The program will include the following:

- Testing to define the various properties of rock strata within each longwall domain
- Installation of a regional network of deep pore pressure monitoring boreholes
- A census of boreholes and gathering of borehole data
- Regular assessment and recalibration of the projects regional groundwater model
- Regular recalibration of methodologies and models used for subsidence effect and impact prediction, as they are applied within the project area.

The results of the program will be incorporated within subsequent Extraction Plans, this would include the sub-plans required under *Condition 5 (g-l), Schedule 3* of the BSO Approval.

5 PERFORMANCE MEASURES AND INDICATORS

The BSO Approval provides Subsidence Impact Performance Measures (*Condition 1, Schedule 3).* **Table 5.1** below details the conditions relevant to watercourses within the Study Area.

In relation to the subsidence impact performance measure for watercourses the term "*negligible"* is defined within the Project Approval as "*small and unimportant, such as not to be worth considering"*.

Table 5.1 – Subsidence Impact Performance Measures

Watercourses (Condition 1 Schedule 3)	
Nepean River	Negligible environmental consequences including: • *negligible* diversion of flows or changes in the natural drainage behaviour of pools; • *negligible* gas releases and iron staining; and • *negligible* increase in water cloudiness
Other Watercourses	No greater subsidence impact or environmental consequences than predicted in the EA and PPR.

In order to mitigate the potential subsidence impacts and environmental consequences from the mining of Longwalls 901 to 904 monitoring and recording will be undertaken prior to mining, throughout the extraction and at the completion of subsidence (refer **Section 6**).

In the event that any subsidence impact is recorded, consideration would be given to implementing appropriate management, remediation and/or mitigation measures in consultation with NoW and other relevant stakeholders (refer **Section 7**).

If the subsidence impact performance measures are exceeded, BHPBIC will notify NoW, DoPE, OEH, DRE, and other stakeholders and implement the Contingency Plan (**Section 8**).

6 MONITORING AND REPORTING

6.1 SURFACE WATER QUALITY MONITORING

Baseline surface flow and water quality monitoring in Nepean River upriver and adjacent to proposed Longwalls 901 to 904, Allens and Harris Creeks and Tributary 1 will continue up until the commencement of Longwall 901 extraction.

Monitoring has commenced at additional sites NR110, NT1_Pool 10, NT1_Pool 20, NT1_Pool 30, NT1_Pool 40 and NT1_Pool 50. This will allow for a more quantifiable understanding of any effects in the River related to longwall mining or other impacts such as agricultural discharges.

Following commencement of Longwall 901, riverine water quality TARPs would be implemented for the adjacent AA9 Nepean River monitoring sites based on the following principles:

- Level 1 pH and DO TARPs for sites NR0, SW3 (NR1) and NR2 should be based on greater than one but less than two standard deviations reduction based on the long term baseline mean levels for these monitoring sites.
- Level 2 pH, DO, EC, Total Fe and Total Mn TARPs for sites NR0, SW3 (NR1) and NR2 should be based on a level reduction greater than two standard deviations from long term baseline mean levels for these monitoring sites.
- Level 3 pH, DO, EC, Total Fe and Total Mn TARPs for sites NR0, SW3 (NR1) and NR2 should be based on Level 2 type reductions in long term baseline mean levels resulting from mining which are sustained for more than 6 consecutive months.

6.2 WATER FLOW MONITORING

Flow monitoring in the Nepean River is undertaken upstream and downstream of the mining area. Water levels in the Nepean River in the mining area are also monitored. Observational monitoring of streams will also take place within the mining area.

Nepean River flow monitoring and analysis for AA9 will be undertaken in the same manner as it is for Appin Area 7. The Longwall 701 to 705 End of Panel Reports provides details of the proposed data analysis and approach. Daily flow records for Maldon, Menangle and Broughtons Pass weirs from 1990 have been assessed in order to study the dry weather recessions in the Nepean River adjacent to the proposed mining areas. The difference in flows should be equivalent to runoff from all catchments between these two weirs responding to local rainfall minus any abstractions by licensed pumps in the River.

Dry weather recessional phases in the Menangle minus Maldon and Broughtons Pass flow datasets significantly removes the influence of catchment inflows and allows analysis of those recessions for normal behaviour, i.e. relative to the record of baseline recessions prior to the commencement of mining. The recession flow period is more sensitive to any diversions of flow as the diversion would be a higher percentage of the total flow during that period and therefore this is the most appropriate period for detailed analysis. These tests have been conducted for the Area 7 End of Panel Reports and proven to be an acceptable measure for identifying any diversions of flow.

51 baseline dry weather recession periods in Nepean River have been identified using the Menangle minus Maldon and Broughtons Pass Weirs flow records prior to mining commencing in Appin Area 7. Each of these recession curve slope fits had good R2 values, ranging from 0.76 to 0.99. The mean dry weather recession rate, excluding seven dry weather recessions during and immediately following the mining of Tower Colliery Longwalls 16 and 17 between October 1998 and May 2000 is -24.4±16.9 ML/day. Out of these 51 baseline (non-mining) recessions the slope of only two recessions (02/04/2002 – 09/04/2002 and 31/05/2002 – 07/06/2002), i.e. only ~4% had slopes steeper than -58.1 ML/day i.e. below two standard deviations below the mean. This indicates the sample of 51 baseline recessions is exhibiting normal statistical behaviour. Recessions curves from the period of mining will be compared to the baseline period.

The location of the Maldon, Menangle and Broughtons Pass gauging sites is included in **Figure 2**. These flow monitoring stations are ideally located on the Nepean River, being directly upstream and downstream of the approved Bulli Seam Operations footprint. Flow monitoring on the Cataract River at Broughtons Pass Weir measures the flow of the major tributary input to Nepean River between the two Nepean River flow stations.

The Nepean River low flow water surface is 61.10mAHD at Douglas Park weir and 60.84mAHD at Menangle. Groundwater monitoring bores between Appin Area 7 mining and the River show that the groundwater levels remain higher than the River, ensuring the hydraulic gradient toward the River is maintained. This includes the NGW6 water level which varied from 2.33 – 4.75m higher in elevation than the river during the Longwall 704 and Longwall 705 monitoring period. This approach to monitoring water levels in the River and the nearby piezometric gradient is a very useful approach to detect any redirection of surface water flow into nearby strata, which could represent a reduction in surface water flow in the River. Groundwater monitoring has been installed between AA9 mining and the Nepean River which will be able to identify any reversal of groundwater gradient away from the River.

The approach to monitoring River flow during AA9 mining is proposed to be the same as for mining in Appin Area 7. There are currently no plans to implement additional flow monitoring (e.g. Douglas Park Weir) on the following basis:

- The proposed photographic, groundwater level, pool water level, flow and cease to flow monitoring are adequate to compare pre, during and post mining recessional behaviour in the River.
- Given the time requirements to install and calibrate flow rating curves for monitoring sites and that mining has commenced in the region (Tower and Appin Area 7) and will commence in AA9 in 2016 there is limited opportunity for gather regional flow baseline data at a Douglas Park site.
- The Douglas Park Weir has a complex construction (e.g. multiple flow paths and a by-pass flow fish ladder) which does not lend itself to developing good gauging e.g. the relationship between water level and flow.

6.3 POOL WATER LEVEL MONITORING

The Nepean River is a ‘gaining river’ in terms of surface water - groundwater interaction. The potential for infiltration of water into the groundwater system is very low as the Nepean River lies in a well incised gorge which represents the regional low point in the piezometric surface. The potential for sub-bed diversion of surface water is very low as the Nepean River is flooded and the gradient is very flat, significantly removing the effects of gravity to force surface flow through any fracture network that develops.

Water levels in the Nepean River and its tributaries are monitored using observations and measured benchmarks. The water level is recorded before, during and after mining and is assessed against catchment rainfall and discharges from the SCA controlled weirs. This method of monitoring has been used for Appin Area 7 with no impacts to the water levels of the Nepean River observed during the period of extraction. Pool water level monitoring is conducted at monitoring sites NR110, NR0, NR2, NT1_Pool 10, NT1_Pool 20, NT1_Pool 30, NT1_Pool 40 and NT1_Pool 50.

6.4 GROUNDWATER MONITORING

An extension of the current groundwater monitoring program will be used to monitor the subsidence effects from the extraction of Longwalls 901 to 904 on groundwater within the Study Area (refer **Table 6.1**).

If significant excursions from the predicted model outcomes occur, this will trigger the need for model re-calibration and/or further investigation.

Consultation with bore owners and the monitoring of bores will be incorporated into the PSMP's for relevant properties and, with the agreement of the landowner would include:

- Interview with landowner before a bore is mined under to determine the normal rate and duration of pumping.
- Details obtained on the type and set up of the pump in each bore, if installed.
- Post mining interview to compare rate and duration of pumping.
- Measurement of the bore yield if used and access is available.
- Observations on the presence and quantum of iron hydroxide precipitating from the pumped water before and after mining.
- Observations of any gas in the bores.

Table 6.1 – Monitoring in BHPBIC Piezometers

Ref	Standing water levels	Vertical profiles of potentiometric head	Groundwater Quality
EAW5		Y	
EAW7		Y	
EAW9		Y	
EAW18		Y	
EAW58		Y	
S2280 (POSP A)		Y	Y
S2281 (POSP B)		Y	Y
Private Bores	Y		Y

Notes:

1. *Where a private bore is used and access is granted, monitoring before and after the site is mined under.*
2. *Monitoring sites will be measured and data logged at least twice daily in the pre-mining baseline, impact and post-mining period.*

6.5 CLIFF SEEPS

The presence and duration of observable cliff seeps within the Study Area will be photographically and semi quantitatively recorded during field monitoring as described in the Landscape Management Plan. Where available and accessible, seep water samples would be collected and assessed for field and laboratory parameters.

6.6 MINE WATER INFLOWS

Statutory inspections of the mine workings will be undertaken by BHPBIC to ensure mine safety. The statutory inspections will identify the first indication of a water inflow to the mine. The statutory inspections are well suited to this monitoring due to the frequency of inspections and familiarity with normal conditions. Any unusual inflows detected during inspections will be sampled and tested as per the BHPBIC groundwater monitoring.

A Mine Water Balance will be used to quantify water inflows by calculating the difference between total mine inflows and mine outflows.

Monitoring of the mine water balance will comprise:

- Metered water reticulated into the mine.
- Metered water reticulated out of the mine.
- Measurement or estimates of moisture content into and out of the mine. Measurement of the in-situ moisture content of the coal during routine channel sampling for coal quality.

Given the large fluctuations in daily water usage and the cycle period for water entering the mine, being used by machinery and draining to sumps for return pumping to the surface, an average (e.g. 20 day) will be used to provide a more realistic estimate of water make.

6.7 REPORTING

Results from the monitoring program will be reported annually in the Annual Environmental Management Report (AEMR). This report will detail the outcomes of monitoring undertaken; provide results of visual inspections: determine whether performance indicators have been exceeded: and whether CMAs are required.

Monitoring results will be reviewed monthly by the BHPBIC Subsidence Management Committee. However, if the findings of monitoring are deemed to warrant an immediate response the Manager Approvals will initiate the requirements of the TARP (refer **Table 7.1**).

Monitoring results will be made publicly available in accordance with BSO Approval *Condition 8 & 11, Schedule 6* and will also be included in the Annual Reporting *Condition 4, Schedule 6.*

7 MANAGEMENT AND MITIGATION STRATEGIES

The predicted impacts for the Nepean River and other watercourses and drainage lines within the Study Area are nil to negligible and no mitigation measures are currently proposed for any of these predicted impacts. Where there are impacts to farm dams these would be repaired utilising standard dam building techniques and/or an alternate water supply would be provided in consultation with the landowner.

The main impacts predicted for groundwater are lowering of some groundwater levels due to dilation of the strata above the longwalls. Where this lowering impacts groundwater sources to landholders the following mitigation measures may be proposed:

- Lowering of the pump intake.
- Extension of the bore depth.
- Establishment of a new bore.

With these mitigation measures in place the impact of lower groundwater levels are predicted to be negligible.

BHPBIC will review the need to implement additional management and mitigation measures during routine monitoring (refer **Section 6**) and during the finalisation of PSMPs with affected landholders.

7.1 TARPS

The AA9 Water Trigger Action Response Plan (TARP) is shown in **Table 7.1**.

Table 7.1 – AA9 Trigger Action Response Plan (TARP)

Monitoring	Trigger	Action
WATER QUALITY		
Adjacent and downstream sites: • Nepean River: – NR0 – SW3 (NR1) – NR2 – If and where strata gas emission plumes above 3000 L/min are detected	***Level 1**** Impact monitoring sites when comparing the baseline period to the mining period for that site: • pH reduction greater than 1 standard deviation but less than 2 standard deviation from pre-mining mean resulting from the mining for two consecutive months • DO reduction greater than 1 standard deviation but less than 2 standard deviation from pre-mining mean resulting from the mining for two consecutive months • Identification of strata gas plume of flow rate < 3000 L/min	• Continue monitoring program • Submit an Impact Report to OEH, DoPI, DPI and other relevant resource managers • Report in the End of Panel Report • Summarise actions and monitoring in AEMR
	Level 2* Impact monitoring sites when comparing the baseline period to the mining period for that site: • pH reduction greater than 2 standard deviation from pre-mining mean resulting from the mining for two consecutive months • DO reduction greater than 2 standard deviation from pre-mining mean resulting from the mining for two consecutive months • EC, total Fe and total Mn increases greater than 2 standard deviation from pre-mining mean resulting from the mining for two consecutive months • Identification of strata gas plume of flow rate >3000 L/min	• *Actions stated for Level 1* • Review monitoring program • Notify relevant technical specialists and seek advice on any CMA required • Implement agreed CMAs as approved <u>Note</u>*: CMAs are to be proposed based on appropriate management of environmental and other consequences of mining impacts i.e. water quality changes with insignificant consequences may not require specific CMAs other than ongoing monitoring to confirm there are no ongoing impacts* *Strata Gas Emission Plume:* • Estimate gas emission flow rates. Re-estimate should significant change be observed • Take sample of plume (if possible) for: – chemical composition – dissolved methane from exactly above gas plume and at established downriver monitoring site – dissolved sulfide and total phenols from exactly above gas plume and at nearest downriver monitoring site
	Level 3* Impact monitoring sites when comparing the baseline period to the mining period for that site: • Level 2-type reduction in water quality resulting from the mining observed for more than 6 consecutive months	• *Actions stated for Level 2* • Notify OEH, DoPE, NoW, DPI, DRE, relevant resource managers and technical specialists and seek advice on any CMA required • Invite stakeholders for site visit • Develop site CMA (subject to stakeholder feedback) • Completion of works following approvals, including monitoring and reporting on success • Review the TARP and Management Plan in consultation with key stakeholders <u>Note</u>*: CMAs are to be proposed based on appropriate management of environmental and other consequences of mining impacts i.e. water quality changes with insignificant consequences may not require specific CMAs other than ongoing monitoring to confirm there are no ongoing impacts*
	Exceeding Performance Measures • Mining results in more than	• *Actions stated for Level 3* • Investigate reasons for the exceedance • Update future predictions based on the

Monitoring	Trigger	Action
	negligible gas releases, iron staining or water cloudiness	outcomes of the investigation • Provide environmental offset if CMAs are unsuccessful
GROUNDWATER		
Groundwater flow into the mine **Groundwater Level:** GW 34425 GW 35033 GW 72249 GW 100673 GW 101133 GW 102043 GW 102584 GW 102798 GW 103161 GW 104068 GW 104602 GW 104661 GW 110671 **BHPBIC Piezometers**: EAW5 EAW7 EAW9 EAW18 EAW58 S2280 S2281	***Level 1**** • Increase in water flow from the goaf between 2.7 to 3 ML/day (over 20 day average) • 5.0 – 7.5 m reduction in the Hawkesbury Sandstone greater than predicted standing water level or pressure (outside of pumping influences in private bores) over a minimum 2 month period	• Continue monitoring program • Submit an Impact Report to OEH, DoPI, DPI and other relevant resource managers • Report in the End of Panel Report • Summarise actions and monitoring in AEMR
	Level 2* • Increase in water flow from the goaf between 3 to 3.4ML (over 20 day average) • 7.5 – 10 m reduction in the Hawkesbury Sandstone greater than predicted standing water level or pressure (outside of pumping influences in private bores) over a minimum 2 month period	• *Actions stated for Level 1* • Review monitoring program • Notify relevant technical specialists and seek advice on any CMA required • Implement agreed CMAs as approved *Note: CMAs are to be proposed based on appropriate management of environmental and other consequences of mining impacts i.e. cracking at the surface with insignificant consequences may not require specific CMAs other than ongoing monitoring to confirm there are no ongoing impacts*
	Level 3* • Abnormal increase in water flow from the goaf >3.4ML (20 day average) • >10m reduction in the Hawkesbury Sandstone standing water level or pressure (outside of pumping influences in private bores) over a minimum 2 month period • Mining results in groundwater bores unsafe, unserviceable or damaged	• *Actions stated for Level 2* • Notify OEH, DoPE, DPI, NoW, DRE, relevant resource managers and technical specialists and seek advice on any CMA required. • Invite stakeholders for site visit • Develop site CMA (subject to stakeholder feedback). This may include: – Make area safe – Any actions agreed to in the Property Subsidence Management Plan – Provisions of alternate water supply where this has been impacted by mining – MSB to repair any infrastructure damaged by mining • Completion of works following approvals, including monitoring and reporting on success • Review the Groundwater Model, TARP and Management Plan in consultation with key stakeholders *Note: CMAs are to be proposed based on appropriate management of environmental and other consequences of mining impacts i.e. cracking at the surface with insignificant consequences may not require specific CMAs other than ongoing monitoring to confirm there are no ongoing impacts*

** These may be revised in consultation with DoPI and DPI and other key stakeholders following analysis of natural variability within the pre-mining baseline data.*

8 CONTINGENCY AND RESPONSE PLAN

In the event the Subsidence Performance Measures detailed in **Section 5** of this WMP are considered to have been exceeded, or are likely to be exceeded, BHPBIC will implement a Contingency Plan to manage any unpredicted impacts and their consequences.

This would involve:

- Capture and record the event.
- Notify relevant stakeholders soon as practicable.
- Notify relevant agencies and specialists as soon as practicable.
- Offer site visits with stakeholders.
- Contract specialists to investigate and report on changes identified.
- Provide incident report to relevant agencies.
- Establish weekly monitoring frequency until stabilised.
- Updates from specialists on investigation process.
- Inform relevant agencies and stakeholders of results of investigation.
- Develop site Corrective Management Action (CMA) in consultation with key stakeholders if required, (pending stakeholder availability) and seek approvals.
- Implement CMA as agreed with stakeholders following approvals.
- Conduct initial follow up monitoring and reporting of CMA completion.
- Review Management Plan.
- Report in regular reporting and AEMR.

BHPBIC will consult with appropriate specialists and relevant agencies in order to devise an appropriate response in respect to any identified exceedance.

The development and implementation of contingency measures will be specifically designed to address the specific circumstances of the exceedance and assessment of environmental consequences.

The following measures will be considered:

- Where low DO concentration in the Nepean River can be attributable to mining induced gas emissions (i.e. falling below the level of Level 1 TARPS), it is proposed that this would trigger a higher degree and frequency of monitoring as well as consultation with stakeholders.
- Where low DO concentration exceeds Level 2 TARPS - undertake further consultation for development and implementation of remedial action.
- Redrilling or cleaning and lowering of pumps for damaged bores.
- In the event that water flow diversion is identified within the Nepean River, grouting will be undertaken to restore surface flow. Either hand grouting, pattern or curtain grouting or deep angle hole cement grouting can be used with appropriate approvals.

If the contingency measures implemented by BHPBIC fail to remediate the impact or the Director-General determines that it is not reasonable or feasible to remediate the impact BHPBIC will provide a suitable offset to compensate for the impact to the satisfaction of the Director-General of DoPE in accordance with the BSO Approval *Condition 2, Schedule 3*.

All incidents will be reported internally through BHPBIC’s Incident Procedure and related records will be maintained in accordance with the Records Management Procedure (refer **Section 10.4**).

9 INCIDENTS, COMPLAINTS, EXCEEDANCES AND NON-CONFORMANCES

9.1 INCIDENTS

BHPBIC will notify DoPE and any other relevant agencies of any incident associated with BSO as soon as practicable after BHPBIC becomes aware of the incident. BHPBIC will provide DoPE and any relevant agencies with a detailed report on the incident within seven days of confirmation of any event.

9.2 COMPLAINTS HANDLING

BHPBIC will:

- Provide a readily accessible contact point through a 24 hour toll-free Community Call Line (1800 102 210). The number will be displayed prominently on BHPBIC sites in a position visible by the public as well as on publications provided to the local community.
- Respond to complaints in accordance with the BHPBIC Community Complaints and Enquiry Procedure.
- Maintain good relations and communication lines between community members and BHPBIC staff.
- Keep a register of any complaints, including the details of the complaint with information such as:
    - Time and date.
    - Person receiving the complaint.
    - Complainant’s contact name and phone number.
    - Description of the complaint.
    - Work area where complaint relates to.
    - Details of any verbal response.
    - Details of any written response where appropriate.
    - Details of any corrective actions.

9.3 NON CONFORMANCE PROTOCOL

The requirement to comply with all approvals, plans and procedures is the responsibility of all personnel (staff and contractors) employed on or in association with the BSO. Regular inspections, internal audits and initiation of any remediation/rectification work in relation to the Extraction Plan will be undertaken by the Manager Approvals.

Non-conformities, corrective actions and preventative actions are managed in accordance with the BHPBIC *Non-Conformance, Preventative and Corrective Action Procedure (ICHP0107)*. This procedure details the processes to be utilised with respect to the identification of non-conformances, the application of appropriate corrective actions(s) to address non-conformances and the establishment of preventative actions to avoid non-conformances. The key elements of the process include:

- Identification of non-conformance and/or non-compliances.
- Recording of non-conformance and/or non-compliance.
- Evaluation of the non-conformance and/or non-compliance to determine specific corrective and preventative actions.
- Corrective and preventative actions to be assigned to the responsible person.

- Management review of corrective actions to ensure the status and effectiveness of the actions.

An Annual Review will be undertaken to assess BHPBIC's compliance with all conditions of the BSO Approval, mining leases and all other approvals and licences.

An independent environmental audit will also be undertaken (*Condition 9, Schedule 6*) to review the adequacy of strategies, plans or programs under these approvals and if appropriate, recommend actions to improve the environmental performance of the BSO. The independent environmental audit will be undertaken by a suitably qualified, experienced and independent team of experts whose appointment has been endorsed by the Director-General of DoPE.

10 PLAN ADMINISTRATION

This WMP will be administered in accordance with the requirements of the AA9 Environmental Management System (EMS) and the BSO Approval Conditions. A summary of the administrative requirements is provided below.

10.1 ROLES AND RESPONSIBILITIES

All statutory obligations applicable to the AA9 operations are identified and managed via an online compliance management system (TICKIT). The online system can be accessed by the responsible BHPBIC managers from the link below.

https://illawarracoal.tod.net.au/login.

The overall responsibility for the implementation of this WMP resides with the Manager Approvals who shall be the WMP's authorising officer.

Parties responsible for environmental management and the implementation of the WMP include:

Head of External Affairs

- Ensure that the requisite personnel and equipment are provided to enable this WMP to be implemented effectively.

Manager Approvals

- Authorise the WMP and any amendments thereto.
- Delegate to an appropriately qualified person the responsibility to document any changes to the WMP, recognising the potential for those changes to affect other aspects of the WMP.
- Provide regular updates to BHPBIC on the results of the WMP.
- Arrange information forums for key stakeholders as required.
- Prepare any report in accordance with the WMP. Maintain records required by the WMP.
- Organise and participate in assessment meetings called to review mining impacts.
- Within 24 hours, respond to any queries or complaints made by members of the public in relation to aspects of the WMP.
- Organise audits and reviews of the WMP.
- Address any identified non-conformances, assess improvement ideas submitted and implement if considered appropriate.

- Arrange for the implementation of any agreed actions, responses or remedial measures.
- Ensure surveys required by this WMP are conducted and record details of instances where circumstances prevent these from taking place.

Environmental Field Team Coordinator

- Instruct suitable person(s) in the required standards for inspections, recording and reporting and be satisfied that these standards are maintained.
- Investigate significant subsidence impacts.
- Identify and report any non-conformances with the WMP.
- Participate in any other assessment meetings called to review subsidence impacts in the area affected by mining.

Survey Coordinator

- Collate survey data and present in an acceptable form for review at assessment meetings.
- Bring to the attention of the Manager Approvals any findings indicating an immediate response may be warranted.
- Bring to the attention of the Manager Approvals any non-conformances identified with the Plan provisions or ideas aimed at improving the WMP.

Technical Experts

- Conduct the roles assigned to them in a competent and timely manner to the satisfaction of the Manager Approvals and formally provide expert opinion as requested.

Person(s) Performing Inspections

- Formally bring to the attention of the Environment Field Team Coordinator any non-conformances identified with the Plan, or ideas aimed at improving the Plan.
- Conduct inspections in a safe manner.

10.2 RESOURCES REQUIRED

The Head of External Affairs provides resources sufficient to support this WMP.

Equipment will be needed for the TARPs provisions of this WMP. Where this equipment is of a specialised nature, it will be provided by the supplier of the relevant service. All equipment is to be appropriately maintained, calibrated and serviced as required in operation manuals.

It shall be the responsibility of the Manager Approvals to ensure that personnel and equipment are provided as required to allow the provisions of this Plan to be implemented.

10.3 TRAINING

All staff and contractors working on BHPBIC sites are required to complete the BHPBIC training program which includes:

- An initial site induction (including all relevant aspects of environment, safety and community).

- Safe Work Methods Statements and Job Safety Analyses, Toolbox Talks and Pre-shift communications.
- On-going job specific training and re-training (where required).

All training records are maintained by the BHPBIC Safety and Training Department (STAX database system), which can be accessed by BHPBIC staff via the online information system iPick.

It shall be the responsibility of the Manager Approvals to ensure that all persons and organisations having responsibilities under this WMP are trained and understand their responsibilities.

The person(s) performing regular inspections shall be under the supervision of the Environment Field Team Coordinator and be trained in observation and reporting. The Environment Field Team Coordinator shall be satisfied that the person(s) performing the inspections are capable of meeting and maintaining this standard.

10.4 RECORD KEEPING AND CONTROL

Environmental Records are maintained in accordance with the BHPBIC procedure *Records Management (ICHP0108)*.

10.5 DOCUMENT CONTROL

The BHPBIC *Document Control procedure (ICHP0103)* outlines the method for control of defined 'business critical' documentation for all BHPBIC operations. The system has been designed in such a manner to ensure that:

- Documents are approved for adequacy by authorised personnel prior to use.
- Obsolete documents are promptly removed from circulation.
- Documents are reissued, or made available, to relevant persons in a timely fashion after changes have been made and the authorisation process is complete.

The WMP and other relevant documentation will be made available on the BHPBIC website (*Condition 11, Schedule 6).*

10.6 MANAGEMENT PLAN REVIEW

A comprehensive review of the objectives and targets associated with the BSO is undertaken on an annual basis via the BHPBIC Balanced Planning (1 year outlook) and Balanced Strategy (5 year outlook) processes. These reviews, which include involvement from senior management and other key site personnel, assess the performance of the mine over the previous year and develop goals and targets for the following period.

An annual review of the environmental performance of BSO will also be undertaken in accordance with *Condition 4 Schedule* 6. More specifically this WMP will be subject to review (and revision if necessary, to the satisfaction of the Director-General) within three months of:

- The submission of an annual review under *Condition 4, Schedule 6.*
- The submission of an incident report under *Condition 7, Schedule 6.*
- The submission of an audit report under *Condition 9, Schedule 6.*
- Any modification to the conditions of this approval.

If deficiencies in the EMS and/or WMP are identified in the interim period, the plans will be modified as required. This process has been designed to ensure that all environmental documentation continues to meet current environmental requirements, including changes in technology and operational practice, and the expectations of stakeholders.

11 REFERENCES

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Mine Subsidence Engineering Consultants 2012, *Appin Colliery – Longwalls 901-904. Subsidence Predictions and Impact Assessments for the Natural Features and Surface Infrastructure in support of the Extraction Plan: Report Number: MSEC448 Revision 3*. A report to BHPBIC.

Attachment A – Appin Area 9 Longwalls 901 to 904 Groundwater Assessment (Geoterra, 2011)

GeoTerra

BHP BILLITON ILLAWARRA COAL PTY LTD

APPIN AREA 9
LONGWALLS 901 to 904
GROUNDWATER ASSESSMENT

Douglas Park, NSW

BHP5-R1B

4 JULY, 2011

GeoTerra PTY LTD ABN 82 117 674 941

77 Abergeldie Street Dulwich Hill NSW 2203

Phone: 02 9560 6583 Fax: 02 9560 6584 Mobile 0417 003 502 Email: geoterra@iinet.net.au

BHP5-R1B (4 JULY, 2011)

GeoTerra

BHP Billiton Illawarra Coal Holdings Pty Ltd
PO Box 514
UNANDERRA NSW 2526

Attention: Gary Brassington

Gary,

RE: BHP Appin Area 9 Longwall 901 - 904 Groundwater Assessment

Please find enclosed a copy of the above mentioned report.

Yours faithfully

GeoTerra Pty Ltd

Andrew Dawkins (AuSIMM CP-Env)

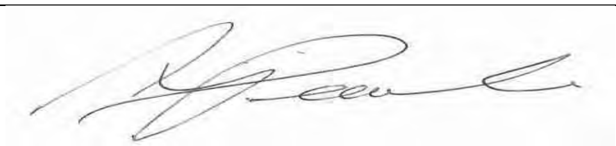
Managing Geoscientist

Distribution:	Original	GeoTerra Pty Ltd
	1 electronic copy	BHPB Illawarra Coal Pty Ltd

GeoTerra PTY LTD **ABN 82 117 674 941**

77 Abergeldie Street Dulwich Hill NSW 2203

Phone: 02 9560 6583 Fax: 02 9560 6584 Mobile 0417 003 502 Email: geoterra@iinet.net.au

Authorised on behalf of Geoterra Pty Ltd:	
Name:	Andrew Dawkins
Signature:	
Position:	Managing Geoscientist

Date	Rev	Comments
22/12/2010		Initial Draft
30/03/2011	A	Incorporate BHP review comments
4/07/2011	B	Incorporate BHP review comments

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1. INTRODUCTION

BHP Billiton Illawarra Coal (BHPB IC) propose to extract the Bulli Seam from Longwalls 901 to 904 within the Appin Colliery near the township of Douglas Park, which is situated to the west of Wollongong in the Southern Coalfield of New South Wales.

The proposed Area 9 longwalls are located to the west of the current Area 7 mining domain as shown in **Drawing 1**.

The longwalls are planned to be 305m wide with 60m wide chain pillars and will vary from 2450 - 3510m long.

All panels are located to the north of the Nepean River gorge, and are situated at least 130m from the centreline of the Nepean River as shown in **Figures 1** and **2**.

The Bulli Seam dips gently to the north, with the depth of cover increasing to the northwest, ranging from approximately 430m in the base of the Nepean River valley to 745m over the western end of Panel 904 under Razorback Range.

It is intended to extract the full 2.6 – 3.15m thickness of the seam in the proposed workings.

The Study Area is defined as the surface area predicted to be affected by the proposed subsidence from Longwalls 901 – 904, and encompasses the following limits (MSEC, 2010);

- 35^0 Angle of Draw Line for the 620m maximum depth of cover (i.e., a horizontal distance of up to 435m outside the limit of the proposed extraction area);
- the 20mm predicted limit of vertical subsidence, which is generally within the 35^0 Angle of Draw, and;
- features sensitive to far-field movements, which includes horizontal, valley closure and valley upsidence movements in the Nepean River gorge which may be outside the 20mm subsidence zone.

The study area for this groundwater assessment includes the area of potential groundwater drawdown as a result of the extraction of Longwalls 901 - 904 in the Douglas Park area.

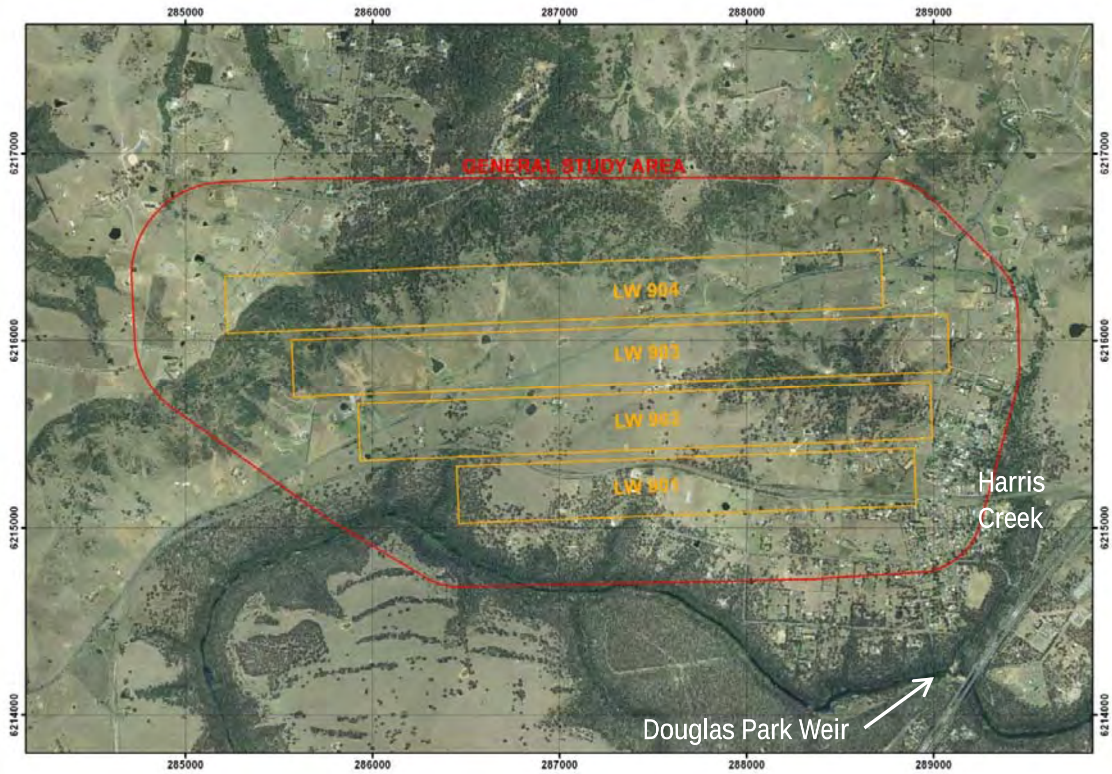


Figure 1 Aerial Photograph of Proposed Longwalls 901 to 904 Study Area

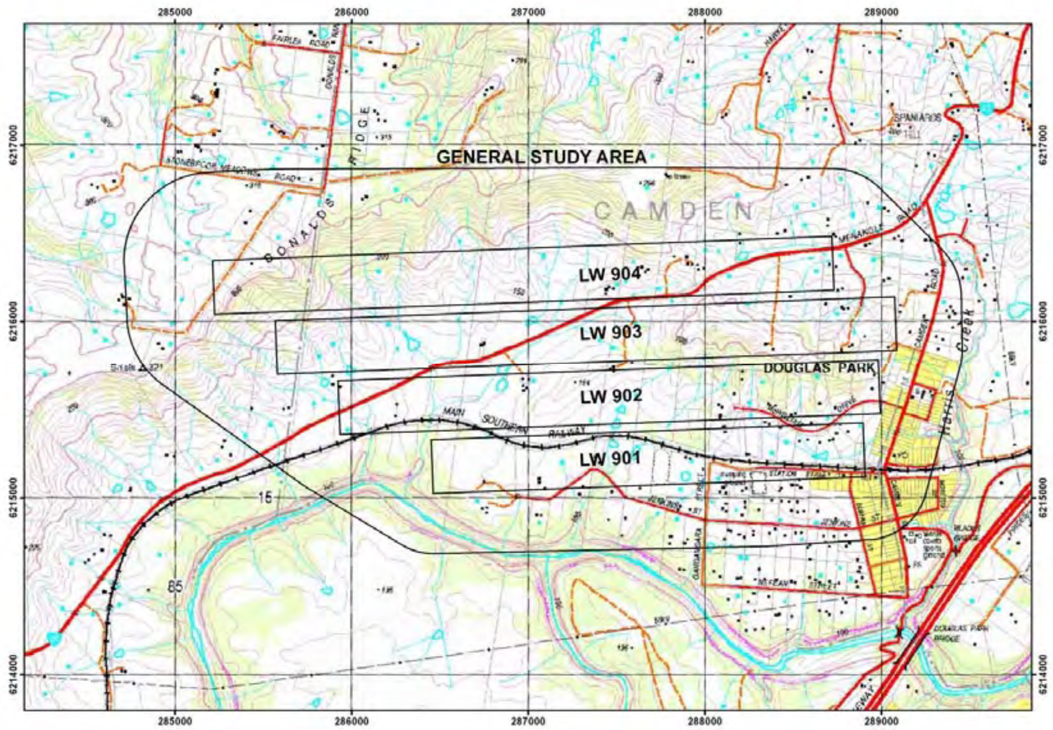


Figure 2 Map of Proposed Longwalls 901 to 904 Study Area

BHPB IC are currently extracting Longwall 704, and have previously mined Longwalls 701, 702 and 703 in Area 7 as shown in **Drawing 1** and **Table 1**.

Table 1 Panels 701 to 703 Extraction Dates

Longwall	Start	Finish
701	27/10/2007	9/5/2008
702	18/9/2008	20/4/2009
703	22/10/2009	08/3/2011

2. SCOPE OF WORK

Geoterra was commissioned by BHPB IC to assess potential hydrogeological impacts and management measures relating to subsidence during extraction of Longwalls 901 to 904.

3. PREVIOUS STUDIES

Numerous associated studies have been conducted in the vicinity of Area 9 as outlined in the references section. The more relevant studies include:

- Heritage Computing, 2010 A Hydrogeological Assessment In Support of the Bulli Seam Operations Environmental Impact Statement, and
- MSEC, 2010 Appin Colliery Longwalls 901 to 904, Subsidence Predictions and Impact Assessments for Natural Features and Surface Infrastructure in Support of the Appin Area 9 Extract Plan.

In addition, this report draws on unpublished data and findings from groundwater and surface water assessments for Longwalls 701 to 710 by Geoterra Pty Ltd, as well as groundwater level and water quality monitoring by BHPB IC in the NGW and EAW series piezometers.

4. EXISTING ENVIRONMENT

4.1 Rainfall and Evapotranspiration

Daily rainfall recorded at Douglas Park (St Marys Towers) since January 2004 is shown in **Figure 3**.

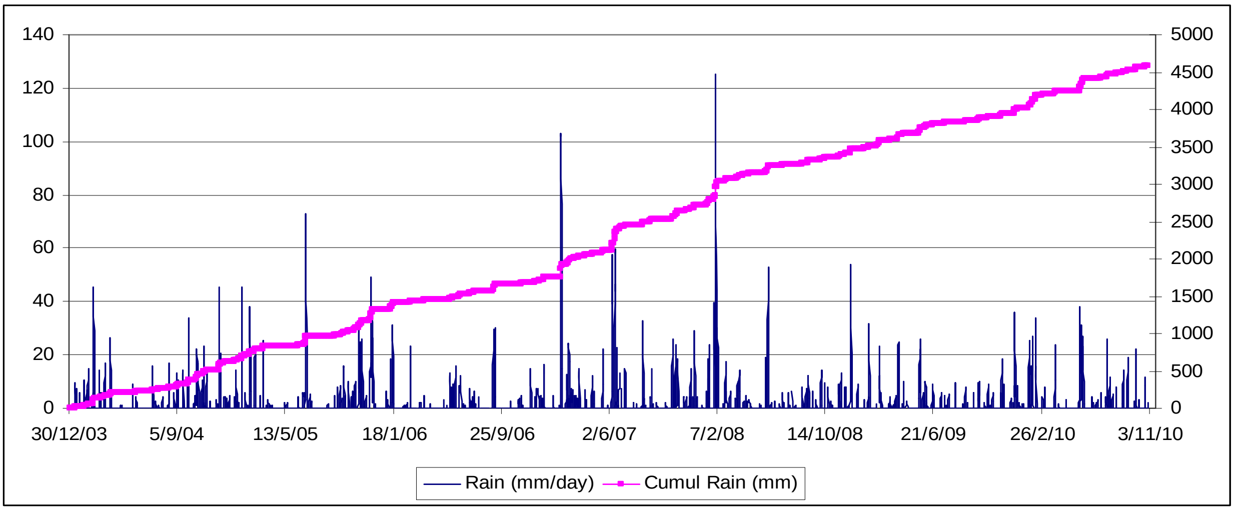


Figure 3 Douglas Park (St Marys Towers) Daily Rainfall

Evapo-transpiration is estimated to average 1.1mm/day in the study area (Ecoengineers, 2005).

4.2 Land Use and Geomorphology

The land to the north of the river is primarily used for rural residential development with fringing undeveloped woodland along the edge of the gorge. Some properties are or have been used for vegetable production, poultry farms, wholesale nurseries, pet farms or equestrian uses.

Domestic water supply is generally obtained from reticulated water and / or rainwater tanks, whilst farm dams and groundwater bores can provide additional water for stock, gardening or irrigation.

4.3 Topography and Drainage

4.3.1 Plateau

The plateau over the Study Area rises from the Nepean River in the south toward Donalds Ridge in the north-west. The gorge is up to 60m deep with steep sided sandstone cliffs and scree slopes. Surface levels vary from approximately 60m at the top of the gorge up to approximately 325m over the north western section of Longwall

904 in the Razorback Range.

The ephemeral headwater creeks predominantly flow southwards to the Nepean River.

There are no upland swamps in the Study Area.

A number of earth wall farm dams are located in the creeks and are used as water sources on the rural properties. All major creeks have dams within their channels and catchment areas.

The upper reaches of the streams generally have clay based alluvium developed on Wianamatta Shale with more exposed bedrock in the lower reaches near the Hawkesbury Sandstone and Wianamatta Shale interface.

Descriptions of the larger drainage lines within the Study Area are provided below:-

- Nepean River Tributary 1 is located directly above the proposed Longwalls 902 to 904. The lower reaches are composed of a fourth order stream, of which 110m of the stream reach is located directly above Longwall 902, with the remainder located south of the proposed longwalls.
- Harris Creek is located east of the proposed longwalls and is 375m from Longwall 903 at its closest point. It is located just outside the Study Area, although could experience valley related movements (MSEC, 2010). The lower reaches are third order and it has a minimum separation distance of 550m south of Longwall 901 at its closest point, whilst being up to approximately 700m long.

4.3.2 Nepean Gorge and Nepean River

The Nepean River is part of the Hawkesbury-Nepean River system with its headwaters in the uplands west of Wollongong. It flows northward past Camden to its junction with the Warragamba River near Wallacia where it becomes part of the main Hawkesbury River. The total length of the river is approximately 145km.

The proposed longwalls do not mine beneath the river, with the closest panel (Longwall 901) located at least 130m from the river centreline, or 125m from the closest riverbank.

The river has dissected the Woronora plateau, forming substantial scarps on the southern bank, with some discrete cliffs as well as scarps on the north bank. Cliffs are usually formed under competent sandstone which can contain stratigraphically controlled cavernous zones with ephemeral seeps.

Sandy alluvium is the dominant soil type located along the southern bank, although boulder races and exposed sandstone are more prevalent upstream and to the west of the Study Area.

The perennial river flow is derived through discharges from Cordeaux, Avon and Nepean Dams. River flow in the Study Area is predominantly controlled by the upstream Maldon Weir and the downstream Douglas Park Weir, which are respectively 5km upstream and 0.9km downstream of the proposed Longwall 901.

The stream section within the Study Area does not form part of a Drinking Water Catchment Area and is not a Declared Special Area.

Historical records supplied by the Sydney Catchment Authority (SCA) for Maldon Weir indicate flows typically vary from 3 - 50ML/day, with an average 25ML/day. Flows at Menangle Weir range from 5 - 100ML/day, with an average 40 ML/day.

The difference in the flow rates is explained by the additional tributaries that enter the river between the weirs, including the Cataract River and a licensed discharge from Appin Colliery.

The river bed within the Study Area is subdivided into the upper *Section 1*, where flow is controlled by boulder fields and rockbars and the lower *Section 2*, where the river is a flooded valley controlled by Douglas Park Weir (MSEC, 2010).

Section 1 is located upstream of Allens Creek and has two rockbars, one of which is submerged. These rockbars are located at a distance of 375m and 290m from the proposed longwalls (MSEC, 2010). A very small weir is also located within Section 1.

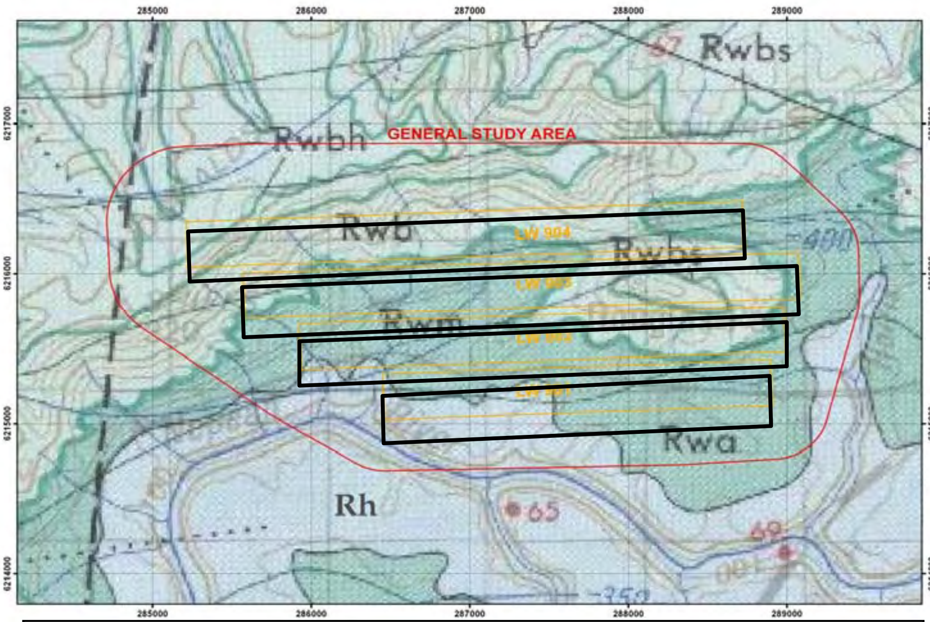
Section 2 is located downstream of Allens Creek in a flooded valley, with the surface water level regulated by Douglas Park Weir, with a weir crest at RL 60.994mAHD.

4.4 Geology

4.4.1 Stratigraphy

4.4.1.1 Plateau to Nepean River

The Hawkesbury Sandstone predominantly outcrops adjacent to and underlies the Nepean River gorge. The plateau is dominated by outcropping Wianamatta Shale in the central-eastern section of Longwalls 901 to 904. The shale ranges from 0m up to 200m thick in the elevated northern area as shown in **Figure 4**.



LEGEND

Rw – Wianamatta Group

Rwb – shale, carbonaceous claystone, laminite, coal	Rwbh – Mt Hercules Sandstone Member
Rwbs – fine to medium grain sandstone	Rwa – laminite and dark grey siltstone
Rwm – interbedded shale – sandstone	Rh – Hawkesbury Sandstone

Figure 4 Local Geology

The Hawkesbury Sandstone is up to 170m thick and consists of fine to medium grain flat bedded sands over medium to coarse sands with minor shale. The units are highly localised and laterally variable, with up to seven lithofacies identified from cores and cliff observations representing arenite (coarse sandstone facies) or lutite, which is a finer mudstone and siltstone facies (BHPB, undated).

The base of the Wianamatta Shale is a distinctive horizon which outcrops to the north of the dissected Nepean River gorge.

The sequence of shale over sandstone is underlain by the generic sequence illustrated in **Figure 5.** The Wianamatta Group is the uppermost unit in the sequence and occurs across much of Area 9.

Cavernous zones in the Nepean River gorge cliffs can be associated with leaching of the sandstone's granular cement by groundwater seeps sourced from "perched" ephemeral aquifers located above the regional piezometric surface.

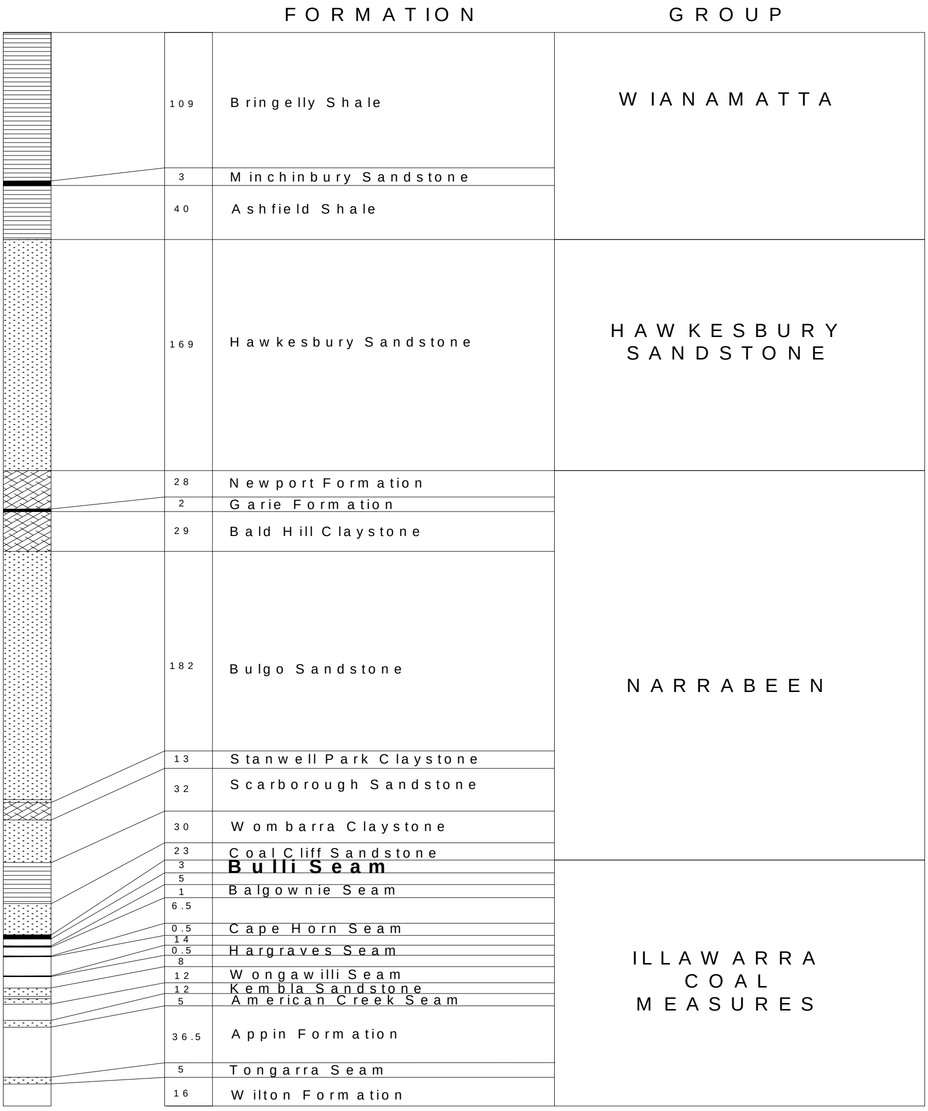


Figure 5 Regional Stratigraphy

4.4.1.2 Nepean River to Bulli Seam

The Hawkesbury Sandstone outcrops within the walls and floor of the Nepean River gorge and can be up to 170m thick.

In Area 9, the Narrabeen Group sequence is developed below the Hawkesbury Sandstone and above the Illawarra Coal Measures. The Narrabeen Group does not outcrop in Area 9.

The Newport Formation consists of interbedded grey shales and sandstones, about 28m thick.

The Bald Hill Claystone consists of the Garie Claystone, a generally hard, grey-brown "oolitic" claystone, about 2m thick, underlain by the characteristic brownish-red coloured "chocolate shale", a physically weak but lithologically stable unit about 29m thick. The "chocolate shale" is an easily recognised marker horizon and is a major aquitard to vertical migration of groundwater through the sequence and essentially divides the groundwater systems above and below the claystone.

The Bulgo Sandstone, averaging 182m thick, consists of strong, thickly bedded, medium to coarse grained lithic sandstone with occasional beds of conglomerate or shale. These strata can be gas bearing, particularly towards the base of the sequence. Gas, while present, is locked into the strata due to the lack of permeability and does not represent an economic resource. The gas can be released up the profile when mining-induced fracturing provides a secondary permeable path.

The Stanwell Park Claystone (13m thick) consists of greenish-grey mudstones and sandstones. These "green shales" are very weak lithologically and fret easily on exposure. The Stanwell Park Claystone becomes sandier in a northerly direction over Area 9 until it becomes unrecognisable from its bounding sandstone units. The absence of this seal may influence the movement of strata gas following mining.

The Scarborough Sandstone is approximately 32m thick and consists mainly of thickly bedded sandstone with shale and sandy shale lenses up to several metres thick.

The Wombarra Shale is approximately 30m thick and has similar properties to the Stanwell Park Claystone described above. However this unit maintains its lithological character across the area.

The Coalcliff Sandstone averages around 23m thick. Away from the coast, the dominance of sandstone diminishes and in many areas the original roof strata of the Bulli Seam, a shale / mudstone unit, (which can become laminated in places) is prominent. The sandstone is common as erosive channels across the Appin area and has completely eroded the mudstone unit in several areas and in some instances into the Bulli Seam.

The Illawarra Coal Measures consist of interbedded shales, mudstones, lithic sandstones and coal seams of which ten are named.

The Bulli Seam has been worked extensively in the Appin area and produces a hard coking coal.

4.4.2 Faulting and Structures

The Bulli Seam gently dips to the north, north-west at 1 in 50, with the longwalls positioned between the Camden Syncline to the west and the Douglas Park Syncline and Narellan Lineament to the east.

Surface lineaments due to differential weathering on joint planes are well developed on outcropping Hawkesbury Sandstone as straight stream courses, which are generally controlled by the underlying sandstone joint fabric and regional topography dip to the northwest, but are generally poorly developed in the Wianamatta Shale.

Mapped and inferred geological structures (BHPB, undated) include a north / south trending zone of faulting to the east of the proposed panels as shown in **Drawing 2**.

Fracturing identified in the NGW series bores to the east, in Area 7, is predominately within 20° of horizontal and associated with bedding planes. The more significant water zones were found to be associated with low angled fractures, whilst jointing and bedding plane fracturing are responsible for the main flow characteristics at river level (BHPB, undated).

Horizontal fractures in moderately weathered facies with slight cavities observed in the NGW core were associated with water loss during drilling and packer testing (BHPB, 2005).

Tight to open vertical fractures were noted at river level in most NGW bores which had higher water intakes than vertical fractures in horizons above the river.

Facies with high angle to vertical fractures had significant water loss on drilling in moderate to intensely weathered zones with intersecting joints or zones with multiple joints.

Major faulting is not apparent on the plateau or river bed, which does not preclude the presence of structures at depth or minor structures not yet identified by mapping.

In the Southern Coalfield, faulting tends to decrease in displacement vertically upwards through the Narrabeen Group and Hawkesbury Sandstone.

4.4.3 Igneous Intrusions

Few intrusions of significance are known in the Study Area. Igneous dykes can be mapped at the surface and generally the exposures support a continued extension of the known underground dykes, however due to extensive agricultural impacts, most dykes are not observable at surface.

One possible NNW / ESE trending dyke is situated over the western end of Longwall 904 as shown in **Drawing 2**.

4.5 Hydrogeology

Extraction is proposed from the Bulli Seam with a depth of cover ranging from 430m to 745m.

No longwall extraction will take place under the Nepean River gorge and the closest Longwall (901) is at least 130m from the centre line of the river.

The Nepean River is a ‘gaining’ system, where groundwater flows from the plateau under a regional hydraulic gradient to the river. These flows are dominantly horizontal, and determined by confined flow along discrete layers underlain by fine grained or relatively impermeable strata within the Hawkesbury Sandstone.

The Hawkesbury Sandstone sequence is characteristic of sedimentary deposition and erosion in a braided stream with individual facies representing local sedimentary processes that generally do not persist across the Study Area.

4.6 Existing Bores and Piezometers

Twelve NSW Office of Water (NOW) registered bores are located within or adjacent to the Study Area along with nine BHPB piezometers as shown in **Drawing 1,** with selected details in **Table 2**.

All private bores were drilled between 70 - 240m below surface, with water obtained primarily from dual porosity sandstone aquifers, however some thin, perched horizons encountered water intersections in the Wianamatta Shale (GW104602 at 29.9 – 30m).

Yields range up to 1.14L/sec from inflow zones in the sandstone which range from 9 - 213m below surface.

NOW data indicates the regionally significant aquifers are generally intersected at or deeper than 64m below surface, however, according to available records, intersections as shallow as 9m may be present in shallow, perched sandstone aquifers with limited extent.

NOW data indicates that the deepest aquifer to date was intersected to the east of Longwall 904 (GW104602) at 213m below surface.

The actual intersected aquifer horizon is generally deeper than the measured static water level in a bore, as when a confined aquifer is intersected, the formation water rises up the bore due to confined lithostatic and hydrostatic pressure. Based on this principle, and on assessment of the NOW data, the majority of aquifer intersections over the proposed mining area lie at or below the elevation of the Nepean River.

Four open standpipe piezometers (NGW series) were installed by BHPB in June 2004 in or near the Study Area in the Hawkesbury Sandstone to 10m below the base of the Nepean River gorge.

An additional five vibrating wire piezometer array bores were installed in 2008 (EAW Series) down to 798m below surface.

NOW test monitoring bore licences for the NGW series piezometers were granted on April 3, 2009 as shown in **Table 3**.

As the EAW piezometers are fully cemented to surface after installation of the vibrating wire piezometers, they were not licensed by NOW.

A Water Access Licence for the Appin underground workings was applied for on 20 December 2007 for 210ML/annum, however the license has not yet been granted (R Walsh, pers comm.).

Table 2 Panels 901 to 904 Bores and Piezometers

GW	N	E	SWL (m)	Depth (m)	Drilled	Aquifer	Lithology	YIELD (L/s)	TDS (mg/L)	Purpose
34425	6215603	289184	14.60	70.10	1972	9.10 – 10.6 21.3 – 24.3 64.0 - 69.4	sandstone sandstone sandstone	0.03 0.04 0.63	n/a	Waste disposal
35033	6214961	288045	54.80	131	1973	17.6 – 17.7 54.8 – 55.1	sandstone sandstone	0.13 0.23	n/a	Stock
72249	6215538	288091	36.60	97.5	1994	76.2 – 76.3 85.3 – 85.5	sandstone sandstone	0.25 1.14	n/a	Dom / Stk
100673	6216160	286235	49.0	104	1995	71 – 74 84 - 87	sandstone sandstone	0.20 0.40	1200 1400	Stock
101133	6214100	289443	61.0	96	1997	78.5 – 78.8	sandstone	1.80	1100	Stk / Dom
102043	6214659	289777	104.0	192	1999	40 – 41 161.5 - 162	sandstone sandstone	0.10 0.20	291 260	Stk / Dom
102584	6216255	289480	60.0	186	1999	54 - 60 64 - 70 108 -112 144 - 150 177 - 179	sandstone sandstone sandstone sandstone sandstone	0.10 0.10 0.20 0.20 0.9	1370 1190 1300 1300 1300	Dom / Stk
102798	6214783	289990	n/a	148	1997	95 – 96 103 - 104	sandstone sandstone	0.25 1.00	n/a 700	Dom / Stk
103161	6216499	289511	25	120	2000	17-18 54 - 56 83 – 84 108 - 110	shale sandstone sandstone sandstone	0.2	1450	Dom / Stk
104068	6214530	289519	62.0	180	2001	95 – 118 152 – 153 163 - 164	sandstone sandstone sandstone	0.52 0.50 0.50	990 1000 1000	Dom / Stk
104602	6216338	289054	42.0	231	2003	29.9 – 30 161 – 161.5 213 – 213. 5	shale sandstone sandstone	0.13 0.75 0.75	2500 n/a n/a	Stock
104661	6216470	288973	68.0	219	2003	113 - 113.1 154 - 154.1 197 - 197.1 212 - 212.2	sandstone sandstone sandstone sandstone	1.05	fresh	Dom / Stk
110671	6216340	288717	82.0	240	2010	72. 0 - 72.2 150.0 -150.3 166 - 166.2 211 – 211.1	sandstone sandstone sandstone sandstone	0.05 0.10 0.90 0.15	400	Dom / Stk
BHPB	**PIEZOS**									
NGW3	1216749.5	275027.4	77.33*	72.1	2004	n/a	sandstone	n/a	n/a	Monit.
NGW4	1216826.2	275789.9	68.56*	78.75	2004	n/a	sandstone	n/a	n/a	Monit.
NGW5	1216327.4	276124	66.71*	66.45	2004	n/a	sandstone	n/a	n/a	Monit.
NGW6	1216680.5	276403.3	66.33*	66.75	2004	n/a	sandstone	n/a	n/a	Monit.
EAW5	6218729	289027	various	612	2008	n/a	various	n/a	n/a	Monit.
EAW7	6217768	291547	various	611	2008	n/a	various	n/a	n/a	Monit.
EAW9	6216341	287181	various	605	2008	n/a	various	n/a	n/a	Monit.
EAW18	6216904	285466	various	798	2008	n/a	various	n/a	n/a	Monit.
EAW58	6215342	289803	various	525	2010	n/a	various	n/a	n/a	Monit.

Note: n/a not available * swl in mAHD RL as at Oct 2010 TDS total dissolved solids

Table 3 NGW Piezometer Licence Numbers

GW	License Number
NGW3	10BL603035
NGW4, 5 and 6	10BL603034
NGW7	10BL603033
NGW8 and 9	10BL603045
NGW10	10BL603044
NGW11	10BL603043

4.6.1 Surface Water / Groundwater Interaction

Surface water drainage on the plateau is mainly within ephemeral tributary streams which flow to the Nepean River via Harris Creek and Tributary 1.

Drainage in smaller first and second order channels also flow to the Nepean River, and from smaller gullies along the cliffs of the gorge which generally discharge via elevated streams cascading down the cliffs after sufficient rain.

The majority of rainfall in the ephemeral catchments would infiltrate into the plateau soils.

Recharge to the regional groundwater system occurs with an extended delay after rainfall has infiltrated into the plateau soil as well as the underlying Wianamatta Shale and / or Hawkesbury Sandstone. The majority of water discharges from temporary seeps in the cliff face of the gorge due to the preferential horizontal flow regime in sub-horizontal bedding planes in the sandstone or at the Wianamatta Shale / Hawkesbury Sandstone interface, which is set back from the gorge.

The predominantly horizontal flow and restricted vertical recharge is essentially determined by the;

- horizontally bedded strata under both sides of the plateau with preferential flow along bedded zones with coarser grain size,
- claystone/mudstone banding at the base and tops of sedimentary facies which restrict vertical migration and enhance horizontal flow at the base of the unit,
- fracture zones enhancing horizontal flow through the strata, and
- bedding planes and unconformities located immediately above finer grained sediments or iron rich zones.

Groundwater under the plateau discharges to the river in a “gaining” system where it flows under gravity to the river, whilst a smaller component of flow moves from high to lower piezometric pressure areas up from the base of the gorge to the river.

The Nepean River does not flow under gravity to the underlying groundwater body as a “losing” system as is observed in the Georges River catchment.

Site inspections to date have not identified any discharging springs in the Nepean River gorge within the Study Area, although non ferruginous discharges below the river water surface may be present.

As the Nepean River is the largest regional surface water feature in the catchment, all drainage from surrounding groundwater systems and tributary streams is toward the base of the gorge. The river then flows under gravity downstream to the Douglas Park and Menangle Weirs.

4.7 Groundwater Chemistry

Groundwater in the NOW registered bores, where reported, is generally fresh to brackish with salinity (total dissolved solids) between 260mg/l and 2500mg/L as outlined in **Table 2**.

4.8 Strata Gas

Gas emissions at the surface have typically occurred within river valleys such as the Nepean, Cataract and George Rivers, although some emissions have also been observed in smaller creeks and in water bores. Analyses of gas compositions indicate the Bulli Seam is not the source of the gas and that the source is the Hawkesbury Sandstone.

Gas emission on the plateau and/or within groundwater bores is possible, and in some instances, such as in Chicken Creek at West Cliff Area 5, small gas emissions have occurred for over a year.

The low permeability Bald Hill Claystone, which separates the Hawkesbury Sandstone and the Bulgo Sandstone, has been observed to maintain its low permeability after subsidence and inhibit the movement of water and gas. If the claystone is fractured by subsidence, it is anticipated that the downward movement of water through the clay would cause it to swell and seal off the cracks if they are small enough, and further inhibit gas or water movement.

Small amounts of the emitted hydrocarbon gas can dissolve in water, depending on its concentration, composition and residence time in the water, which can then be consumed by bacteria (Ecoengineers, 2008).

5. HYDROGEOLOGY ASSESSMENTS

5.1 NGW Series Piezometers and Private Bores Over and Adjacent to Longwalls 701 to 703

The hydrogeology of Area 7, which is adjacent to the eastern edge of Area 9, was investigated by core drilling, packer testing and piezometer installation in eight bores installed to 10m below the base of the Nepean River in the “NGW” series. Single vibrating wire piezometers were installed in open standpipe bores at locations shown in **Drawing 1**. Further installation and monitoring details are contained in (Geoterra, 2008).

Groundwater level monitoring has been conducted in NGW3, 4, 5 and 6 within the vicinity of Longwalls 701 to 703 since June 2004.

In addition, two private bores on the Nahkle (GW104154) and the Boustani (GW101437) properties overlying Longwall 703 have been monitored since 28/7/08.

Water levels have been monitored in the disused Nahkle bore at 12 hourly intervals since 18/2/09, whilst the logger is downloaded and field bore water quality is monitored bi-monthly.

The relevant piezometer and bore locations are also shown in **Figure 6**.

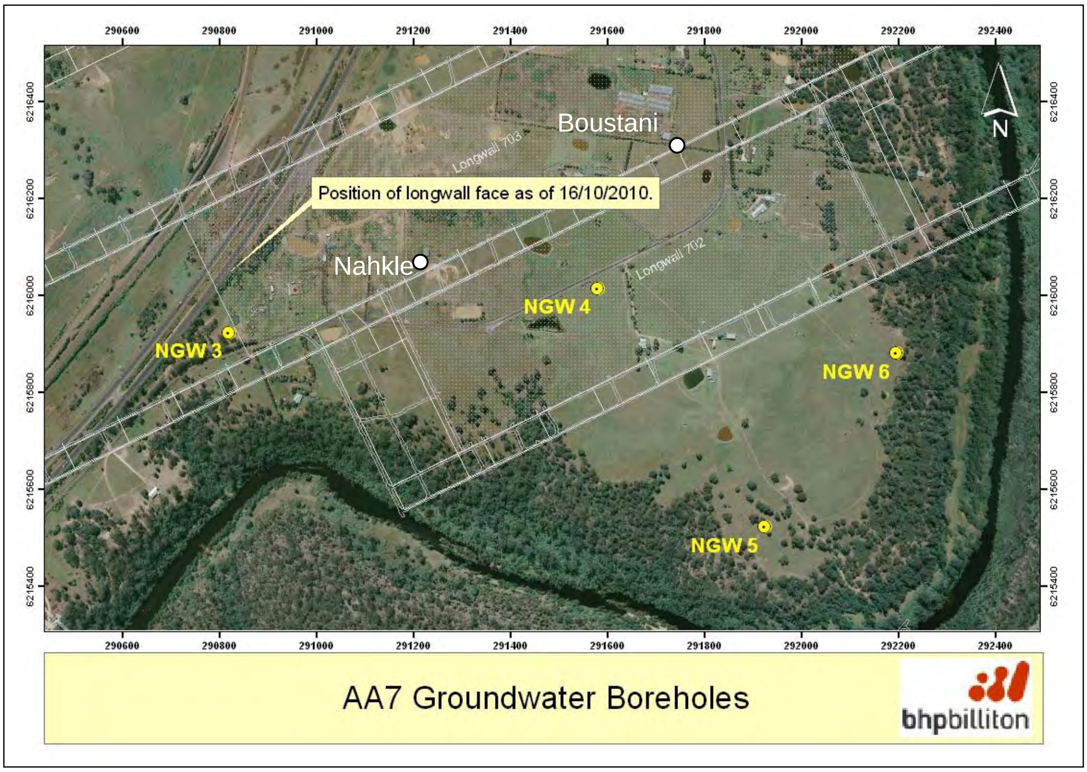


Figure 6 Piezometer and Private Bore Locations

5.2 EAW Series Piezometers in the Appin Area 7 and Area 9 Mining Domains

Four bores were installed with multi-level sealed vibrating wire piezometers down to the Wongawilli Seam in the EAW series during 2008. These studies were conducted in order to;

- provide detailed information on the local stratigraphy and identify stratigraphic units associated with visible groundwater seeps on nearby cliffs,
- measure and assess changes to local groundwater levels in response to rainfall,
- measure the water bearing capacity, transmission characteristics and hydrostatic groundwater pressures in the sequence,
- understand any association between the plateau groundwater system and the Nepean River,

- develop a conceptual and numerical groundwater model in order to assess the potential impact of mining Longwalls 901 to 904 through obtaining an understanding of local groundwater dynamics in the sequence, and to
- enable groundwater monitoring to be conducted before, during and after mining in the area.

The EAW bores were installed both within and outside the predicted 20mm subsidence area to enable monitoring of baseline and potential subsidence affected standing water levels in the stratigraphic sequence above and adjacent to the proposed and existing workings.

Hydraulic testing was performed with inflatable packers in selected stratigraphic units and fracture zones. Each interval was subjected to transient water injection and recovery tests, with the injection pressure held constant.

Each bore is protected by a 75mm steel tube with a blank plate bolted to the upper flange that allows for manual water level monitoring and attachment of vibrating wire piezometers. The loggers are self-contained units that transfer data to a portable receiver.

The core drilling process uses injected water to lubricate the drill rods and flush out cuttings. This restricts the ability to directly identify shallow or perched aquifers with low water inflows, which are effectively over-printed by circulation of the injected core drilling water.

As a result, interpretation of hydraulic parameters in the completed bore is limited to packer test data and monitoring in the slotted or vibrating wire piezometer intake section, with low yielding perched aquifers above the monitored zones not being identified.

5.3 Private Bores Located over Longwalls 901 to 904

Private bores were inspected during August 2010 where access was granted to properties within the Study Area as shown in **Table 4**.

Table 4 Private Bore Inspections over Longwalls 901 to 904

GW	N	E	Location	SWL (m)	Water Sample	Comment
34425	6215603	289184	East of LW902	-	-	Bore not present
35033	6214961	288045	South of Mid LW 901	54.80	-	Bore inaccessible
72249	6215538	288091	Over LW902	n/a	n/a	Bore not used
104602	6216338	289054	East of LW904	n/a	See Tables 3 & 4	No access inside bore
104661	6216470	288973	Northeast of LW904	n/a	See Tables 3 & 4	No access inside bore
110671	6216340	288717	East end of LW904	n/a	See Tables 3 & 4	No access inside bore
100673	6216160	286235	Over west end of LW904	n/a	n/a	No access granted

Note: n/a not available

5.4 Hydraulic Parameters

5.4.1 Hawkesbury Sandstone "NGW" Series Tests

No consistent water bearing horizons were identified above the base of the Nepean River during drilling the "NGW" series bores, either because they are not present or because the intersection flows were too small to be observed during water lubricated core drilling.

Potential water migration zones were assessed through interpretation of the drilling, packer testing and cliff inspection data. This data indicates generally low permeability with no discrete continuous permeable zones that can be extrapolated over the study area.

Water injection testing intakes below the pervasive L-MS facies were generally low, with migration along joint planes restricted to strata above the river and in close proximity to the cliffs where lack of horizontal confinement enables seeps to develop.

Bore yields in the general area obtained from the NOW database indicate the sandstone is generally low yielding (up to 1.8L/s).

Higher permeabilities were found to occur in low-angle cross-stratified to crudely stratified coarse sandstones and large-scale planar/tabular cross-stratified medium to coarse sandstones. Lower permeability zones occur in small-scale trough to planar/tabular cross-stratified, fine-medium grained sandstones and lutites (BHPB, undated).

Coarser sandstones were found to have higher water inflows during packer testing compared to finer grained facies.

Groundwater flow is primarily controlled by the presence of finer grained aquitards which underlie higher porosity, coarser sandstones, with the finer grained layers appearing as fresh (grey) to moderately weathered and heavily stained (orange to deep red) bands.

Packer tests indicate that water intake is generally low in the sandstone, with lower relative intakes on the western side of the river. Intake between holes was variable, with no systematic higher permeability zones identified, although the large water intake of NGW9 and NGW10 is more likely to be due to intensely jointed zones or fractures along bedding planes in the test interval (Geoterra, 2006 GW).

Circulation loss was experienced when major fracture or joint systems were drilled through. The fractures did not generally relate to observed standing water levels with the loss likely to occur on bedding plane surfaces. No consistent loss could be attributed to natural joint systems.

The lack of homogeneity in the packer tests can be attributed to:

- the partially saturated to unsaturated nature of the strata,
- a highly variable sandstone sequence at similar depths with varying permeabilities,
- localised barriers in the strata, such as siderite and clay lenses and joints,

- variable sample interval thickness, where several units with potentially different characteristics may be included in one test,
- thin water transmission zones compared to the sample thickness,
- concentration of high permeability zones on bedding planes and unconformities, and
- lack of visual geological characteristics to define test intervals.

Miall and Jones (2003) inferred that seeps observed through remnant iron staining on cliffs indicate the presence of a vertical permeability barrier, such as mudstone. Liu *et. al.* (1996) observed that permeability was more variable vertically than horizontally and that permeability in the Hawkesbury Sandstone is extremely variable and primarily relates to sedimentary structures, such as types of cross-bedding, along with variations in grain size and sorting.

5.5 EAW Series Permeability Tests

Packer based permeabilities for Bore EAW5 obtained in May 2008 between the Wianamatta Shale and the Scarborough Sandstone as shown in **Figure 7** (GHD Geotechnics Pty Ltd, 2008) indicate permeabilities below $1x10^{-6}$ m/sec which decrease with the depth of cover generally to around $1x10^{-7}$ and $1x10^{-8}$ m/sec.

One anomalous zone in EAW5 returned a permeability in the Hawkesbury Sandstone of $1x10^{-3}$m/sec from 134.3 to 140.3mbgl.

Packer testing of the Bulli Seam during 2008 indicated the coal has a permeability of 0.14m/day (EAW5), 2.9m/day (EAW7), 0.18m/day (EAW9) and 0.99m/day (EAW18).

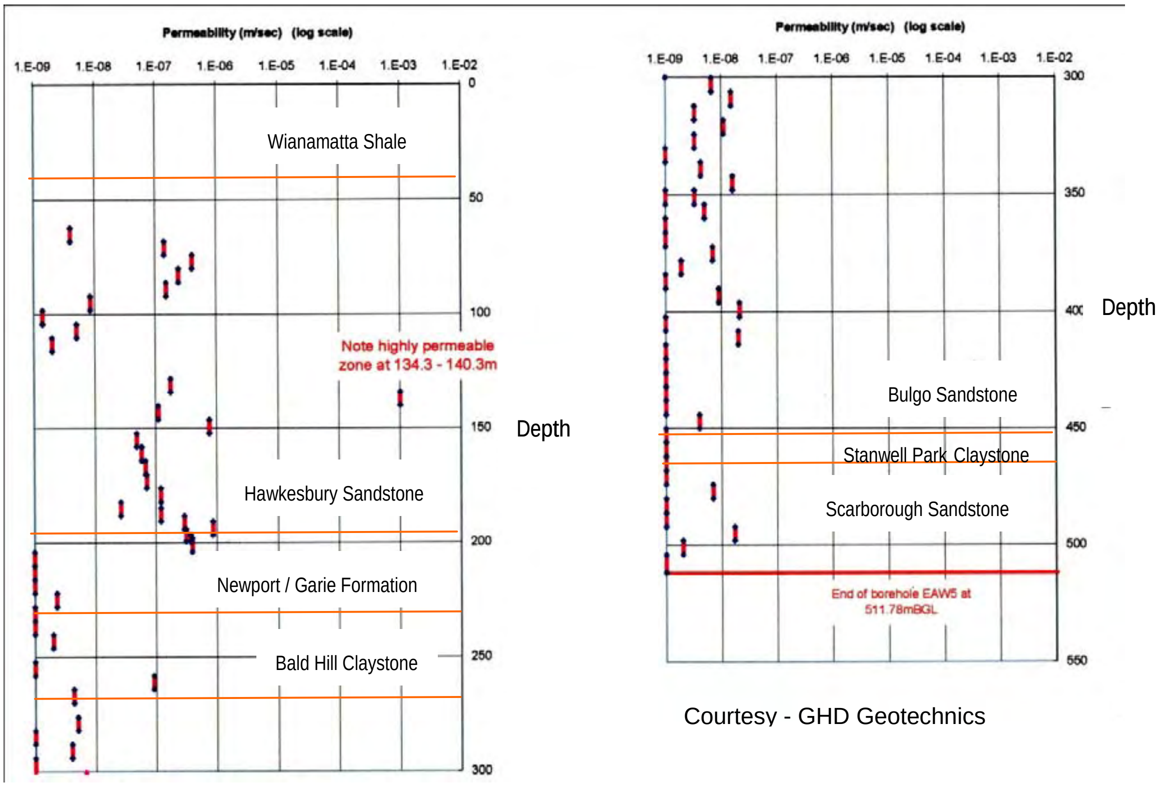


Figure 7 Bore EAW5 Packer Test Permeability

6. GROUNDWATER RESPONSE TO MINING LONGWALLS 701 TO 703

6.1 NGW Series Piezometer Water Levels

As shown in **Figure 8**, a groundwater level reduction of greater than 5m over a 2 month period occurred in NGW6, between June and July 2010, where the water level fell from approximately 66.1mbgl to 60.2mbgl.

Since July 18 2010, the water level in NGW6 has been gradually recovering.

During the Longwall 703 extraction period, groundwater levels in piezometer;

- NGW3 were essentially unaffected for the majority of the time, although as the panel advanced toward the piezometer, water level rose by 6.5m.
- NGW4 rose by 4.7m and subsequently fell by 2.2m, and
- NGW5 rose by 1.1m and subsequently fell by 1.0m

Ongoing monitoring will determine the effects on the bore water levels from Longwall 704 extraction.

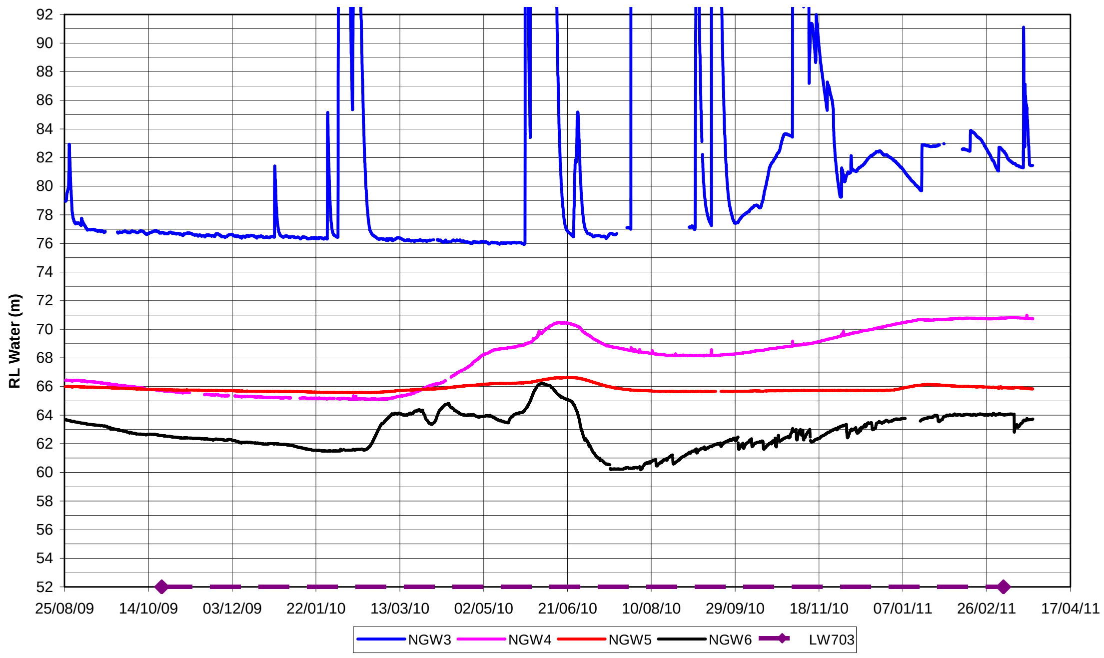


Figure 8 **NGW3, 4, 5 and NGW6 Water Levels**

6.2 Private Bore Water Levels

6.2.1 Nahkle Bore

As shown in **Figure 9**, a groundwater level reduction of greater than 5m (for a total of 16.96m) occurred in the Nahkle bore between 30/6/10 and 4/9/10, although it was contained within an overall 21.9m rise since 17/6/10.

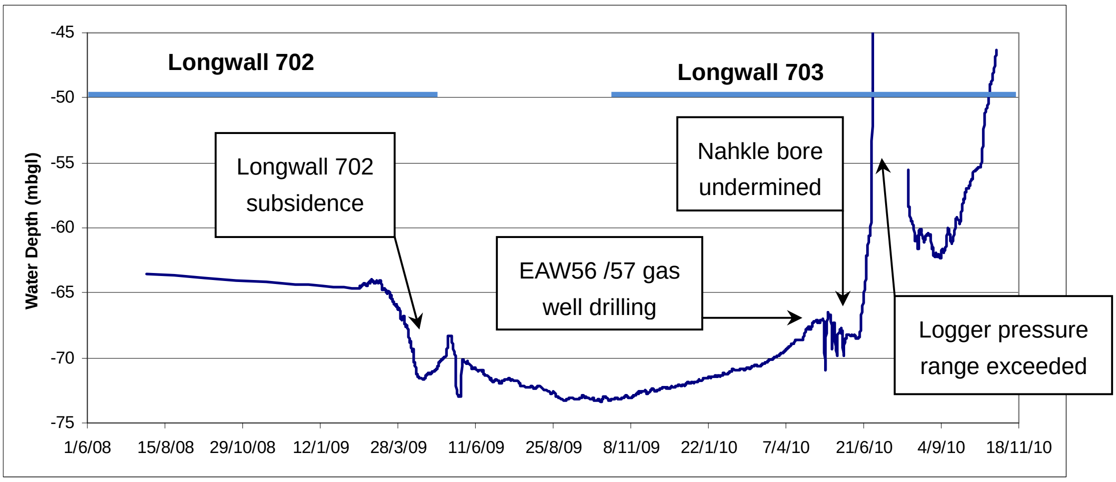


Figure 9 **Nahkle Bore Water Levels**

The bore water level was temporarily affected by adjacent drilling and regional pressurisation of the local groundwater system during and after installation and operation of two gas wells (EAW56 and EAW57) to the north and south of the Nahkle bore, prior to undermining of the Nahkle bore.

The gas well periods of drilling are shown in the Nahkle water level plot in **Figure 9** whilst their location is shown in **Figure 10**.

Figure 10 Gas Wells and Nahkle Bore Locations

Groundwater levels in the Nahkle bore began to rise around 17/6/2010 from 68.2mbgl, reaching a peak of 44.86mbgl (a rise of approximately 23.3m) on 30/6/2010.

As the bore was being undermined the water level rose and exceeded the pressure range of the installed logger on 30/6/10 until 3/8/10, where the water level receded to 62.26mbgl on 4/9/10.

Since 4/9/10, the bore water level increased from 61.96mbgl to 46.28mbgl on 27/10/10, which is approximately 21.90m higher than its level prior to mining.

Inspection of the Nahkle bore on and since 9/8/2010 has consistently indicated a cascading of water into the bore, from above the current water level, which is assessed to be the reason for the post subsidence rise, on the basis that the volume of water cascading into the bore exceeds the volume dissipating into the formation below the standing water surface.

The cascade was not present prior to undermining, however manual dip meter based monitoring of water levels in the bore were obstructed before it was undermined by a wet muddy film in the open, uncased bore annulus at around 45m below surface.

The approximately 45m pre-mining "sticky wall" zone is taken to be where the post subsidence water cascade is entering the bore and may represent the maximum height to which the water level rise may stabilise.

It is assessed that the cascading water occurred as a result of shallow level subsidence fracturing in the Hawkesbury Sandstone in a perched aquifer above the regional standing water table, with the inflow currently exceeding outflow to the regional groundwater system beneath the water table.

6.2.2 Boustani Bore

During an inspection with the property owner of the Boustani Bore on 24/8/2010, it was reported that the discharging water had a "smell". Water samples were taken and sent to a laboratory for a range of analyses, including hydrogen sulfide, however our observation is that the hydrogen sulfide smell is not significant and is often observed in many similar bores in the Southern Coalfield, and is not a health or irrigation hazard.

BHPB commissioned contractors to remove the pump from the bore on 1 February 2011, during which time the pump installation and fittings were inspected, a corroded suspension cable and wellhead fittings were replaced, a small stone was removed from the one way valve in the pump and a downhole camera was used to inspect the bore annulus following a complaint from the landowner that the pumping rate was slightly reduced compared to before the bore was undermined.

The standing water level on 1 February 2011 was monitored to be 2.3m above the 1997 bore installation water level.

Loose material (cabling, plastic tape etc) was forced to the bottom of the hole by pouring some coarse gravel into the hole, so that the pump intake would not be obstructed.

After the pump was replaced in the bore, the 0.71L/sec pumping rate was determined to be the same as reported in the NOW database, with no reduction due to mining related impacts.

Further details of the bore maintenance and inspection works are contained in (Geoterra, 2011).

EAW Series Piezometer Water Levels

Standing water level records for EAW5, 7, 9, 18 and 58 are shown in **Figures 11** to **14.**

The two closest piezometers to Longwalls 702 and 703 are EAW7 (1050m to the north of Longwall 703) and EAW58 (620m to the south west of Longwall 703) as shown in **Drawing 1**.

No water level response to the extraction of Longwalls 702 or 703 can be assessed from the EAW7 plot due to an incomplete data record.

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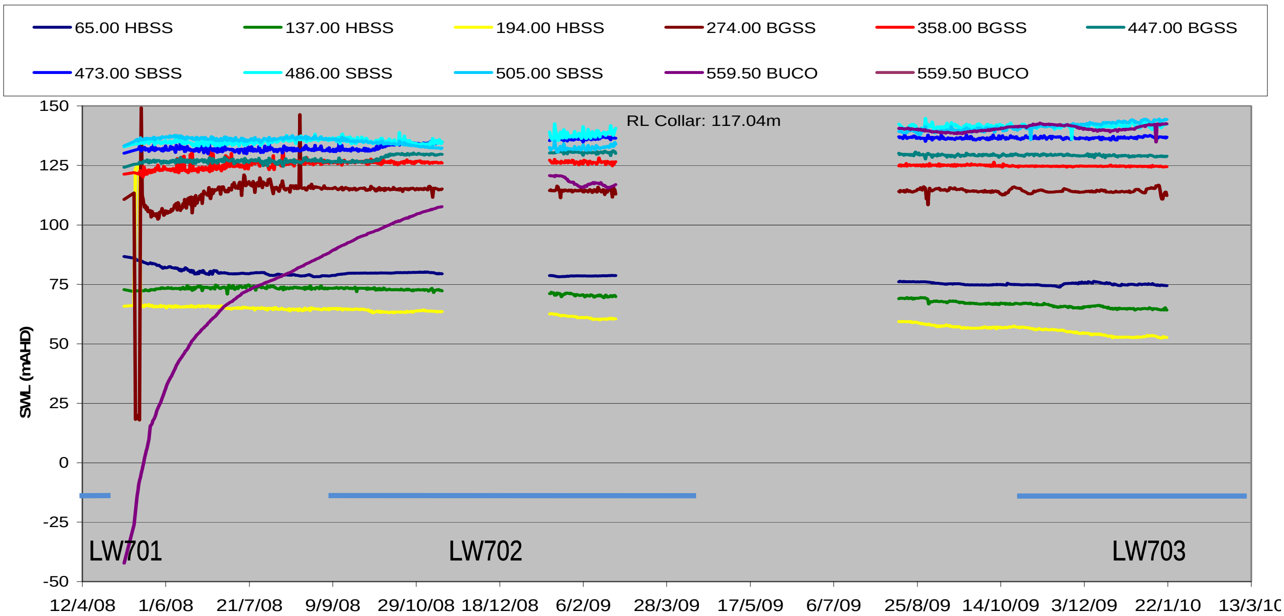


Figure 11 EAW5 Water Levels

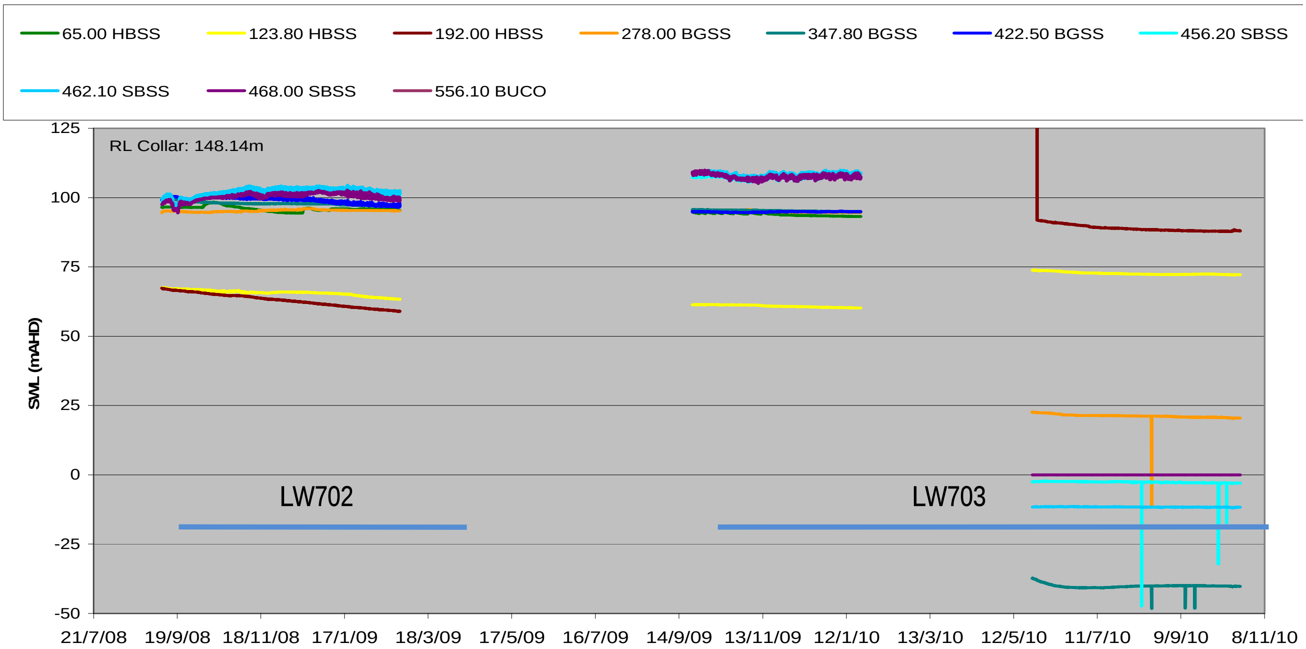


Figure 12 EAW7 Water Levels

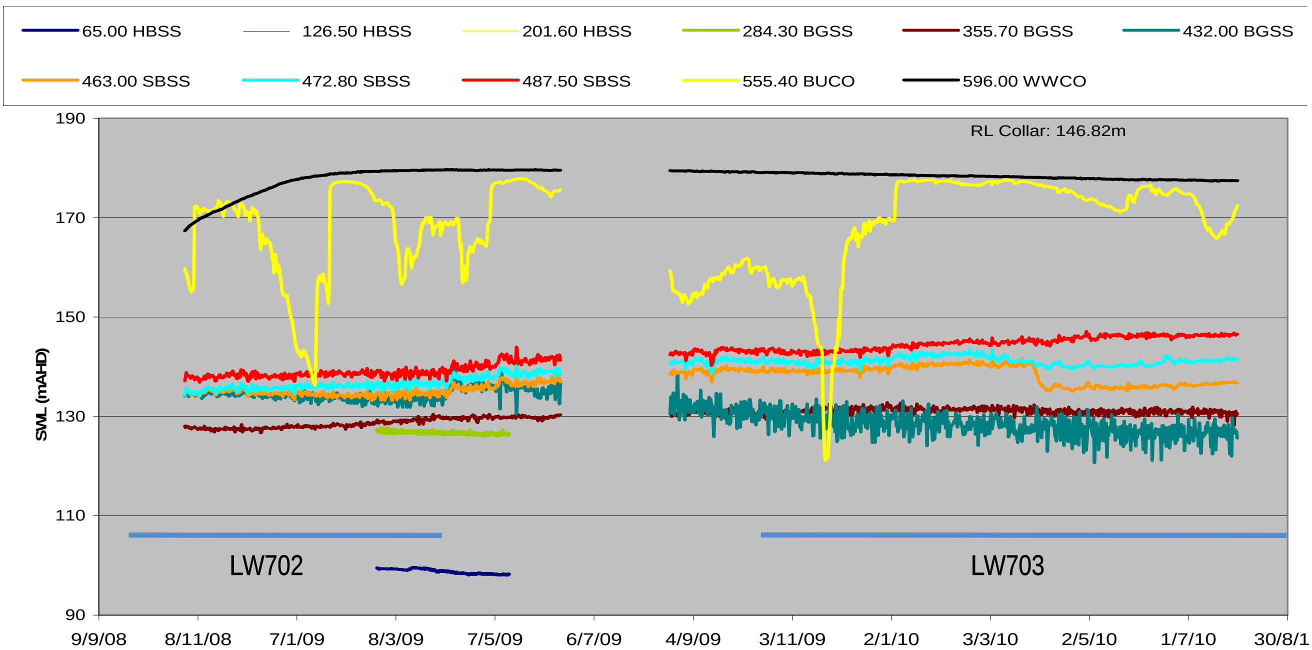


Figure 13 EAW9 Water Levels

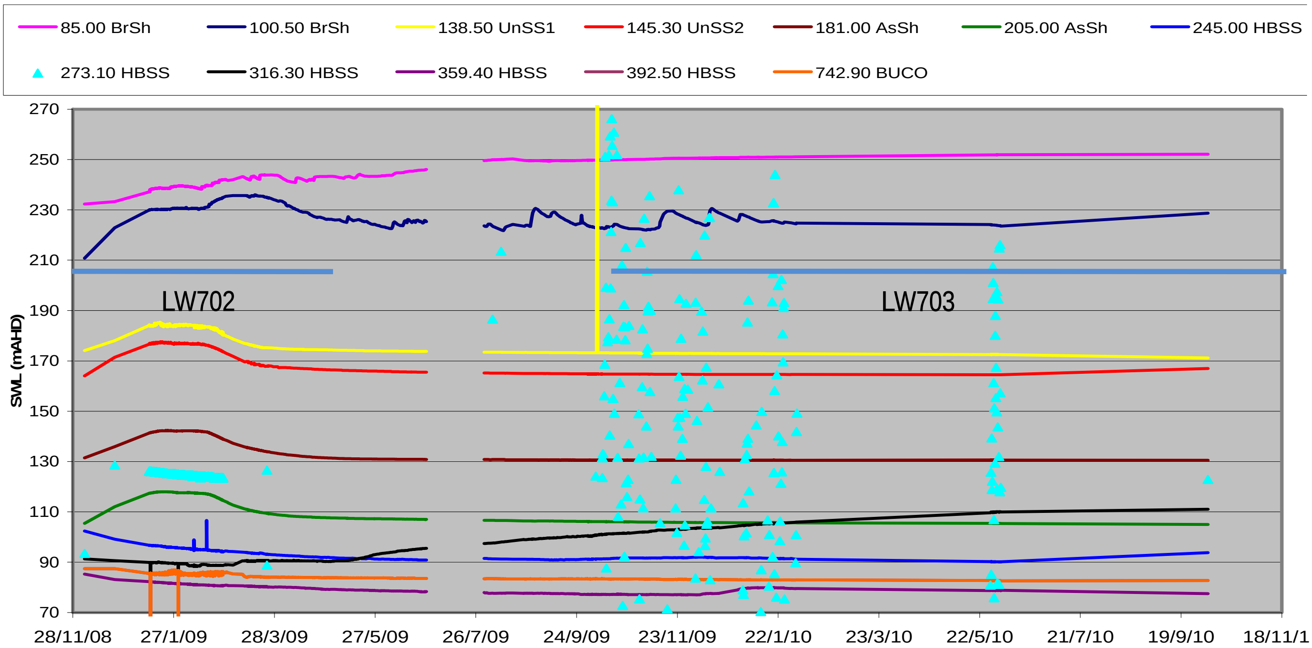


Figure 14 EAW18 Water Levels

As shown in **Figure 15**, water levels at EAW 58, which is located approximately 620m to the southwest of Longwall 703, showed declines starting around the 16th September 2010 of around 11.7m in the Bulgo Sandstone (417mbgl), 9.4m and 6.3m in the Scarborough Sandstone (440 and 447mbgl respectively) up to late September / early October, before a recovery was observed.

Other piezometer intakes that showed a gradual reduction in water levels were the Hawkesbury Sandstone at 65mbgl and 95mbgl, with falls between late August to mid November 2010 of 4.8 and 3.8m respectively.

The greatest water level reduction was observed in the Coalcliff Sandstone, which showed a gradual reduction from late August to late November 2010 of approximately 19.8m.

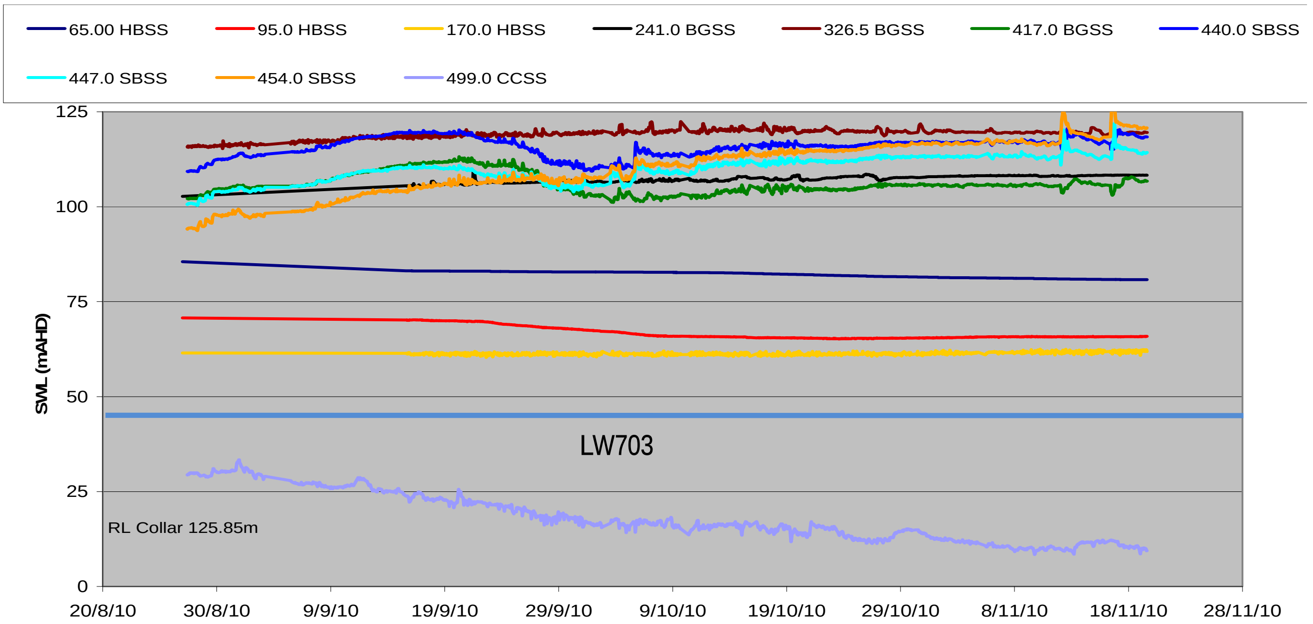


Figure 15 EAW58 Water Levels

The piezometric head versus depth plot shown in **Figure 16** illustrates the change in water pressures in the Coalcliff Sandstone as a transmitted effect from depressurisation of the Bulli Seam and immediately overlying lithologies through extraction of Longwall 703.

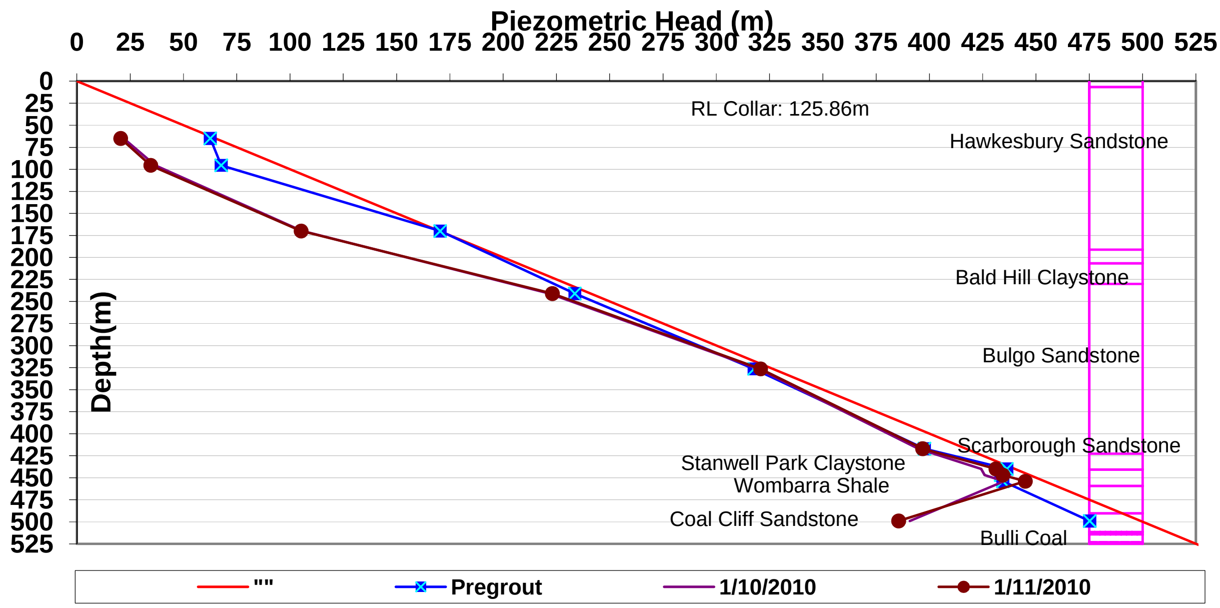


Figure 16 EAW58 Head Pressure vs. Depth

The same depressurisation was observed in the lithologies within and immediately overlying the Bulli Seam at EAW5 as shown in **Figure 17**, however the change is assumed to be due to dewatering of the Bulli Seam for gas extraction purposes.

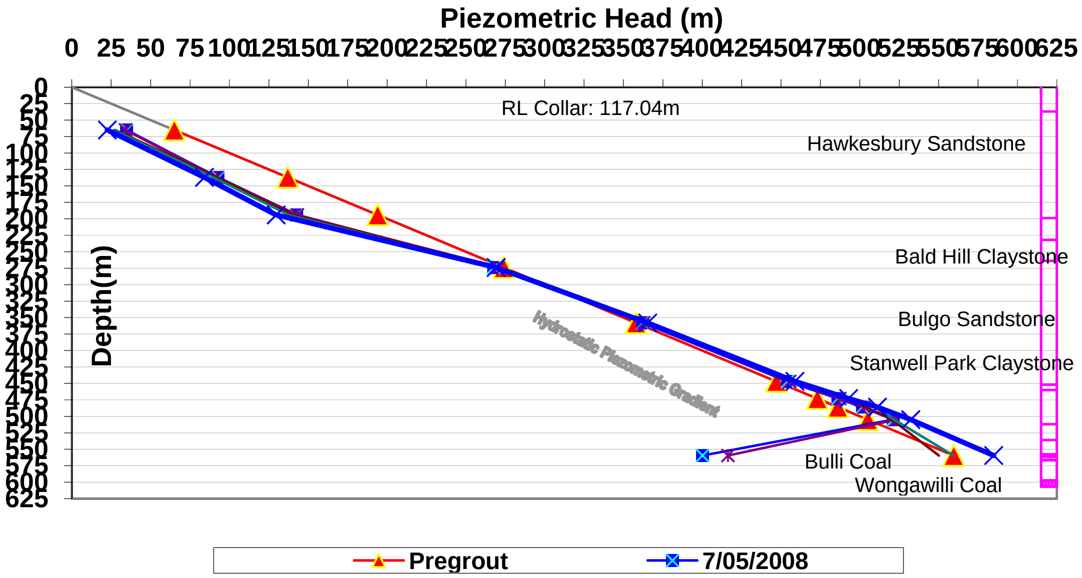


Figure 17 EAW5 Head Pressure vs. Depth

6.3 Groundwater Quality

Groundwater sampling and detailed laboratory analysis was conducted in the available Area 9 private bores piezometers during August 2010 as shown in **Tables 5** and **6.**

The data indicates that the Area 9 private bores exceed the ANZECC 2000 irrigation criteria for hardness. Chloride and total iron also exceed the criteria in the Jordan bore (GW104661).

Groundwater from the EAW bores was not sampled or analysed as they were sealed after installation of the vibrating wire piezometers.

Table 5 Private Bore Groundwater Quality (Non Metals)

	ANZECC 2000 (Irrigation)	HOLZ (GW 104602)	DENNIS (GW110671)	JORDAN (GW 104661)
Sample Date		**09/08/2010**	**13/08/2010**	**24/8/2010**
Odour	**-**	Sulfide smell	No odour	No odour
pH	**6 – 8.5**	7.05	6.96	7.02
EC (µS/cm)	**-**	1631	1956	3380
TDS	**-**	930	1070	1860
Na	**115 – 460**	**220**	**280**	**240**
Ca	**-**	87	62	180
K	**-**	12	11	11
Mg	**-**	39	60	200
Hardness (as CaCO3)	**350**	**378**	**402**	**1273**
Cl	**175 – 700**	**280**	**340**	**870**
HCO3	**-**	550	640	620
SO4	**-**	12	22	36
F	**-**	0.2	0.36	0.24
Total Phosphorous	**0.8 - 1.2**	<0.01	<0.01	0.02
Total Nitrogen	**25 - 125**	1.4	0.7	0.6
Dissolved Organic Carbon	**-**	1.0	2	<1.0

NOTE: all parameters in mg/L except as shown

- ANZECC 2000 irrigation water quality trigger values for selected vegetables (tomato, cucumber) and general water use

- Total Nitrogen , Total Phosphorous and metal criteria for short term use (up to 20 years)

- Bold values exceed the lower criteria but are below the upper criteria

- **Bold and highlighted** values exceed the upper criteria

Table 6 Private Bore Groundwater Quality (Metals)

	ANZECC 2000 (Irrigation)	HOLZ (GW 104602)	DENNIS (GW110671)	JORDAN (GW 104661)
Sample Date		**09/08/2010**	**13/08/2010**	**24/8/2010**
Total Fe	**10**	0.13	0.08	**15**
Filtered Fe	**10**	0.09	0.03	<0.01
Total Mn	**10**	0.06	0.1	0.06
Filtered Mn	**10**	0.04	0.04	0.03
Filtered Cu	**5.0**	<0.001	0.001	<0.001
Filtered Zn	**5.0**	0.038	1.2	0.004
Filtered Ni	**2.0**	<0.01	<0.01	<0.01
Filtered Al	**20.0**	<0.01	<0.01	0.02
Filtered As	**2.0**	<0.01	<0.01	<0.01
Filtered Li	**-**	0.086	0.12	0.09
Filtered Ba	**-**	2.3	1.2	0.65
Filtered Sr	**-**	1.0	1.3	2.1

NOTE: all parameters in mg/L except as shown

- ANZECC 2000 irrigation water quality trigger values for selected vegetables (tomato, cucumber) and general water use

- **Bold and highlighted** values exceed the upper criteria

7. POTENTIAL SUBSIDENCE IMPACTS

7.1 Groundwater Related Subsidence Predictions

The maximum predicted subsidence at the private bores and BHPB piezometers after completion of Longwalls 901-904 is shown in **Table 7** (MSEC, 2010).

Table 7 Maximum Predicted Cumulative Subsidence

GW	Northing	Easting	Maximum Predicted Subsidence (mm)
34425	6215603	289184	20 - 50
35033	6214961	288045	100 - 200
72249	6215538	288091	1000
100673	6216160	286235	50 - 100
102043	6214659	289777	<20
102584	6216255	289480	<20
102798	6214783	289990	<20
103161	6216499	289511	<20
104068	6214530	289519	<20
104602	6216338	289054	<20
104661	6216470	288973	<20
110671	6216340	288717	20 - 50
BHPB	**PIEZOS**		
NGW3	1216749.5	275027.4	<20
NGW4	1216826.2	275789.9	<20
NGW5	1216327.4	276124	<20
NGW6	1216680.5	276403.3	<20
EAW5	6218729	289027	<20
EAW7	6217768	291547	<20
EAW9	6216341	287181	20
EAW18	6216904	285466	<20
EAW58	6215342	289803	<20

Source: (MSEC, 2010)

7.2 Potential Height of Fracturing and Hydraulic Changes

It is generally considered that increased panel width results in increased height of fracturing and strata dilation, with the theoretical fractured zone height estimated to be the panel width (W) minus the span (w) divided by twice the tangent of the angle of break as shown in **Figure 18** (MSEC, 2010).

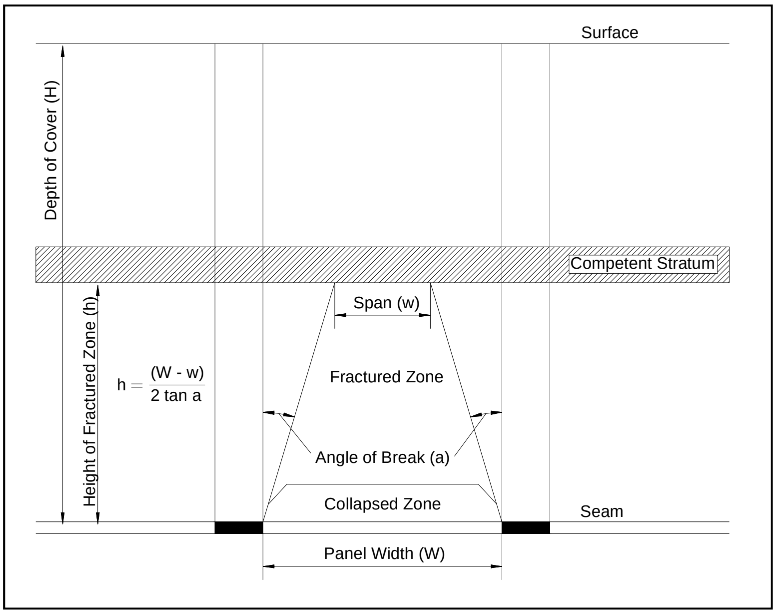


Figure 18 Theoretical Model Illustrating the Development and Limit of the Fractured Zone

In the Southern Coalfield, the upper Hawkesbury Sandstone is relatively strong and is assessed to be capable of spanning at least 30 metres. Using an average angle of break of 20 degrees for a 305m panel width, then it is predicted that up to 375m would be required above the seam to reduce the effective span to 30 metres. If an angle of break of 23 degrees is assumed, then a height of 325 metres would be required (MSEC, 2010).

The depth of cover directly above the proposed longwalls varies from 475 - 725m and, therefore, it is unlikely that the fractured zone would extend up to the surface.

It should be noted, however, that the overall theoretical fracture zone height does not equate to a zone of free drainage through the strata, as plastic strata deformation is present between the upper extent of the goaf and the lower extent of the tensional surface cracking. This “constrained zone” primarily involves bedding separation with increased horizontal permeability, without an increase in vertical permeability.

The constrained zone comprises strata that sags, but, because the zone is constrained, it absorbs most of the strain without significant fracturing or change to the original vertical permeability. Some bed separation or slippage can occur along with discontinuous vertical cracks (usually on the underside of thick strong beds). Weak or soft beds in this zone may suffer plastic deformation.

It is possible that the height of the overall fractured zone above the proposed longwalls could extend up to the Bald Hill Claystone, which lies approximately 270 m above the base of the Bulli Seam. Some horizontal bedding dilation above the Bald Hill Claystone is possible in the Hawkesbury Sandstone, without an increase in vertical permeability through the Bald Hill Claystone, which is expected to continue to respond as an aquitard.

Figure 19 indicates results from a literature study conducted (MSEC, 2010) which compares the theoretical results using an angle of break of 20 degrees and spanning width of 30 metres with lines representing factors of 1.0 - 1.5 times the panel width, as suggested by Gale (2008). The figure indicates the MSEC model and Gale's 1.0 - 1.5 factors are conservative compared to observed data.

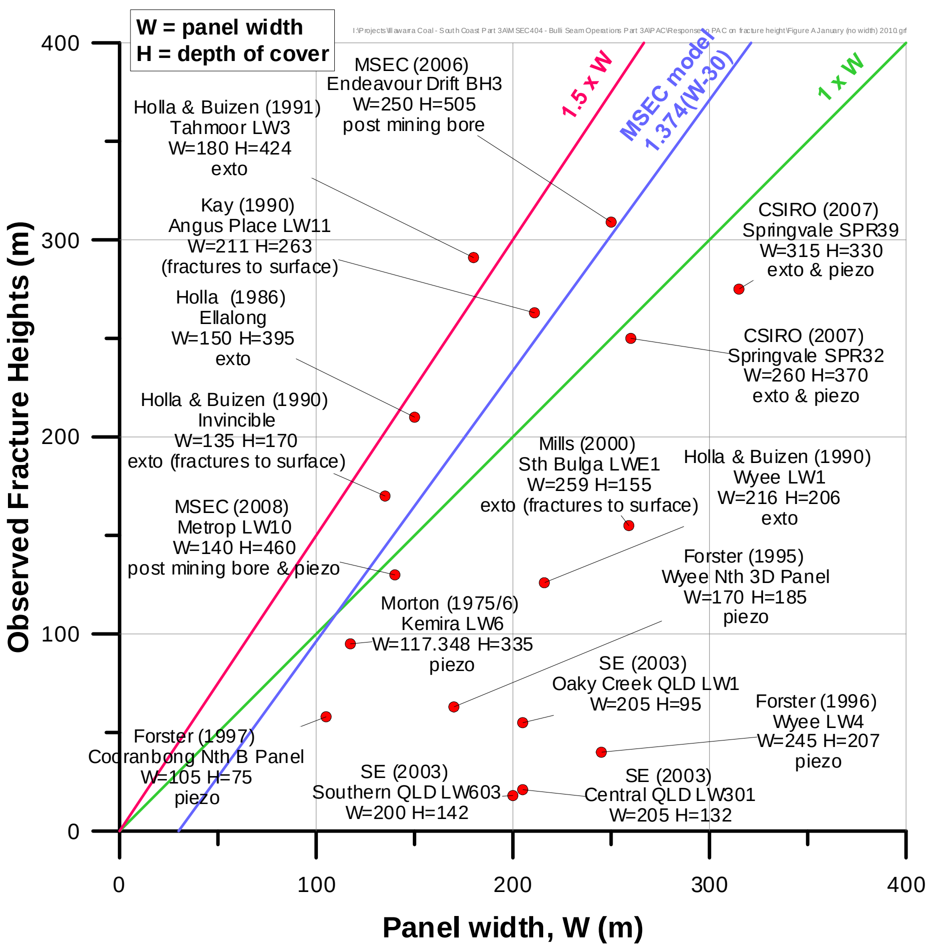


Figure 19 Observed Fracture Heights versus Panel Width

8. GROUNDWATER IMPACTS IN SIMILAR MINING AREAS

This section outlines the observed effects of subsidence on groundwater systems over longwall mines located within similar terrain and with similar layouts to the proposed Appin Area 9 workings.

Mines used for comparative purposes are primarily located within the Southern Coalfield of NSW where the Bulli Seam has been mined at depths of cover between 400 - 550m below the surface and in areas dominated by Hawkesbury Sandstone and Wianamatta Shale plateaus with deeply incised gorges. Observations used to assess the potential effects on groundwater in Area 9 are derived principally from monitoring over Appin Mine Longwalls 701 to 703 and Tahmoor Colliery.

The proposed Appin Area 9 mine plan is in a similar terrain to the Area 7 panels in that the;

- Area 9 mine plan does not involve longwall extraction beneath the Nepean River;
- regional groundwater system flows to the Nepean River, which is the lowest hydrological point in the regional groundwater / surface water system;
- longwall and pillar widths are similar;
- depth of cover is similar, and the
- set back from the Nepean River (and Bargo) gorge is similar.

8.1 Groundwater Levels

Groundwater systems experience standing water level (or piezometric head pressure) changes caused by bedrock fracturing due to subsidence. The new fracture voids fill with water, generating head drops, particularly in confined aquifers. In general, unconfined or unconsolidated aquifers are not significantly affected by mining (Booth, C.J., 2002).

After subsidence is completed, water levels may recover due to partial closure of fractures and by recharge flowing back to the affected area. This is usually premised on the basis there is no sustained discharge from the subsided zone out of the system. These outflow paths could be through, for example, post subsidence springs flowing into valleys or by connection to enhanced permeability goaf zones over mined out longwalls.

The response to mining and permeability changes varies both spatially and temporally within a mined area. Factors such as topographic relief and stratigraphic variation have a significant effect on the observed response.

Overburden at the advancing front of the subsidence trough undergoes a sequence of horizontal tension and compression of the rock, known as a “subsidence wave” which manifests as volumetric dilation followed by compression of the strata. The strata movement occurs through fracturing, bedding separation and changes in existing joint apertures which can result in substantial changes in fracture porosity and rock permeability. This in turn leads to changes in piezometric heads, groundwater flow patterns and potentially well yields.

A rapid response and temporary decline in piezometric heads can be primarily related to in situ hydraulic property changes in bedrock aquifers caused by:

- a sudden increase in fracture porosity and drainage of groundwater into new void space, with confined aquifers potentially altering to an unconfined or threshold unconfined condition, whilst unconfined aquifers have a significantly less sensitive response.
- a secondary effect of transmitted drawdown around the potentiometric low which

spreads laterally and exponentially from the subsided area. This regional effect generally spreads ahead of mining and is generally the first observed response in standing water levels, with greater regional responses usually observed in higher transmissivity aquifers. The actual observed drop in head relates to the depth of a bore, its intake lithology and its confined or unconfined nature, a bores distance from the subsidence zone, its overburden thickness or separation distance from the bottom of the bore to the top of the disturbed goaf as well as the local relief.

- leakage from upper to lower aquifers through fractured aquitards, with discharge to lower aquifers or local surface water systems. Groundwater flow patterns are affected in areas with high topographical relief by a combination of the topography which drives vertical flow and the layered stratigraphy which favours lateral flow, with subsidence changing the balance toward the topographic driven system. Bores below the regional drainage level may rise due to dewatering of perched aquifers and increased recharge through subsidence fractured layers.
- changes in hydraulic gradients caused by increased permeabilities, as permeability is linked to hydraulic gradient and specific discharge.

If the permeability is increased due to secondary fracture generation, the hydraulic gradient must decline or the specific discharge must increase to maintain stasis. Heads can decline up gradient and rise downgradient from the affected area and groundwater discharges may increase. The overall effect will be seen as an increase in spring or stream flow and a lowering of groundwater levels and loss of stream flow in upland recharge areas.

Groundwater level recovery is driven by two separate mechanisms, which are compression and recharge of the overburden. Partial re-compression of faceline cracks generally follows the dilational subsidence phase, with tension fractures closing, causing a reduction in secondary void space in the bedrock and a resultant increase in groundwater head pressures. Settlement of beds may also result in some closure of bedding separations and groundwater level recovery.

Water level recovery can also occur as regional recharge water flows back to the temporary potentiometric low over a period of a few months. This recovery is dependent on connection to sources of groundwater recharge, the ability of the aquifer to transmit water back into the affected area and the amount of rainfall recharge. Areas of low transmissivity will require longer recovery periods than those in higher transmissive formations.

Changes in permeability can permanently affect the groundwater flow system, with the degree of recovery relating to the degree of fracture recompression. A higher permeability residual fracture network generally remains along the rib line tensional edges of the subsidence trough compared to the inner sections of the trough where faceline cracking has a higher post subsidence recompression ratio. Areas directly over the rib line area can have permanent head losses, with lesser changes in the mid or external panel areas. The combination of the two effects can make long term groundwater system recovery assessment difficult to predict although valley water levels are more likely to recover than hilltop areas or in lithologies below the regional water table compared to perched aquifers (Booth, C. J., 2002).

8.1.1 Observed Water Level Responses

Monitoring conducted in a multi-level vibrating wire piezometer array in Bore EAW58, which extended from the upper Hawkesbury Sandstone down to the Coalcliff Sandstone and was situated approximately 630m southwest of Longwall 703 is shown in **Figure 24**.

The data indicates the upper to mid Hawkesbury Sandstone water levels were marginally depressurised, with a 2.32m drawdown at 65m below surface and 4.25m at 95m below surface, whilst the lower Hawkesbury Sandstone at 170m below surface was essentially unaffected since late August 2010.

The Bulgo Sandstone at 241m and 326.5m below surface was also unaffected, whilst the lower Bulgo Sandstone at 417m below surface underwent an approximate 10.2m drawdown between 20/9/10 and 4/10/10, and a gradual, although reduced recovery, up to mid November 2010.

The deeper strata in the upper to mid Scarborough Sandstone, which would be stratigraphically just above the strongly fractured goaf above the Bulli Seam over Longwall 702 and 703, experienced an overall “flat” response to the mining of Longwall 702 and 703, albeit with a short term fall between 20/9/10 and 1/10/10 of approximately 10.2m at 440m and 5.0m at 447m below surface. The lower Scarborough Sandstone experienced a continued general rise in water levels from late August 2009 to mid November 2010, with a significantly subdued response over the same period as was noted in the mid to upper Scarborough Sandstone.

On the other hand, the deeper Coalcliff Sandstone at 499m below surface experienced a continued decline in water pressures since August 2009 of approximately 20.2m.

Water level monitoring in open standpipe piezometers directly over Longwall 703 in the Nahkle private bore and the NGW3 piezometer as shown in **Figure 9** indicates an anomalous rise in water levels which has not been observed before, and is not yet explained.

It was observed in the Nahkle bore (GW104154) that directly after undermining, “cascading” in the bore annulus was noted, indicating a new, or enhanced, higher elevation water source was generated in the open, uncased bore which supplied water at a rate greater than the lower aquifer could dissipate it back into the sandstone aquifer.

A similar effect was observed in NGW3 as shown in **Figure 9**, even though the data trace is affected by short term water level rises following rain events where recharge enters the improperly sealed bore annulus.

Groundwater levels in piezometers located over and adjacent to Tahmoor Colliery, on the plateau of the Bargo River gorge to the west of Appin Area 9, in the Bargo River catchment, showed water level declines of up to 8.9m over the monitored extracted longwalls, with a gradual, although reduced, recovery over a 9 month period (in a drought event).

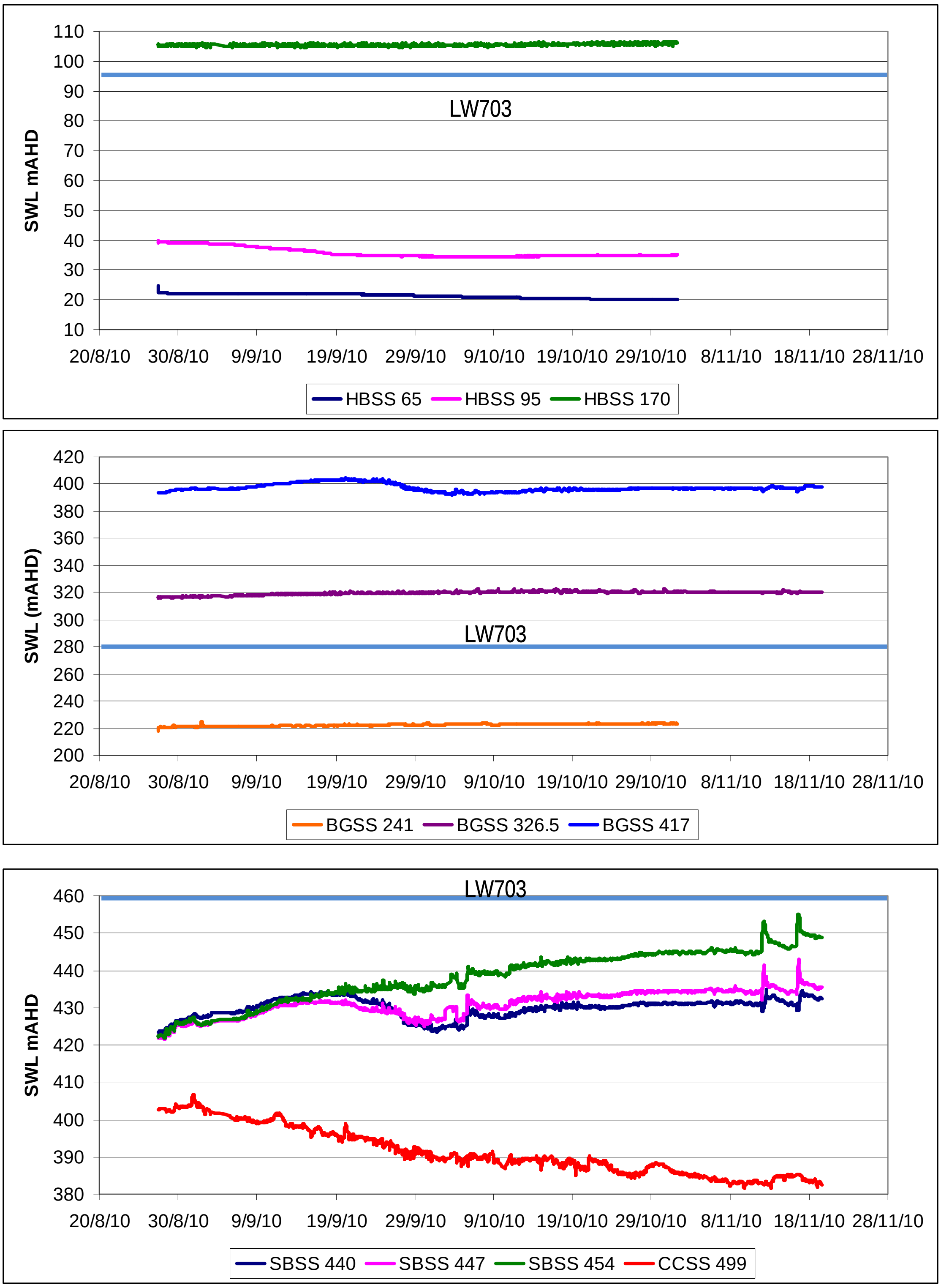


Figure 20 EAW58 Groundwater Levels

8.2 Bore Yield

Bore yield is defined as the volume of water per unit time that is discharged from a well, and is usually quantified in either L/s or ML/day.

The yield relates to the combined effect of the standing water level and hydraulic properties of a bore. Faster water level recovery following hydraulic conductivity enhancement of a formation due to mining can enhance a bore's yield. However the water quality may be reduced due to interaction with a greater surface area of unweathered lithologies around the bore.

The yield can also be reduced if a bore runs "dry" due to lowering of the regional standing water level after subsidence so that the pump runs out of water. Reduced yields were reported following subsidence at Tahmoor Colliery, which was remedied by either redrilling the bore or cleaning and lowering the pump intake.

Assessing changes in yield due to mining has been difficult to date at Tahmoor as the bores were generally not monitored before mining. In these circumstances, a reported loss of yield could result from one or more of the following factors:

- mining,
- regional water level reductions after extended drought,
- neighbouring bores being extracted at increasing rates or duration,
- additional extraction from a nearby or connected system, and
- normal operational or maintenance related problems.

Quantification of the impacts from subsidence requires pre-mining baseline data as well as regular monitoring during mining and after the completion of mining if there have been effects identified. In addition to purpose built monitoring bores, other sites that should be monitored include extraction bores in the subsidence zone and neighbouring bores. The parameters to be monitored should, where possible, include usage patterns, flow rates, standing water levels and bore construction details. Ongoing monitoring of water levels and usage patterns should be assessed during and after subsidence has developed.

No reduced bore yields have been observed over Longwalls 701 to 703.

Five private bores on the Nepean River plateau to the east of BHPB Tower Colliery Longwall 17 were monitored before the panel was extracted, with no adverse change to bore yield reported by landowners.

Isolated complaints were received from landowners adjacent to Tahmoor Colliery who had bores located approximately 175 - 475m from a mined panel. The bores were replaced or reconditioned where it was determined mining had impacted on them, although it was not possible to quantify the impact on the bores as they had not been monitored prior to mining.

8.3 Groundwater Quality

Groundwater quality within subsidence affected aquifers is an important issue to consider when assessing the significance of potential impacts on streams, groundwater dependent ecosystems or groundwater use.

No significant adverse groundwater quality changes have been generally reported from subsided bores in the Southern Coalfields. However, it is likely that water quality changes have occurred, but not been observed due to the relatively low level of groundwater resource use in mining areas.

Potential impacts likely to have occurred include increased iron concentrations and precipitation of iron hydroxide. This has the potential to impact pipes, dams or other water transfer systems through pumping and aeration of groundwater.

Other more subtle changes may occur with regard to dissolved nickel, zinc or manganese levels through oxidation and dissolution of iron and manganese carbonates (siderite, rhodochrosite) and iron sulfides (marcasite) following subsidence induced fracturing around a bore. Identification of subsidence related changes in dissolved metals requires the appropriate collection, preservation and laboratory analysis of samples during a range of pumping situations and durations that a bore is normally subjected to.

In comparison to the controlled samples collected since 2008, the Boustani Bore has increased its salinity from an average pre-Longwall 703 salinity of 3,933mg/L to a post subsidence average of 4,744mg/L, with the early February 2011 sample at 4,460mg/L indicating a gradual lowering with time. Sulfate also rose from 30 to 103mg/L which would be related to the increased hydrogen sulfide smell in the bore water as reported by the landowner (as H_2S oxidises to sulfate relatively quickly through oxidation whilst sampling and in storage / transit to the lab).

The Nahkle bore increased its average pre-Longwall 703 subsidence salinity of 2,500mg/L to a post subsidence average of 5,385mg/L, which appears to be reducing with time, whilst sulfate rose from 69 to 131mg/L.

The sulfate levels in both bores do not exceed the irrigation water quality criteria, although the water is not suitable for drinking.

No comparative pre and post-mining observations on groundwater quality were conducted at Tower Colliery.

Monitoring at Tahmoor Colliery do not indicate any significant observable change and no complaints regarding groundwater quality have been received from landowners within the subsidence area.

8.4 Upland Plateau Ferruginous Springs

The generation or enhancement of shallow groundwater ferruginous springs following subsidence have been observed in similar plateau areas in the vicinity of the proposed Longwall 901 to 904 workings within sub-catchments of the Nepean River, as well as other areas in the Southern Coalfields.

Broad scale upland plateau subsidence can delaminate and dilate erosion surfaces and bedding planes within and between strata, such as on the interface between the Wianamatta Shale / Mittagong Formation and the underlying sub-cropping Hawkesbury Sandstone, can produce enhanced permeabilities and generation of upland springs.

This occurs due to the increased detention and storage of infiltrating meteoric waters in the shale and close to the shale/sandstone interface, with the stored water draining to a creek or river. In some cases it can also travel down natural or induced vertical cracks and along widened bedding planes in the sandstone and subsequently appear as well-defined springs. That significant water storage at the Wianamatta/Hawkesbury interface occurs and is pronounced is indicated by:

- water yields recovered from various shallow boreholes in the Southern Coalfield on plateau mantled with shale (i.e. those drilled just into the upper layers of the Hawkesbury);
- periodic longwall mining-induced seepages (e.g., in the Cataract Tunnel); and by
- the emergence of highly visible ferruginous springs (e.g., in the Upper Georges and Cataract Rivers).

Mining induced subsidence effects on shale-mantled upland catchments might generate ferruginous springs from upland catchments at a maximum recharge/discharge rate of about 0.8 mm/day and a mean recharge/discharge rate of about 0.2 mm/day. This could generate average flows of the order of 0.2 ML/day and maximum flows of around 0.4 ML/day per km^2 of catchment (Ecoengineers, 2008).

Previous geochemical investigations (Ecoengineers, 2008) indicate that shale originated water has a geochemical signature of marine shale soil modified by cation exchange processes on clays for sodium, potassium, calcium, magnesium and strontium, clay adsorption (for boron), and iron / manganese oxide dissolution effects during percolation.

The shale waters often exhibit elevated levels of dissolved iron and manganese typically ranging from 0.2 – 40 mg/L and 0.1 – 2 mg/L respectively through dissolution of Fe / Mn oxides after siderite and rhodocrosite carbonate minerals have weathered in the shale. Reductive dissolution of the Fe / Mn oxides ('bleaching') also occurs in subsoil storage under the influence of bacteria (Geobacter species) that oxidise percolating dissolved organic matter and use such oxides as their terminal electron acceptors (Ecoengineers, 2008).

As distinct from the oxidative dissolution of marcasite that can occur in freshly fractured Hawkesbury Sandstone, the reductive dissolution (bleaching) of disseminated Fe and Mn oxides in the Wianamatta Shales does not increase sulfate ion concentrations and does not produce acidity and hence lowering of pH in situ, although this does occur on emergence into the open air of such waters (Ecoengineers, 2008). As a result, these waters generally maintain constant sulphate ion concentrations, although it increases with greater depths of shale infiltration and the extent of salt leaching involved, and they generally have near-neutral to only weakly acidic pHs when properly sampled in situ or immediately upon emergence and if not subsequently passed through bulk fractured sandstone.

When a spring of this ‘Wianamatta Shale-type water’ emerges into the open air it tends to immediately react with the oxygen in the air or dissolved in the water of the creek or river it may flow into. This results in the precipitation of Fe and Mn hydrous oxides, generating acidity and consuming oxygen (Ecoengineers, 2008).

Iron precipitate was also observed in Upper Nepean Creek within the BHPB Area 7 in 2007 near Longwall 701, which possibly indicates a pre-existing spring in the upper reaches of Nepean Creek.

On the basis of previous monitoring over the Appin, Tower and West Cliff longwalls, it is assessed that springs, if they exist:

- may be generated by a catchment of as small as approximately 0.2 km^2;
- are likely to have a lifetime of at least 4 years with or without significant diminution in intensity; and in the worst case
- may be relatively permanent once instigated, depending upon the size of the dilated catchment area providing their water supply.

The experience of the Cataract Gorge SW2 Springs suggests that a catchment size of the order of only 1 km^2 appears to be sufficient to confer a lifetime in excess of 10 years (Ecoengineers, 2008).

8.5 Groundwater Baseflow to the Nepean River

The development of new or relocated seeps or springs and resultant changes to baseflow have been observed through the interaction of shallow groundwater and stream systems in the Cataract, Georges and Bargo Rivers. Due to its location in the base of the regional hydrological system, as opposed to the upland streams mentioned above, no increased baseflow has been observed into the Nepean River. Increased rates of low volume seepage to the river may have been generated, but it would be insignificant when compared to the volume of water flowing down the river.

The change results from the effects of subsidence, valley closure and upsidence in the base of gorges increasing permeability and interconnection between the river bed and banks.

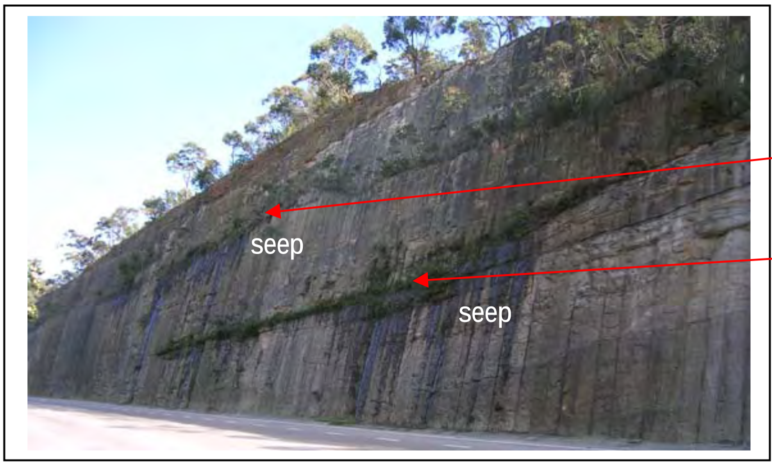
No observable change to seeps, springs or baseflow to the Nepean River were noted despite regular inspections of the gorge during extraction of Longwalls 16, 17 and 20 at Tower Colliery, or from Longwalls 701, 702 and 703 at Appin Area 7.

As shown in **Figure 8,** an up to 1m water level decline in NGW5 and 6m in NGW6 was observed during extraction, between Longwall 702 and the Nepean River, which could have marginally reduced the regional groundwater gradient toward the river, and therefore baseflow seepage to the river, however the effect was isolated and temporary.

Groundwater flow to the Nepean River is difficult to directly observe or measure as the gorge sides are mostly covered with vegetated scree slopes and alluvial terraces, with only limited exposed cliff exposures that enable observation of seeps in the Study Area.

Low volume and short duration seeps can be observed approximately 5m above the Nepean River near the Appin Park causeway, upstream of the extracted Longwall 17 after rain periods.

An example of a short duration, dual-level perched seep that flows for a few days to weeks after significant rainfall is shown in **Figure 21**. The illustrated seeps discharge at the interface between coarser and underlying finer sandstone or shale layers which restrict vertical flow through the bedrock. This enhanced lateral flow consists of a short duration rate estimated at less than 1L/s. It is anticipated that similar seeps would be present in the study area although they are difficult to observe due to sediment accumulations and vegetation.



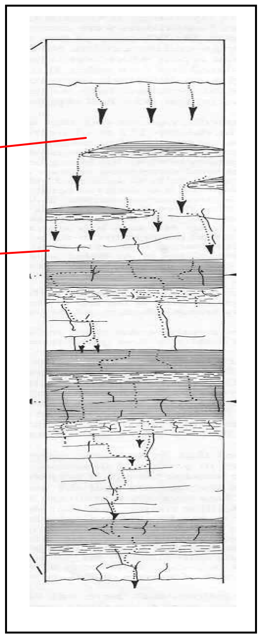


Figure 21 Dual Layered Seep on the F3 Freeway

Groundwater modelling (Heritage Computing, 2010) indicates that old and current mine workings in the "Appin" area have caused negligible changes in groundwater baseflow to streams and that approximately 5.3ML/day of baseflow enters the entire Nepean River catchment.

8.6 Mine Inflow

No observed inflows to workings have been noted in the northern, deeper mines of the Southern Coalfield where the workings range from approximately 400 to 550m below surface.

Field tests over selected collieries indicated vertical permeabilities in the overburden ranging from $3x10^{-1}$m/day in the goafed lithologies directly above the workings and disturbed shallow surface zones to 2×10^{-6} m/day in undisturbed strata, with the majority of intervals tested ranging from 10^{-7} to 10^{-8}m/day.

Interpretation of the field tests indicated that vertical flow through the stratigraphy could occur, however it would be too small to measure, with flow dominantly in the horizontal direction (Reynolds, 1977).

Permeability is variable in the Bald Hill Claystone, Bulgo Sandstone, Stanwell Park Claystone and Scarborough Sandstone, with the strata being unsaturated within 250m above the workings (Reynolds, 1977). At Tower Colliery, groundwater conditions were interpreted to be unconfined from the workings to the Bulgo Sandstone (Coffey Partners International 1997).

Based on the remnant low permeability of the Bald Hill Claystone aquitard after mining, and the continued hydraulic separation of the Hawkesbury Sandstone from the Narrabeen Group aquifers, groundwater modelling (Heritage Computing, 2010) predicts that from Years 4 to 7 there will be no discernible flow into the proposed Appin Area 9 workings and that the bulk permeability of the aquitards remains essentially unchanged after mining.

A minimum thickness of unfractured overburden is required to maintain hydraulic separation between a mine and saturated aquifers, with the critical value depending on lithology, structure and topography. The separation distance has been established through observation and research in NSW mines as ranging from 90 - 150m, although it may be less than 90m if suitable ductile confining layers are present, such as thick sequences of shale or clay (Booth, C.J., 2002). The separation distance over Longwalls 901 to 904 is well in excess of 150m under both the gorge and the plateau.

Two dimensional numerical modelling using the computer code (UDEC) indicated that general movement of rock and fracturing can occur, with the following features (Wold, W. B, 2005):

- loosening, fracturing and local shear on joints and bedding of rock blocks on the cliff lines and valley slopes,
- lateral convergence of cliff lines in the valley and associated shear on bedding planes at the valley floor,
- overall subsidence of the valley with a tendency for uplift of the valley floor relative to the cliff lines. Local buckling and uplift of blocky strata on the river bed due to horizontal thrusting, and
- fracturing and yield failure extend to 150m above the workings. The interburden strata above this zone remains essentially intact and subsides with shearing on

bedding planes.

In the Study Area the Bald Hill Claystone aquitard is situated at approximately 350 – 380m below surface where the Bringelly Shale (109m deep), Michinbury Sandstone (3m deep) and Ashfield Shale (40m deep) are thickest, with the Hawkesbury Sandstone being hydraulically separated from the lower Narrabeen Group aquifers.

The Hawkesbury Sandstone is dominated by horizontal flow to the valley floor or locally upwards from below the river bed, along with potentially localised flow in mining induced shear zones on bedding planes at the base of the gorge.

Groundwater modelling (Heritage Computing, 2010) indicates the entire existing Appin workings generate approximately 1.246ML/day of inflow, compared to approximately 0.5 ML/day of measured inflow.

8.6.1 Bore Gas Emissions

There has been very limited reports of gas adversely affecting groundwater supply bores in the Southern Coalfields over longwall subsided areas apart from one instance at the Morrison Dairy in 1998 (Ecoengineers, 1998).

The bore was drilled to 509mbgl, into and below the Bulli Seam, which is significantly different to the depth of private bores over Longwalls 901 to 904, which are all completed within the Hawkesbury Sandstone.

9. POTENTIAL GROUNDWATER IMPACTS

9.1 Wianamatta Group Shale and Sandstone Groundwater Levels

Mining induced fracturing of strata over the extraction area will occur on the plateau, and may extend to 20m below surface (Seedsman, R., Dawkins, A., 2007) with potential for dilation of strata below the surface tensional zone.

In the upper 20m, tensional subsidence fracturing shifts the dominance of pre-mining horizontal flow along and above aquitards and bedding planes to a combination of vertical and horizontal flow where the water drains from higher to lower strata.

Vertical flow continues down the strata until it is restricted by intact aquitards or natural bedding planes, where the flow resumes its horizontal dominance.

Below the fractured zone, an increased horizontal flow component can occur due to dilation and bending of strata, even though the layers are not breached by vertical fracturing. The increased horizontal permeability extends across the subsided area, and gradually diminishes as the subsidence / dilation decreases to the edge of the subsidence zone.

No adverse interconnection of aquifers and aquitards is anticipated within 20m of the plateau surface as there are no recorded perennial aquifers in this interval, which is predominantly within the Wianamatta Group shales and sandstone units, except over the south western section of Longwall 901. There may be an increased rate of recharge into the plateau following rainfall due to the increased porosity and permeability of the fractured sandstone / shales. This can either result in higher discharge volumes and duration of temporary rain dependent seeps, and/or higher recharge rates to underlying aquifers.

The resultant enhanced seepage or altered vertical recharge patterns will depend on which preferential flow path, or paths, develops. Even though there is insufficient knowledge of the variables to predict which flow patterns will develop, the effect is not significant, and, in addition, the variability of the shale and sandstone sequence is such that predictions would be difficult to develop between known bore data.

Water level reductions in the Wianamatta Group perched aquifers may potentially reduce by between 5 – 10m.

9.2 Hawkesbury Sandstone Groundwater Levels

Even though the regional piezometric surface lies beneath the potential 20m deep fracture zone in the Wianamatta Group shales and sandstones, and to a lesser degree, the Hawkesbury Sandstone over the south western section of Longwall 901, there may be temporary lowering of the piezometric surface over the subsidence area due to horizontal dilation of strata and increased secondary porosity.

This effect will be more notable directly over the area of greatest subsidence and dilation, and will dissipate laterally out to the edge of the subsidence zone.

Based on observations over Appin Longwalls 701 to 703, the sandstone groundwater levels may reduce by up to 10m.

Six NOW registered bores within or near the proposed Longwall 901-904 area may be affected by subsidence, where the bores predominantly obtain water from the Hawkesbury Sandstone, rather than the overlying Wianamatta Group shale and sandstones.

Three are located over Longwall 902 (GW72249) and Longwall 904 (GW110671 and GW100673), whilst three are located to the south or east of the proposed Longwalls (GW35033, 34425 and 104602) as shown in **Table 8**.

Table 8 Potentially Affected Water Levels in Private Bores

GW	Northing	Easting	Potential Drawdown (m)	Maximum Predicted Subsidence (mm)
34425	6215603	289184	<5	20 - 50
35033	6214961	288045	<5	100 - 200
72249	6215538	288091	5 - 10	1000
100673	6216160	286235	5 - 10	50 - 100
104602	6216338	289054	<5	<20
110671	6216340	288717	5 - 10	20 - 50

The depressurisation may stay at the reduced level until maximum subsidence develops at a specific location. The duration of the reduction depends on the time required to develop maximum subsidence, the time for subsidence effects to migrate away from a location as mining advances and the time required to recharge the secondary voids.

Groundwater modelling of the upward migration of depressurisation from the deeper Illawarra Coal Measures and Narrabeen Group strata (Heritage Computing, 2010) indicates no depressurisation in the Hawkesbury Sandstone or Bulgo Sandstone in the first five years of mining within the proposed Longwalls 901 to 904 area, although there is a substantial predicted drawdown in the Bulli Seam of around 100 – 200m. Although the model did not assess the change in permeability due to tensional fracturing in the Hawkesbury Sandstone or Wianamatta Group lithologies, previous monitoring at Area 7 indicates possible temporary depressurisation in the upper Hawkesbury Sandstone of up to 10m.

The impact of subsidence on a bore extracting from the Hawkesbury Sandstone is related to the degree of groundwater level decline, which rises with increased proximity to a subsided Longwall. It is also significantly affected by rainfall recharge to an aquifer as well as changes in the rate or duration of groundwater extraction in the bore and adjacent bores.

On the basis that the pre-mining circumstances of rainfall recharge and bore pumping remain the same, then groundwater levels in the Hawkesbury Sandstone will generally recover over a few months as the newly developed secondary porosity is recharged by rainfall sourced water. If drought conditions prevail, the recharge period would be extended.

There is generally no permanent post mining reduction in water level in the plateau unless a new outflow path develops, which can occur in close proximity to cliffs where new or enhanced seeps may be generated. This effect will reduce with increased distance from the cliff.

It is anticipated there will be no permanent reduction in groundwater levels underneath the Nepean River, as once the subsidence induced cracks are filled with water, there is no vertical discharge path through which groundwater can flow out of the system, so there will be no ongoing water flow into the cracked basement of the gorge and riverbed.

Any river water diversion that does potentially occur would be replenished by the large volume of water in the ponded river sections and the large daily flow down the river (minimum of 3 ML/day).

Due to the short term nature of any groundwater level reductions it is concluded that there is unlikely to be a significant impact to groundwater resources in the Hawkesbury Sandstone aquifers resulting from the proposed extraction.

9.3 Narrabeen Group and Illawarra Coal Measures Groundwater Levels

Immediately above a mined coal seam, the overburden collapses into the void created by the removal of coal to form a caved zone, whilst a highly fractured zone develops above the caved zone that results in a higher vertical and horizontal permeability.

Although no direct measurements over the Area 7 workings are available, it is anticipated that significant depressurisation of the deep aquifers in the fractured zone above the goaf extends to approximately 150m from the top of the goaf, while transient pressure effects can extend up into the lower to mid Bulgo Sandstone, with a pronounced increase in vertical hydraulic gradient in the deep groundwater system over the mined longwalls.

Above goaf zones there can be substantial changes in fracture porosity and permeability due to opening of existing joints, as well as creation of new fractures and bed separation. Permeability increases are accompanied by reduction in lateral hydraulic gradients with associated changes in groundwater levels and pressures. However, substantial groundwater level changes can occur without significant drainage to the workings, particularly from the Narrabeen Group sandstones.

Water level reductions in the Narrabeen Group lithologies under the Bald Hill Claystone will vary depending on the vertical proximity to the fractured goaf and depressurised area directly over the proposed workings, as well as the proximity of a bore / piezometer to the horizontal extent of the subsidence trough.

Although no deep multi-level piezometers are located over the existing Area 7 workings, the maximum depressurisation of 20.2m was measured in the Coalcliff Sandstone within EAW58, which is 630m southwest of Longwall 703.

Due to the substantial depths of cover at Longwall 901-904, connective cracking from the mined workings to the surface is not anticipated to be generated. Groundwater modelling indicates that there is anticipated to be an eventual recovery of deep groundwater system pressures over many decades following cessation of mining.

9.4 Seeps Springs and Baseflow to the Nepean River

Lowering of the outflow seepage elevation of perched ephemeral seeps along the cliffs of the Nepean River gorge may occur after subsidence through fracturing of underlying confining, low permeability layers in the plateau strata.

Fracturing can enable pre-mining perched water to seep out at lower levels down the cliff, compared to pre subsidence levels. Any current seeps, if present, would generally be short lived, with the volume and duration of flow directly related to the amount and intensity of rainfall. The seeps flow after wet periods and stop flowing after prolonged dry periods.

No large seeps were identified during the study along the potentially affected stretch of the river, however the large scree slope and thick vegetation cover along the gorge makes identification difficult.

The volume of flow from the seeps may increase due to enhanced rainfall recharge through the plateau after rain and the duration of seepage may reduce due to the increased ability for water to drain from the higher post subsidence permeability areas.

No plateau springs have been identified in the area that may be affected by subsidence, however, based on observations associated with previous longwalls in the area, it is possible that interface drainage ferruginous (brackish to saline) seeps may be generated in streams on the plateau over Longwalls 901 to 904, particularly at the interface between shale and sandstone lithologies. It should be noted that no groundwater sources of significance have been intersected in the Wianamatta Group shales and sandstones, although low flow, temporary perched seeps may be present.

Data contained in the NOW bore listings as shown in **Table 9** indicates that between Longwall 901 and the Nepean River gorge, perched water was intercepted at 17.6m below surface in GW30533, with a low yield of 0.13L/sec in sandstone, with the bore located 490m from the gorge. Bore GW102403 also intercepted a perched aquifer at 40m below surface in sandstone with a low yield of 0.1L/sec, with the bore located 350m from the gorge.

Groundwater intercepts above the base of the gorge occurred in GW30533 (17.6 – 17.7m) and GW102043 (40 – 41m).

The initial intercept of the deeper, regional Hawkesbury Sandstone aquifer was located between 55m and 95m below surface with yields ranging from 0.2 – 1.8L/sec, with the majority of the regional aquifer intercept depths are below the basal elevation of the Nepean River gorge.

The data indicates that the potential for permanent springs in the Study Area to provide baseflow to the Nepean River is low, although temporary, elevated springs may be present in the upper sandstone after significant rain events.

Table 9 Private Bores Located Between Longwall 901 and the Gorge

GW	N	E	SWL (m)	Depth (m)	Aquifer	Lithology	YIELD (L/s)	Distance From Gorge (m)
35033	6214961	288045	54.80	131	17.6 – 17.7 54.8 – 55.1	sandstone sandstone	0.13 0.23	490
101133	6214100	289443	61.0	96	78.5 – 78.8	sandstone	1.80	170
102043	6214659	289777	104.0	192	40 – 41 161.5 - 162	sandstone sandstone	0.10 0.20	350
102798	6214783	289990	n/a	148	95 – 96 103 - 104	sandstone sandstone	0.25 1.00	225
104068	6214530	289519	62.0	180	95 – 118 152 – 153 163 - 164	sandstone sandstone sandstone	0.52 0.50 0.50	465

NOTES: TDS = total dissolved solids

shading indicates water intercept above the base of the Nepean River gorge

The low order creeks on the plateau will be subjected to relatively low tensile strains and are not expected to be significantly impacted by subsidence related surface cracking, particularly where shale is present as it has a higher ability to deflect rather than fracture when subsided due to its higher ductility compared to more brittle sandstones.

It is not expected that buckling or fracturing of exposed bedrock in the plateau creek beds will occur. Similarly, it is not expected that observable loss of water from the creeks will occur.

It is not expected that any observable change to Harris Creek or Nepean River Tributary 1 flows or ponding will occur due to the low predicted tilts, which are notably less than the natural gradient of the creeks.

The risk of any significant loss of catchment yield is very low unless a major geological discontinuity is encountered during mining that provides a direct hydraulic connection between the surface and the 430 – 745m deep mine workings, which is considered highly unlikley.

Due to the low levels of strain on the plateau area and limited potential for fracturing of rock, cracking of soil and water loss, it is unlikely that the proposed mining in Longwall 901-904 will significantly impact lower order streams, seeps, springs and flow to the Nepean River.

9.5 Well Yield and Bore Serviceability

Horizontal displacement of strata can make a bore inaccessible if a bore is sheared.

Strata dilation and subsequent refilling of the newly created secondary voids can temporarily lower standing water levels, whilst increasing the potential yield of a bore through enhanced permeability and secondary porosity.

Of the six potentially affected bores, only the ones overlying the proposed workings have any significant potential for being adversely affected.

Of the six, the bores most prone to potential reductions in well yield or bore serviceability are located in surface areas that may undergo the highest lateral tensile strain or bedding dislocation / shearing.

Bores close to the end or longitudinal edge of a subsidence trough, where the panel “falls in” to itself, where the highest tilts are also located, are more susceptible, such as;

- GW72249 near the south eastern longitudinal edge of Longwall 902;
- GW110671 at the eastern end of Longwall 904, and;
- GW100673 on the south western longitudinal edge of Longwall 904.

Table 10 Potentially Affected Well Yield and Serviceability in Private Bores

GW	Northing	Easting	Potential Effect on Yield or Serviceability	Maximum Predicted Subsidence (mm)
34425	6215603	289184	low	20 - 50
35033	6214961	288045	moderate	100 - 200
72249	6215538	288091	elevated	1000
100673	6216160	286235	elevated	50 - 100
104602	6216338	289054	very low	<20
110671	6216340	288717	moderate - elevated	20 - 50

Bores outside the panels or on the edge of the Study Area are less likely to undergo adverse subsidence effects.

Damage to bores can be readily managed. Should the accessibility, available drawdown or yield of a bore be adversely impacted due to subsidence, the Colliery is required to provide an alternative water supply.

If the level does not sufficiently recover and the effect is due to subsidence rather than regional climatic or anthropogenic factors, repairs or maintenance to a bore can be undertaken after maximum subsidence has developed. At this time the pump intake can be lowered, the bore depth can be extended or a new bore can be established.

With the suggested mitigation measures in place it is unlikely that water supply to properties will be significantly impacted in the long term by the proposed mining in Longwall 901-904.

9.6 Potential Inflow to Mine Workings

Loss of stream flow or substrate groundwater to the Bulli Seam workings has not been observed in any mines in the Southern Coalfield at similar depths of cover that exist at Area 9.

Free draining vertical hydraulic connection to the workings is essentially blocked from entering the mine as the Bald Hill Claystone continues to act as a confining layer after subsidence.

It is highly unlikely that the Bald Hill Claystone will be breached due to subsidence as it is sufficiently higher than the anticipated height of free draining fracturing above the extracted workings, and below the approximately 20m deep extent of tensile strain surface cracking.

Groundwater seepage into the workings will increase as flows from the highly fractured and free draining lower goaf zone develop.

Groundwater modelling (Heritage Computing, 2010) predicts flow into the Appin Mine could increase from the current prediction of 1.246ML/day to 2.7 – 3.4ML/day. This value includes all proposed workings, of which Longwalls 901 – 904 are a small component.

The horizontal permeability of the Hawkesbury Sandstone and mid to upper Bulgo Sandstone above and below the Bald Hill Claystone may be enhanced after subsidence, however no free draining direct vertical hydraulic conductivity connection to the Bulli Seam workings is anticipated.

As a result, the hydrologic systems above and below the Bald Hill Claystone are anticipated to remain separate, although an increased mine water make through drainage from the highly fractured lower goaf area is anticipated.

9.1 Groundwater Quality

Previous observations indicate that water quality of subsided private bores in the Southern Coalfield has not generally been adversely affected.

There may be increased iron and manganese hydroxide precipitation due to subsidence related exposure of previously unweathered iron and manganese carbonates along with a lowering of pH if the aquifer is exposed to previously unweathered iron sulfides (marcasite) in the strata.

In addition, bore water salinity can be increased after subsidence, particularly where interface drainage between shale and sandstone lithologies occurs following bedding plane separation or fracturing.

The degree of dissolved iron and/or manganese generation, pH or salinity change resulting from subsidence is difficult to predict, and can range from no observable change to a distinct discolouration of the pumped water. The effect also depends on the overburden over a panel, where there are different geochemical signatures for subsidence effects in Wianamatta Group shales compared to Hawkesbury Sandstone as discussed earlier in this report.

The discolouration does not pose any health hazard, however it can result in clogging of pumping equipment and piping in extreme cases.

It should be noted that many Hawkesbury Sandstone bores in the Southern Coalfield already have significant iron hydroxide levels, and a pre-mining survey is required to assess the baseline water quality prior to mining the area.

Acidity (pH) changes of up to 1 order of magnitude can occur in Hawkesbury sandstone bores, however any change will be substantially reduced where there is sufficient bicarbonate ion levels.

It is recommended that direct monitoring of potentially affected bores within Area 9 should be conducted prior to, during and after development of subsidence at specific bore locations.

If groundwater quality impacts resulting from subsidence are identified, alternate supplies of water should be provided to any affected water user until a similar supply can be re-established with similar water quality characteristics.

With these mitigation measures in place it is unlikely that there will be any significant impacts to water quality supplies from the proposed mining.

9.2 Gas

It is not anticipated that significant strata gas will be discharged in private bores over Longwalls 901 to 904.

Overall, there is a limited potential for strata gas emissions into private bores, and any emissions that may occur will be localised and may last for approximately one year.

10. RECOMMENDED MONITORING

10.1 BHPB Piezometer Standing Water levels and Pressures

Standing water levels should continue to be measured and data logged at least twice daily in the pre-mining baseline, impact and post-mining period in NGW3, 4, 5 and 6.

Data from the piezometers should be downloaded monthly and the measured vertical hydraulic head profiles for these piezometers should be compared against the predicted vertical hydraulic head profiles for each bore.

Two additional open standpipe piezometers (POSP A and B) should be installed between Longwall 901 and the Nepean River. They should be installed by dry percussion drilling to the first water make where the dust cuts out, and then drilled a further 10m. The dry drilling method should enable assessment of the depth of the highest perched or regional aquifer and targeting of the piezometer intake at 10m below the regional water table within the Hawkesbury Sandstone.

The location of the open standpipe bore and bore installation method depends on obtaining access approval from any selected properties.

Vertical profiles of potentiometric head should also be monitored in EAW5, 7, 9, 18 and 58. The vertical profile can be an effective monitor of the capacity of an aquifer system to maintain pressure during the formation of deformation zones caused by caving and subsidence.

The profiles show a characteristic reduction in head with depth due to mining. That is, as mining moves closer, groundwater pressures can fall.

No additional vibrating wire piezometer arrays are proposed at this stage in the Wianamatta Group, Hawkesbury Sandstone, Narrabeen Group or Illawarra Coal Measures.

10.2 BHPB Piezometer Groundwater Quality

At least one appropriately purged groundwater sample should be collected from piezometers NGW3, 4, 5 and 6 and the proposed open piezometers between Longwall 901 and the Nepean River in the pre-mining phase and analysed for;

- field pH, electrical conductivity, temperature;
- total dissolved solids;
- filterable Na / Ca / Na / K / SO_4;
- Cl, F;
- total alkalinity;
- total / filterable Fe, Mn, Al;
- filterable Ni, Zn, As, Ba, Cs, Cu, Pb, Li, Rb, Se, Sr, B;
- total nitrogen and total phosphorous.

The pre-mining water sampling and analysis should be repeated at the end of mining Longwalls 901 to 904 sequentially for the same suite of analytes to enable ongoing assessment of any subsidence related changes in groundwater quality.

10.3 NOW Registered Bore Standing Water Levels and Groundwater Quality

Where access to each property and bore is possible, standing water levels should be measured at least once before the area is mined under in private bores within the Study Area, as well as at least once after each bore is mined under.

At least one appropriately purged groundwater sample should be collected from each private bore in the pre and post mining phase and analysed as per the BHPB piezometer holes;

10.4 NOW Registered Bore Yield and Groundwater Use

With the approval of the landholder, the bore owner should be interviewed before and after a bore is mined under to describe their rate and duration of pumping. The bore yield should also be measured and details obtained on the type and set up of the pump in each bore, if installed.

The use of the water should be ascertained and observations made on the quantum of iron hydroxide precipitating from the pumped water before and after mining.

Consultation with bore owners and the monitoring of bores should be incorporated into the Property Subsidence Management Plans for relevant properties.

10.5 NOW Registered Bore Gas

Bore owners should be asked to report on any observed gas into their bores as part of the Property Subsidence Management Plans.

10.6 Cliff Seeps

The presence and duration of observable cliff seeps within the Extraction Plan area should be photographically and semi quantitatively recorded during field monitoring.

Where available and accessible, seep water samples should be collected and assessed for the same field and laboratory parameters outlined in Section 10.1.

10.7 Nepean River Water Levels

The water level of the Nepean River should be monitored weekly at a downstream mid-stream (i.e, adjacent to the middle of Longwall 901) and upstream location within the Study Area.

10.8 Mine Water Inflows

Statutory inspections of the mine workings are undertaken by colliery officials to ensure mine safety. The statutory inspections are expected to provide the first indication of water inflow to the mine due to the frequency of inspections and familiarity with normal conditions. Inflows detected during statutory inspections will be sampled and tested (as per BHPB Groundwater Bores refer Section 10.2). The water chemistry can define if the water is sourced from groundwater or surface water sources.

A Mine Water Balance is used to quantify water inflows by calculating the difference between total mine inflows (reticulated water into the mine, moisture in the downcast ventilation and the coal in-situ moisture content) and mine outflows (reticulated water out of the mine, moisture in the exhaust ventilation, and moisture in the ROM coal).

Monitoring of the mine water balance should comprise:

- metered water reticulated into the mine (recorded continuously and downloaded monthly).
- metered water reticulated out of the mine (recorded continuously and downloaded monthly).
- measurement of moisture content into and out of the mine through the mine ventilation system using digital psychrometers. Measurement of the in-situ moisture content of the coal during routine channel sampling for coal quality.
- Measurement of the moisture content of run-of-mine (ROM) coal conveyed out of the mine at the drift portal

Given the large fluctuations in daily water usage and the cycle period for water entering the mine, being used by machinery and draining to sumps for return pumping to the surface, a 20 day average should be used to provide a more reliable estimate of water make.

10.9 Groundwater Model Updating

Significant excursions from the predicted model outcomes should signal a need for model re-calibration and/or further investigation.

11. PERFORMANCE MEASURES AND INDICATORS

The Project Approval requires BHP IC not to exceed the subsidence impact performance measures outlined in Table 1 of Condition 1, Schedule 3 which for the Nepean River include:

- Negligible environmental consequences, including negligible diversion of flows or changes in the natural drainage behaviour of pools;
- minimal gas releases and iron staining, and;
- minimal and transient increase in water cloudiness.

Monitoring results should be used to assess the Project against the performance indicators and performance measures detailed in **Table 11**.

If data analysis indicates a performance indicator has been exceeded or is likely to be exceeded, an assessment should be made against the performance measure, and if the data analysis indicates that the performance indicator is likely to be exceeded if management measures are not implemented, BHPB IC should implement suitable measures and continue to monitor the relevant sites and parameters.

If the data analyses indicates the performance indicator has been exceeded, an assessment should be made against the performance measure.

If required, the data analyses may be revised in consultation with the DoP, NOW, DTRIS and OEH.

If required, the analyses should be peer reviewed by a specialist approved by the DoP and the results should be reported to DoP, NOW, DTRIS and OEH.

Table 11 Water Resource / Watercourse Performance Indicators and Measures

Performance Measure	Performance Indicator(s)
Negligible reduction to the quantity of water seepage reaching the Nepean River	Changes in the quantity of water entering the Nepean River are not to be significantly different post-mining compared to pre-mining.
Negligible reduction in the quality of water seepage reaching the Nepean River	Negligible change in the quality of water entering the Nepean River post-mining compared to pre-mining.
No connective cracking between the surface and the mine	• visual inspection should not identify abnormal water flow from the goaf, geological structure, or the strata generally, analysis of water from underground sources should be old, saline water • the 20-day average mine water balance should not exceed 3ML/day • significant departures from the predicted vertical potentiometric head profiles should not occur.
Negligible leakage from the Nepean River	The groundwater head in the plateau should be higher than the Nepean River water level, so that a “gaining” hydraulic gradient exists from the plateau to the river

11.1.1 Seepage Water Quantity

Groundwater levels should be monitored particularly in bores EAW9, 18 and 58 and the two proposed open standpipe piezometers (POSP A & B), as well as any accessible private bores between Longwall 901 and the river, which should be compared to measured water levels in the Nepean River.

Analysis of the groundwater data from the bores should be conducted six monthly to assess whether the performance indicator *groundwater head of the plateau groundwater is higher than the Nepean River water level*.

The performance indicator should be considered to have been exceeded if data analysis indicates that there is a reversal or significant reduction in the hydraulic gradient to the river, specifically if the 7-day average potentiometric head in the new piezometer/s located between Longwall 901 and the river is less than the river water level for greater than one month.

The monitoring data should be used to assess the following performance indicators:

- visual inspection does not identify abnormal water flow from the goaf, geological structure, or the strata generally.
- the 20 day average mine water make does not exceed 3 ML/day.

If the monitoring indicates a performance indicator has been exceeded, an assessment should be made against the performance measure, and the performance indicators may be revised in consultation with the DoP, NOW, DTRIS and OEH.

The subsidence impact performance measure, *no connective cracking between the surface and the mine*, should be assessed to determine if the increased water make is likely to have been caused by connective cracking between the surface and the mine.

The performance measure should be deemed to have been exceeded if analysis of the monitoring results confirms that the Longwall 901-904 has resulted in connective cracking between the surface and the mine.

Vertical groundwater head profiles should be used to assess the connective cracking between the surface and the mine in EAW9.

Data analyses should be conducted every six months to assess whether the *significant departures from the predicted envelope of vertical potentiometric head profiles do not occur* performance indicator has been exceeded.

The performance indicator should be considered to have been exceeded if data analysis indicates a significant change (i.e. reduction) in pressure in the monitored bores, or an inconsistency in profile shape with what has been predicted: specifically if the measured potentiometric head profile (averaged over the preceding month) lies significantly to the left of the predicted high-inflow model curve.

The performance measure, *no connective cracking between the surface and the mine*, should be assessed to determine if the change in the vertical head profile of the monitored bores is likely to have been caused by connective cracking between the surface and the mine.

This should be assessed by modifying the height and hydraulic properties of the fractured zone in the groundwater model until the measured profile is reasonably replicated. The performance measure should be considered to have been exceeded if the re-modelled fractured zone indicates extension of the fractured zone to the land surface.

11.1.4 Negligible Leakage from the Nepean River

The performance measure, *negligible leakage from the Nepean River*, should be assessed to determine if the change in groundwater levels in the new open standpipe piezometers (POSP A & B) and EAW58 could result in an impact on the Nepean River vertical leakage that is not negligible (i.e. small and unimportant, so as to be not worth considering). This should be assessed by modifying the groundwater model until the measured time-series plots at bores EAW58, as well as the two proposed open standpipe piezometers are reasonably replicated, and by recording the rate of predicted leakage from the river within the Study Area.

In addition, the downstream monitoring location should also be assessed for any potential mining related effects on water level or water flows at Douglas Park Weir.

The performance measure should be deemed to be exceeded if analysis of the monitoring results confirms that the Project has resulted in a greater than negligible leakage from the Nepean River.

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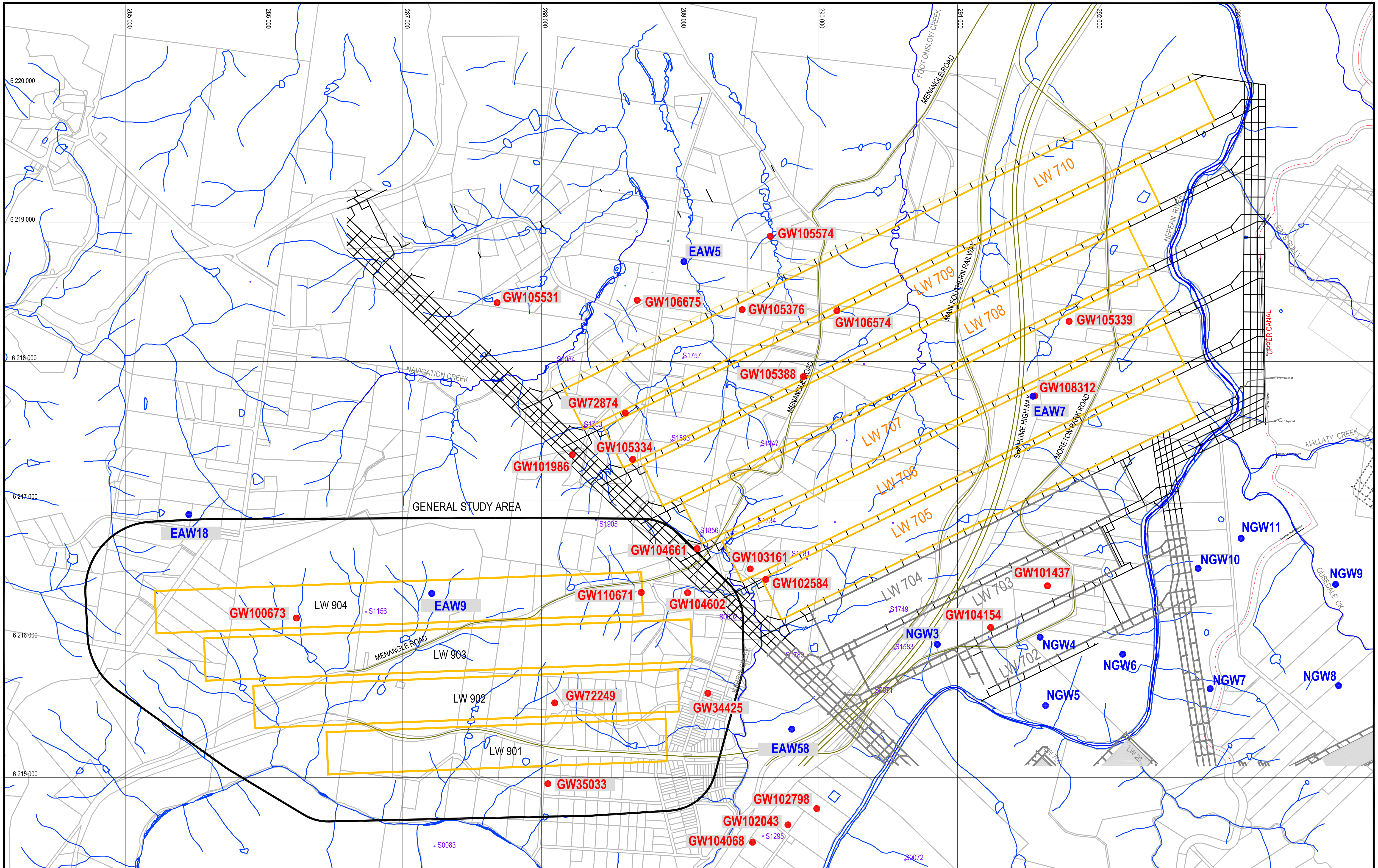


LEGEND

- GROUNDWATER BORES
- EXPLORATION BORES
- NOW REGISTERED BORE
- BHPB IC PIEZOMETER

0 0.25 0.5 0.75 1 1.25
SCALE KILOMETERS

PROJECT:	BHPB4-R1
DRAWN:	A. DAWKINS
DATE:	22 NOV 2010
SCALE:	1:25 000

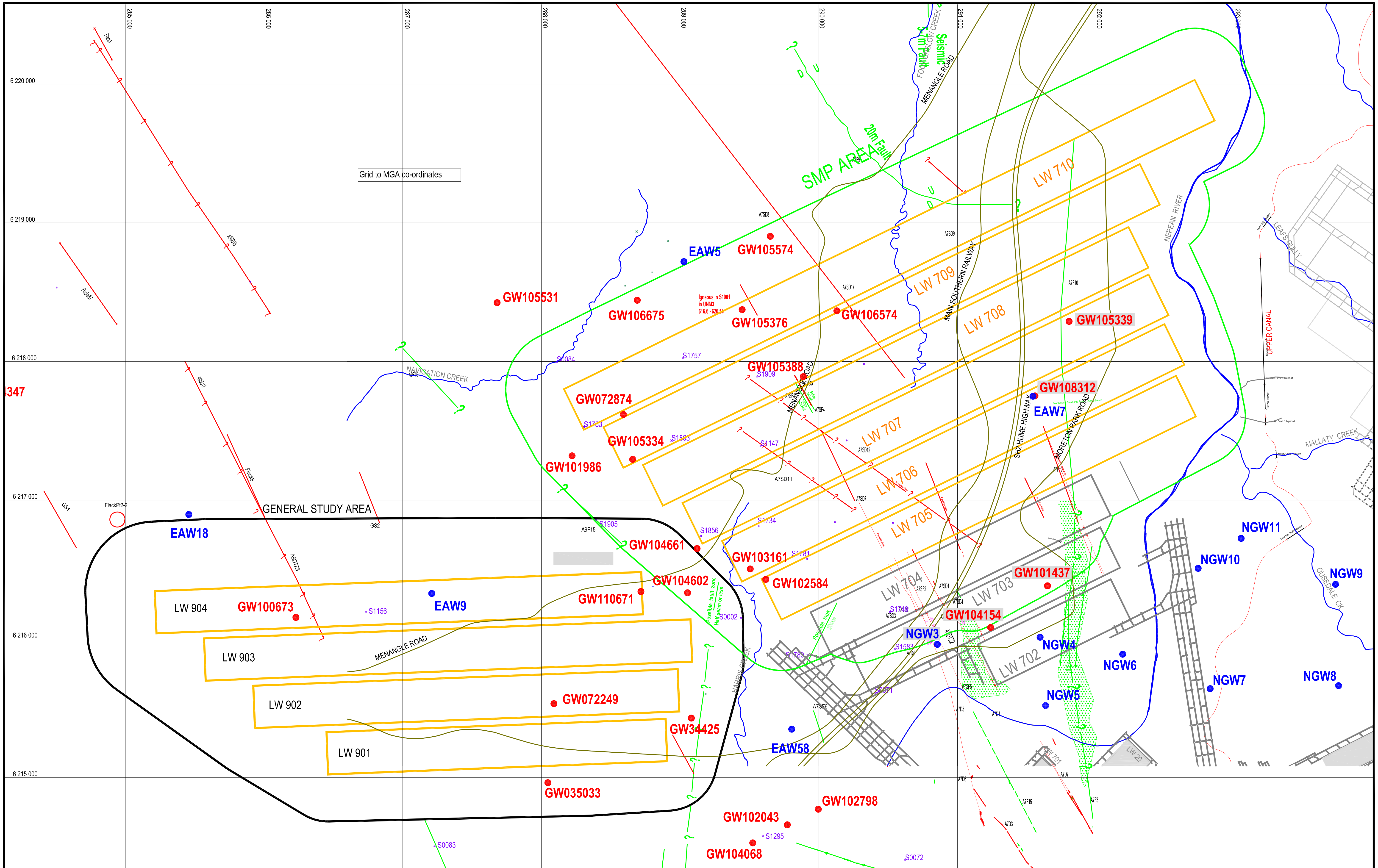
BHP BILLITON ILLAWARRA COAL P/L
LONGWALLS 901 TO 904
DOUGLAS PARK

Study Area, Piezometer and Bore Locations

GeoTerra

DRAWING 1

Drawing Base Courtesy MSEC



LEGEND

- GROUNDWATER BORES
- EXPLORATION BORES
- SURVEY CONTROL MARKS
- DWE REGISTERED BORE
- BHPB PIEZOMETER
- FAULT
- DYKE / INTRUSION

SCALE 0 0.25 0.5 0.75 1 1.25 KILOMETERS

Drawing Base Courtesy MSEC

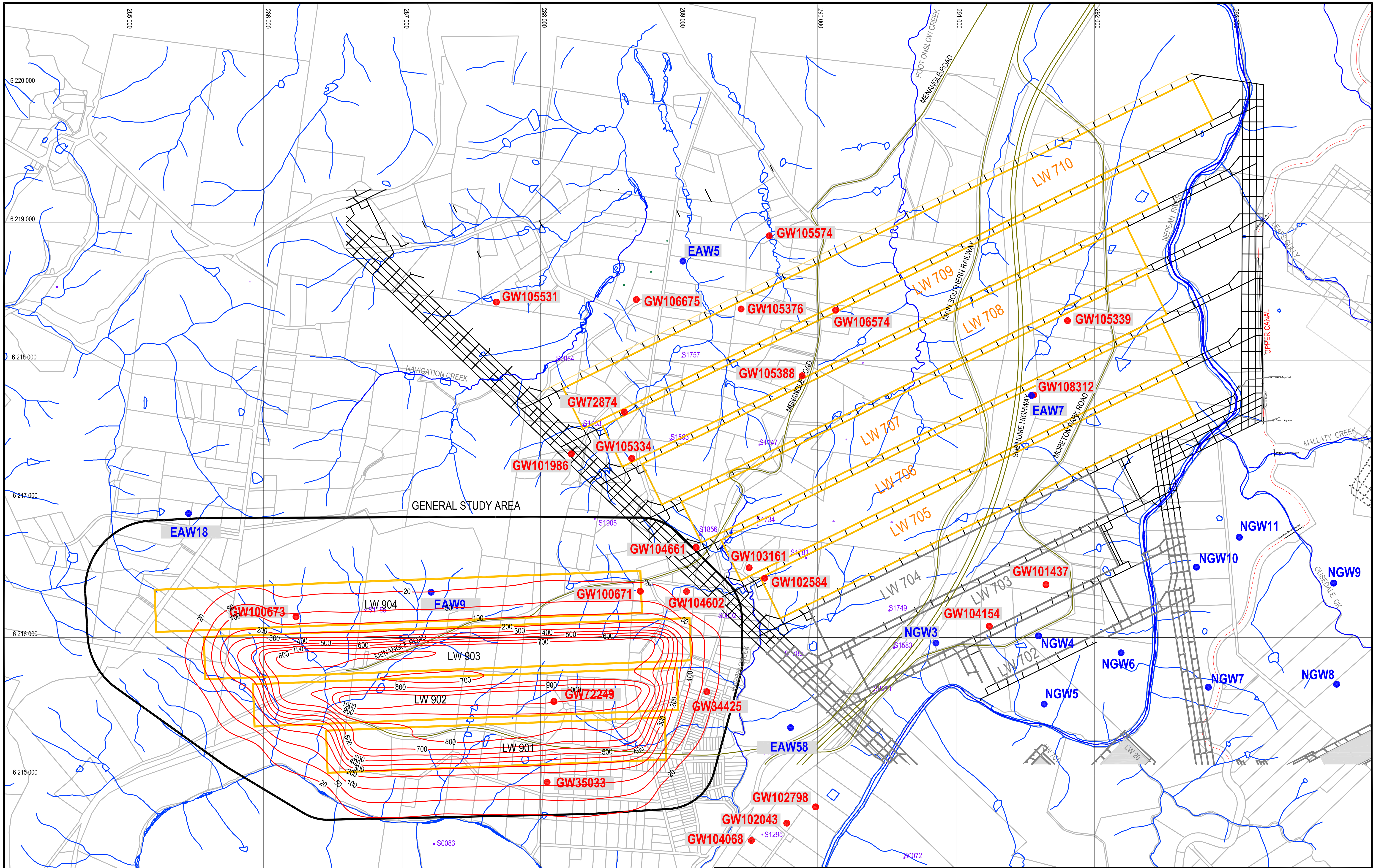
PROJECT:	BHPB4-R1
DRAWN:	A. DAWKINS
DATE:	22 NOV 2010
SCALE:	1:25 000

BHP BILLITON ILLAWARRA COAL P/L
LONGWALLS 901 TO 904
DOUGLAS PARK

Geological Structures

GeoTerra

DRAWING 2



LEGEND

GROUNDWATER BORES	DWE REGISTERED BORE
EXPLORATION BORES	BHPB PIEZOMETER

SCALE 0 0.25 0.5 0.75 1 1.25 KILOMETERS

Drawing Base Courtesy MSEC

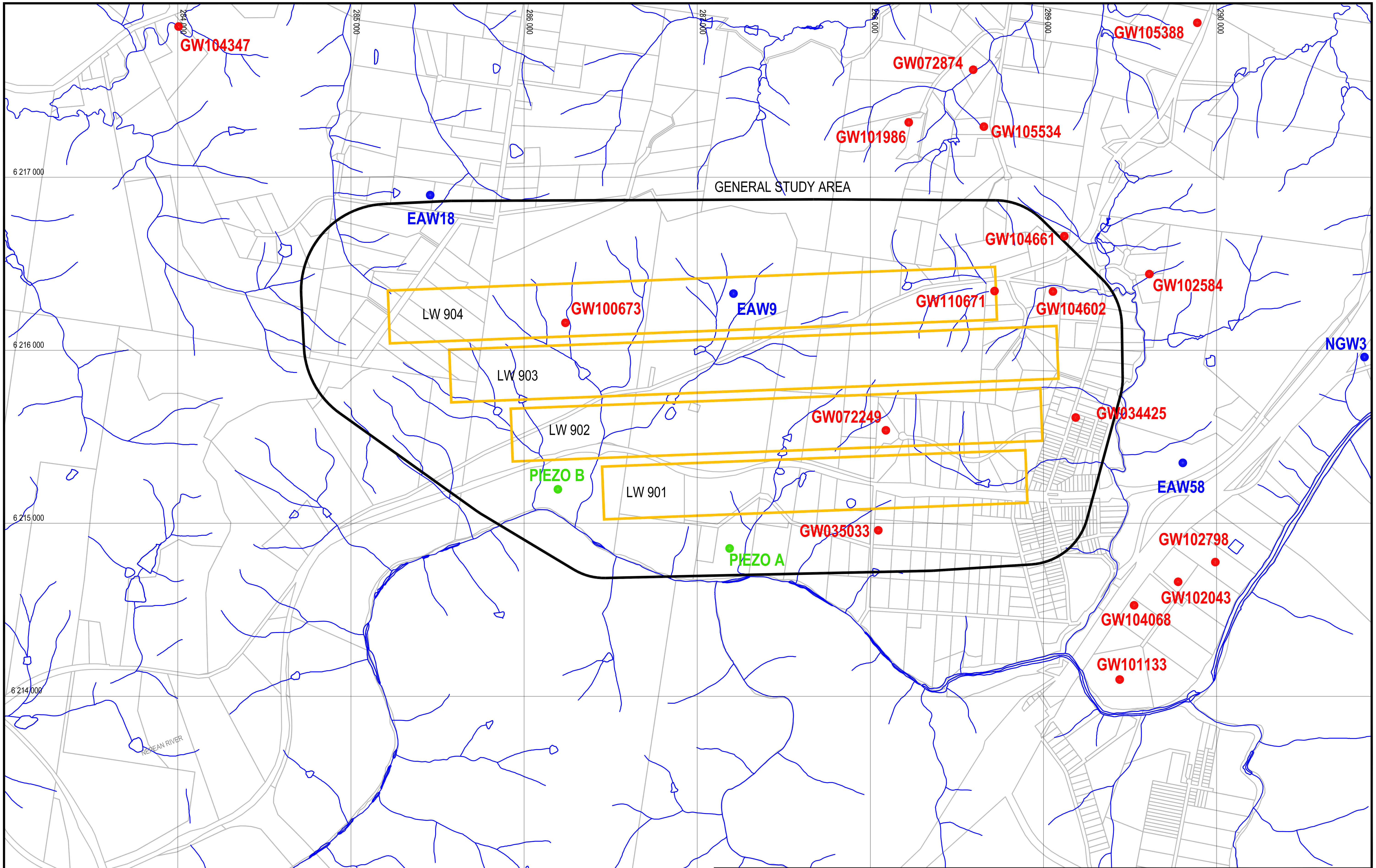
PROJECT:	BHPB4-R1
DRAWN:	A. DAWKINS
DATE:	22 NOV 2010
SCALE:	1:25 000

BHP BILLITON ILLAWARRA COAL P/L
LONGWALLS 901 TO 904
DOUGLAS PARK

Predicted Subsidence

GeoTerra

DRAWING 3



LEGEND

- NOW REGISTERED GROUNDWATER BORES
- BHPB IC PIEZOMETERS
- PROPOSED BHPB IC PIEZOMETER

PROJECT:	BHP??????
DRAWN:	A. DAWKINS
DATE:	22 NOV 2010
SCALE:	1:20 000

BHP BILLITON ILLAWARRA COAL P/L
LONGWALLS 901 TO 904

Proposed Piezometer Locations

GeoTerra

DRAWING 4

Attachment B – Assessment of Surface Water Flow and Quality Effects Appin Colliery Longwalls 901 to 904 (Ecoengineers, 2012)

ASSESSMENT OF SURFACE WATER FLOW AND QUALITY EFFECTS

APPIN COLLIERY LONGWALLS 901 TO 904

for

BHP BILLITON ILLAWARRA COAL

June 2012

ECOENGINEERS Pty Ltd
9 Sunninghill Circuit
Mount Ousley NSW
Australia 2519
Tel: 61 2 4227 4174 Fax: 61 2 4227 5154
www.ecoengineers.com
ABN 74 078 666 510

PROJECT: Area 9
TITLE: Assessment of Surface Flow and Water Quality Effects Appin Colliery Area 9 Longwalls 901-904
DOCUMENT REFERENCE NO: 2012/5

PROJECT MANAGER: S. Short	**FILE: Assessment of Water Quality Effects Proposed Appin Area 9 Longwalls 901– 904 Rev4.doc**
SPELL CHECK BY: S. Short	**SUBJECT: Appin Colliery**

Document Details		**Preparation & Self Check**	**Independent Review By:**	**Corrective Action**	**Approved By:**
Revision 4	**Name & Date**	J. Cairns 15/12/10 D. Ward 30/06/11 K. Bowles 31/05/12	S. Short 16/12/10 S. Short 13/08/11 D. Thompson 08/06/12	S. Short 12/06/12	G. Brassington 12/06/12
Reviewers Comments:					

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EXECUTIVE SUMMARY

Likely and possible surface water quality and hydrological effects associated with proposed Longwalls 901 to 904 at Appin Colliery Area 9 have been assessed in accord with the requirements of the surface water-related conditions set down in the Bulli Seam Operations Approval issued by the NSW Minister of Planning in September 2011. This assessment also re-considers matters addressed in the prior assessment conducted by Gilbert and Associates, presented as Appendix C of the Environmental Assessment prepared for the BHP Billiton Illawarra Coal Bulli Seam Operations.

Background

The proposed Longwalls 901 – 904 in Appin Area 9 are immediately adjacent and upstream of the existing Appin Area 7. BHP Billiton Illawarra Coal water quality monitoring data for the Nepean River was assessed for the Appin Area 7 baseline period from commencement of monitoring in July 2002 to the commencement of the first longwall of Appin Area 7, Longwall 701 in mid-October 2007. Since then, surface water quality has continued to be monitored weekly and laboratory analysis samples collected monthly both adjacent to Area 7 and upriver and downriver of it, including the stretch of the River adjacent to and just upriver of the proposed Appin Area 9.

End of Panel reports have previously been prepared by us, assessing the surface water quality and river flow effects of the mining of Longwalls 701, 702 and 703.The stretch of the River adjacent-to and downriver of these Area 7 longwalls (lying below Douglas Park Causeway) is one in which water levels are controlled by back flooding from Menangle Weir to the north. The Area 9 stretch of the River below the Allens Creek confluence designated by Mine Subsidence Engineering Consultants (2012) as ‘Section 2’ in which water levels are similarly controlled by back flooding induced by the Douglas Park Causeway is similar hydrologically to the entire stretch adjacent to the Area 7 longwalls.

Observations and assessments have previously been made of surface-water related effects of Bulli Seam longwall mining in the region. Area 7, with Longwalls 701 through 703 which have been mined to within similar buffer distances from the river as proposed for Longwalls 901 – 904, particularly provides useful proxy indicators of potential effects in Area 9. These observations suggest strata gas emissions in Nepean River and dilation-induced ferruginous springs at margins of Wianamatta Shale outcrop are the principal <u>potential</u> effects which might give rise to water-related environmental effects from the mining of Longwalls 901 through 904.

Gas Emissions in Nepean River

Field inspections carried out by representatives of the BHPBIC Environmental Field Team included monitoring of gas release zones and related iron stain zones arising from reduction of iron oxides in the river bed strata by methanotrophic iron-reducing bacteria. Eight gas zones and one iron stain zone were identified during the mining of Longwalls 701 and 702. Four gas zones, first identified during the mining of Longwall 701 and 702, became reactivated during the period of mining Longwall 703.

After the completion of Longwall 703, all gas releases ceased in the river (excluding Gas Zone 5 situated in Elladale Creek on the southern side of the river i.e. the opposite side to Longwalls 702 and 703). Gas Zone 5 has continued to release minor, slow, intermittent gas releases. No iron staining has been observed in the river since the completion of Longwall 703. These experiences with the two earliest Area 7 longwalls, where they mined closest to the river, are useful proxies for predicting the likely magnitude of such effects from the mining of Area 9 Longwalls 901 through 904.

Minor emissions of methane-rich strata gas into the Nepean River are therefore inferred to be a likely consequence of the mining of proposed Longwalls 901 to 904.

Dissolved oxygen 'sags' of various magnitudes have been observed in the Nepean River which were attributable to both non-mining (agricultural) and mining-related causes. Such conditions were observed during the extended pre-mining baseline period for Appin Area 7 and during the mining of Area 7 Longwalls 701, 702 and 703.

Those dissolved oxygen sags could principally be attributed to inputs of water with low dissolved oxygen and high dissolved iron concentration from Cataract River into Nepean River and/or inputs of water elevated in available nitrogen and phosphorus nutrients in storm water runoff from agricultural land on both sides of Nepean River. However, minor sagging attributable to reduction in dissolved oxygen in the river due to microbiological consumption of dissolved methane around gas releases by natural aerobic methanotrophic bacteria ('obligate aerobes') could not be ruled out.

The section of the River adjacent to proposed Longwalls 901 through 904 is relatively narrow and flooded from Douglas Park Causeway to Allens Creek, but above Allens Creek the River contains a large number of flow controlling features such as extensive emergent boulder fields, several low, generally submerged but shallow rockbars and a low weir. It is therefore expected to exhibit a re-aeration coefficient significantly higher than previously seen in the flooded section of the river adjacent to Longwalls 701 through 703.

Emissions of strata gas into the Nepean River might give rise to some temporary dissolved oxygen sagging during the mining of Longwalls 901 through 904 but such sags are likely to have negligible environmental consequences. Monitoring and analysis (including dissolved methane measurements down river and gas solubility modeling) is necessary to better quantify any subsequent dissolved oxygen reduction and its possible aquatic ecological impact.

In the extremely unlikely event that prolonged low riverine dissolved oxygen conditions directly attributed to gas emissions are observed it is recommended that BHPB Illawarra Coal prepare a contingency response plan to mitigate this effect, in consultation with relevant stakeholders.

Visible iron precipitates could also occur in the Nepean River in association with groundwater inflows or gas release sites. Geochemical modeling indicates no adverse effect on water quality is likely to occur from such 'iron staining' and it would have negligible ecological impact.

Groundwater Outflows and Ferruginous Springs

The inducement of ferruginous springs due to mining has been occasionally observed in Bulli Seam mining areas, especially along margins of outcropping Wianamatta Shale e.g. along Cataract and Georges Rivers and along Ousedale and Mallaty Creeks. However, mining of Longwalls 701 and 702 did not lead to induction of any detectable ferruginous springs either in the walls of the Nepean River gorge itself or along adjacent tributaries e.g. Harris Creek.

Modelling indicated such springs, even if they should arise, would not contain sufficient dissolved iron and manganese to cause a significant local depression of Nepean River pH or dissolved oxygen levels through oxidation and precipitation of hydrous iron and manganese oxides. This is also because the Nepean River water contains sufficient buffering bicarbonate/carbonate alkalinity and again (as with gas emissions) because there would be adequate re-aeration in the local stretch of the River.

Based on these considerations, and the recent experience with Longwalls 701 to 703, there is considered to be only a low likelihood of ferruginous springs being induced in the walls of the River gorge adjacent to Longwalls 901 through 904. Should any occur, the high inherent alkalinity and re-aeration capacity of the river would render their ecological impact to negligible.

Sub-Bed Flow Diversions and Un-Natural Pool Drainage

No field evidence for sub-bed diversion of Nepean River flows or abnormal rates of drainage of pools induced by coal mining ‘upsidence’ has previously been visually detected in Nepean River, both during the lengthy period of the mining of Tower Colliery Longwalls 15 to 20, and most recently during the mining of Longwalls 701 to 703.

River valley closure predictions due to the offset of the Area 9 Longwall 901 from the River as described by MSEC (2012) are similar to the confirmed closures produced by previous Area 7 longwalls. Longwalls 902 through 904, being even further from the River are predicted by MSEC (2012) to induce by progressively less closure increments.

We previously found a lack of statistically significant change in the log-linear slopes of the most sensitive low flow recessions computed for the difference between river flows at Maldon and Menangle Weirs between the pre-mining baseline period and the post-mining periods of Longwalls 701 and 702. If there had been any sub-bed flow diversions the slopes of the recessions would have been exhibited statistically significant variation between the pre-mining and post-mining periods.

The likelihood of any Nepean River upsidence-induced bedrock fracturing causing sub-bed flow diversions is therefore considered to be negligible.

Unfortunately, a similar exercise could not be conducted for the Longwall 703 End of Panel Report due to a lack of River flow gauging at Menangle Weir for almost the entire duration of mining of Longwall 703 from 31 December 2009 and following completion of the longwall up to at least May of 2011 due to fish ladder construction.

Geochemical modelling based on typical past magnitudes of maximum discrete zones of acid production in other rivers and streams subject to direct under mining-induced bedrock fracturing shows that total alkalinity of the River water is more than adequate to neutralize any acid produced from increases in dissolution of siderite and trace accessory sulfide minerals in the sandstone of the river bed, ensuring negligible reduction in river water pH.

Modeling also showed that precipitation of any iron and manganese released, and carbonate alkalinity-related aqueous speciation of any trace nickel or zinc released, would ensure riverine ecological effects would also be negligible.

Streams and Farm Dams.

Mining of Longwalls 702 and 703 just to the east of Harris Creek did not led to the induction of any detectable ferruginous and/or saline springs in the creek.

Furthermore, Harris Creek is ephemeral in nature with ongoing agricultural land use and it is unlikely that there would be any significant impact to creek water quality resulting from the formation of springs in the creek over and above current agriculture-related effects. Examination of existing baseline water quality data for the creek (BHPBIC site NR3) and for the upriver and downriver sites (BHPBIC sites NR2/NR2a and NR4/NR4a) showed that there is no significant input from Harris Creek to River flows below the confluence of the River and the creek – as would be expected for the sporadic nature of creek flows.

On the basis of this information we conclude there will be negligible environmental consequences on the creek or immediately downriver from the mining of Longwalls 901 through 904.

The northern parts of Area 9 are drained by the upper reaches of Racecourse Creek (including Apps Gully), Matahill Creek and the headwaters of Navigation Creek. These creeks are neither mined under, nor approached closely by, proposed Longwalls 901 through 904 and were not considered further in this assessment.

A large number of farms dams have been monitored by BHPBIC Environmental Field Team during and following the mining of Longwalls 701, 702 and 703. In most cases impacts on farms dams from the mining (beneath them) of those three longwalls were found to be undetectable to very minor. In one instance, impacts to a dam over Longwall 702 resulted in a very shallow dam becoming dry. However, in consultation with the owner there was no requirement for remedial works as the dam was not considered an important part of the proposed land use for the property.

It is therefore inferred that a similar outcome will occur with Longwalls 901 through 904 i.e. impact on farms dams will be minor to negligible and where impacts are observed, these can be repaired and/or alternate water supply provided to the landowner.

Water Quality Monitoring and TARP Recommendations

Baseline surface flow and water quality monitoring occurring in Nepean River upriver and adjacent to proposed Longwalls 901 - 904 and in lower Allens and Harris Creeks should continue up until the commencement of Longwall 901.

We have also proposed the early implementation of an additional site in the Nepean River (to be designated NR110) between the current sites NR120 and NR0 but situated downstream of Byrnes Creek at or about the location shown in **Figure 5.1** in **Section 5**. This would allow for a more quantitative understanding of any effects in the River which are unrelated to the longwall mining of Area 9, particularly with respect to any impact of discharges from Byrnes Creek immediately upriver of the General Study Area and provide a means of ensuring that the TARPs to be established for site NR0 adjacent to the upriver 'Section 1' part of Area 9 were not triggered by upriver effects unrelated to the mining of Area 9, e.g. agricultural activities.

Analogously, it is proposed that River sites SW2 and SW4 respectively upriver and downriver of the confidence with Allens Creek and the lower Allens Creek site SW3 (refer **Figure 5.1**) be used to ensure TARPs established for site NR2 adjacent-to the downriver 'Section 2' part of Area 9 site NR2 were not triggered by effects e.g. agricultural or other activities, in Allens Creek unrelated to the mining of Area 9.

It is recommended that, following commencement of Longwall 901, riverine water quality TARPs for pH, Electrical Conductivity, Dissolved Oxygen, Total Iron and

Total Manganese be implemented for the adjacent Area 9 Nepean River monitoring sites NR0 and 2 based on the following principles:

1. Within Prediction Level 1: pH, Electrical Conductivity, Dissolved Oxygen, Total Iron and Total Manganese TARPs for River sites NR0 and NR2 any surface water monitoring station should be based on greater than one and less than two standard deviations respectively below, above, below, above and above long term baseline mean levels for these effects monitoring sites.
2. Within Prediction Level 2: pH, Electrical Conductivity, Dissolved Oxygen, Total Iron and Total Manganese for River sites NR0 and NR2 should be based on a level greater than two standard deviations respectively below, above, below, above and above long term baseline mean levels for these effects monitoring sites.
3. Exceeding Prediction Level 2: pH, Electrical Conductivity, Dissolved Oxygen, Total Iron and Total Manganese for River sites NR0 and NR2 should be based on greater than two standard deviations respectively below, above, below, above and above long term baseline mean levels resulting from the mining which are sustained for more than 6 consecutive months.

A TARP at River site NR0 should only be considered to have been triggered whenever a two standard deviation change (from the long term mean) is <u>not</u> exhibited for the same parameter at the upstream site NR110.

A TARP at River site NR2 should only be considered to have been triggered when an equivalent change (from the long term mean) in excess of two standard deviations is <u>not</u> exhibited for the same water quality analyte at the upstream River sites SW3 and SW4 (above and below the Allens Creek confluence.)

The TARPs described above and the appropriate triggered Actions which are proposed to be adopted for each level are listed in **Table 5.1** in **Section 5**.

It is also proposed that the water quality TARPs as described above be applied to any detected site(s) of any significant, identified strata gas plumes greater than (say) 3000 L/min, these values to be refined if possible by further field data collection as listed below and gas solubility modelling.

1. Detected gas emission flow rates should be estimated and then re-estimated whenever a significant increase is observed.
2. Detected gas emission of greater than 3000L/min should be sampled for chemical composition.
3. Samples for dissolved methane should be collected both exactly over any gas plumes and at the regular down river monitoring sites. Analysis should be made by a method with a limit of resolution (LOR) of no more than 1 µg/L.
4. Samples for total dissolved sulfide and total phenols in surface waters should be collected both exactly over the gas plume and at the closest down river monitoring sites. Analysis should be by sensitive methods which provide the lowest possible LOR.

1. INTRODUCTION

Ecoengineers Pty Ltd ('Ecoengineers') were engaged by BHP Billiton Illawarra Coal ('BHPBIC'), to prepare an assessment of water quality effects that may arise from the proposed extraction of four longwalls numbered 901 through 904. The mining of these longwalls is required to be in accord with the conditions set down in the approval issued on 22 September 2011 by the NSW Minister of Planning under Section 75J of the Environmental Planning and Assessment ACT 1979 for the BHPBIC Bulli Seam Operations.

The regional location of the 'General Study Area' for Longwalls 901 - 904 has been defined by Mine Subsidence Engineering Consultants (MSEC, 2012) to be the area that is likely to be affected by the proposed longwalls with respect to mine subsidence effects.

The extent of the General Study Area has been calculated by combining the areas bounded by the following limits:-

- A 35 degree angle of draw line from the proposed extents of Longwalls 901 to 904;
- the predicted vertical limit of subsidence, taken as the 20 mm subsidence contour resulting from the extraction of the proposed Longwalls 901 to 904; and
- features sensitive to far-field movements.

Given that the depth of cover above the proposed longwalls varies between 485 and 725 metres, the 35 degree angle of draw line has been conservatively determined by drawing a line that is a horizontal distance, varying between 340 and 510 m around the limits of the proposed extraction areas of Longwalls 901 - 904.

Figure 1.1 below shows the general layout of the proposed longwalls, indicating the extents of the MSEC-defined General Study Area. Key features of the proposed Longwalls 901 through 904 are:

- they do not directly mine beneath the Nepean River;
- they have been offset from the river such that they are located at a minimum (closest approach) distance of 130 metres from the centreline of the river;
- depth of cover to the Bulli Seam within the General Study Area varies between 485 and 725 metres; and
- seam thickness within the proposed Area 9 longwall goaf areas varies between 2.6 and 3.15 metres.

Figure 1.2 shows the region surrounding Appin Area 9 and identifies important water courses.

Figure 1.1 General Layout of Proposed Longwalls 901 - 904.

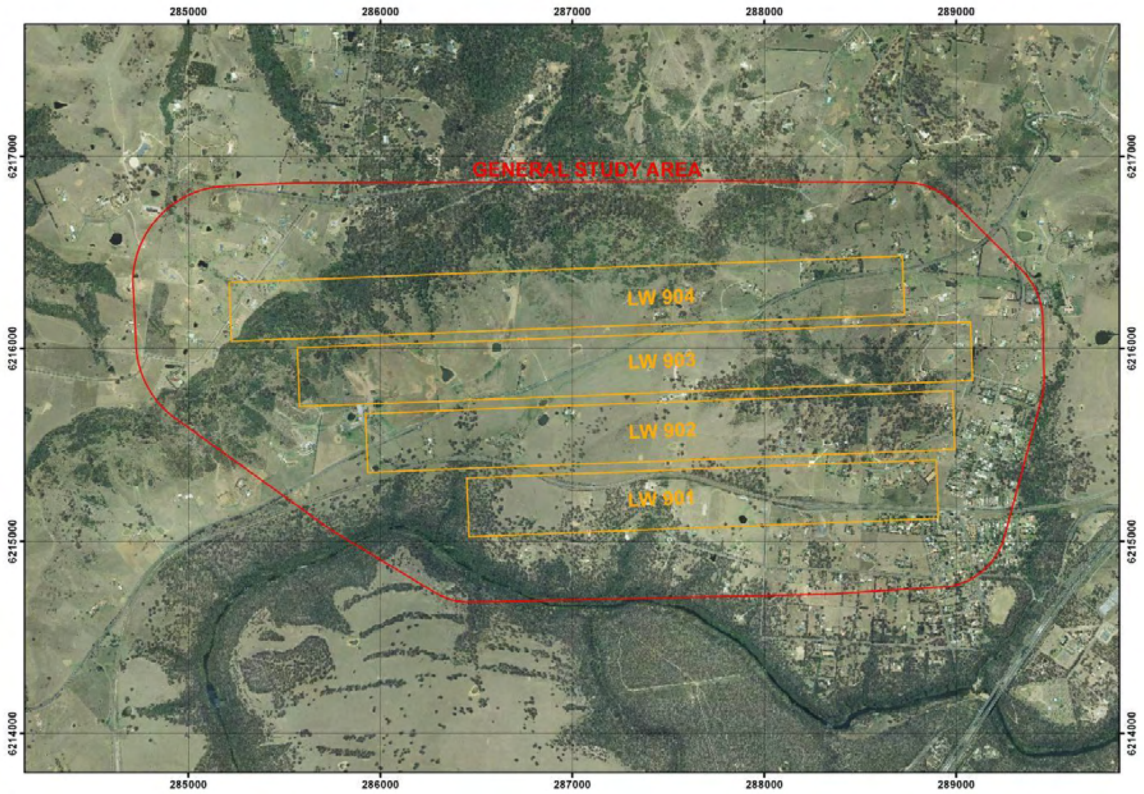
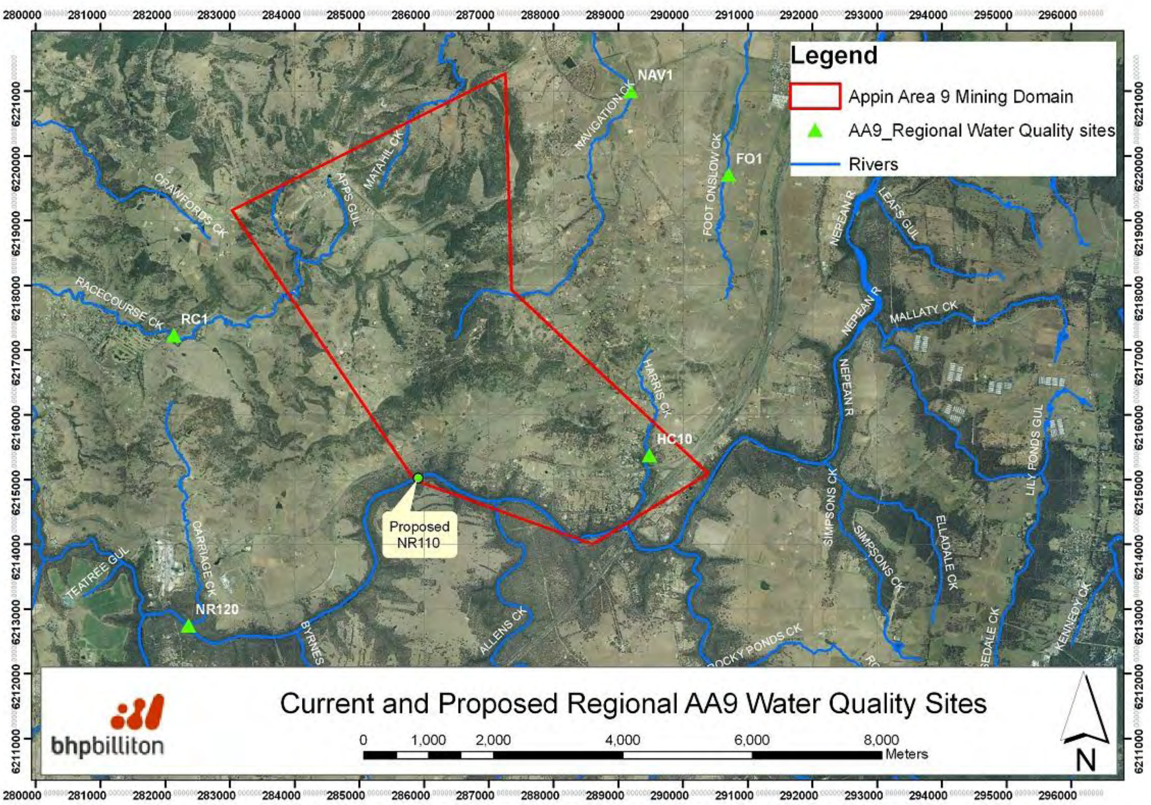


Figure 1.2 Appin Area 9 and regional water courses



The total length of the Nepean River within the General Study Area is approximately 1.3 km, passing from approximately 1 km west of Longwall 901 to approximately 350 m south of the south-west corner of the longwall.

The Nepean River is part of the Hawkesbury-Nepean River system which begins in the uplands west of Wollongong and flows northward past Camden to its junction with the Warragamba River near Wallacia, where it becomes part of the Hawkesbury. The total length of the Nepean River is approximately 145 km.

The section of the River which flows through the General Study Area has been characterised into two distinct sections by Mine Subsidence Engineering Consultants (MSEC, 2012).

Surface flows in 'Section 1', defined as the stretch of River upstream of Allens Creek, (the major permanent flow tributary of the river lying on the south side of the river) are controlled by steam features such as boulder fields and rock bars.

The stretch of the river downstream of Allens Creek designated 'Section 2' is described as a *flooded valley* with surface water levels in this section of the Nepean regulated by the Douglas Park Causeway/Weir (seen in **Figure 1.1** above lying just to the west of the Hume Highway) located approximately 900 meters south of proposed Longwall 901.

River water levels down river of the General Study Area i.e. down river of Douglas Park Causeway, are regulated by the downstream Menangle Weir located approximately 6.3 km north of the General Study Area, which acts as a dam.

River water flows upstream of the General Study Area are regulated by the Maldon Weir, which is located approximately 4.8 km south-west of the General Study Area. The length of the Nepean River between the two weirs is approximately 24 km.

BHPBIC has previously mined the following longwalls in the local area:

- former Tower Colliery Longwalls 15 to 17 along and adjacent to the Nepean River down-river and to the south-east of proposed Longwalls 901 to 904, beneath the major eastern tributary Cataract River between December 1997 and April 2000;
- former Tower Colliery Longwalls 18 to 20, to the southeast of the proposed Area 9 Longwalls, adjacent to the river and beneath the minor eastern tributary Elladale Creek between September 2000 and January 2002; and most recently
- Appin Area 7 Longwall 701 to the south east of Area 9 (on the southern side of Nepean River) and Longwall 702 (on the northern side of the river) between October 2007 and May 2009. Longwall 703 was recently mined just to the north of Longwall 702 over the period October 2009 to March 2011.

1.1 REGULATORY CONTEXT AND BASIS OF ASSESSMENTS

The Nepean River is considered a significant watercourse which has been subject to many considerations of its value as an important national water resource and aquatic ecosystem over many years e.g. Independent Expert Panel on Environmental Flows for the Hawkesbury Nepean, Shoalhaven and Woronora Catchment (2002a, b, c) and has therefore, been defined as an *area of environmental sensitivity* for the purposes of this Extraction Plan application.

There are no specific Water Quality Objectives established by the Independent Inquiry into the Hawkesbury-Nepean River System by the Healthy Rivers Commission. The Commission recommended using the trigger values in the national water quality guidelines (ANZECC&ARMCANZ, 2000).

There are no drinking water catchment areas or declared special areas within the General Study Area. The nearest drinking water catchment area is the *Upper Nepean Catchment Area*, which is also part of the Metropolitan Special Area, administered by Sydney Catchment Authority ('SCA'). The closest point of this catchment area to the proposed longwalls is at Broughtons Pass Weir, which is located over 6 km south of the proposed longwalls.

This assessment of surface-water flow and quality is based upon past experience in the investigation and assessment of water quality effects induced by mining in the Southern Coalfield in the vicinity of Nepean River and specifically from:

- hydrologic and water quality monitoring studies conducted by BHPBIC Environmental Field Team in the Nepean River from up-river of the proposed Longwall 901 to well down-river of the longwall, from 10 July 2002 to the present day;
- regional aquatic ecological studies of the Nepean River and its major tributaries, namely Elladale Creek, Ousedale Creek, Mallaty Creek and Upper Nepean Creek, conducted by The Ecology Lab since 2003 (e.g. The Ecology Lab 2004a,b,c,d,e, 2005, 2006a,b and 2007);
- geochemical studies conducted at the former Tower Colliery since 1998 by us (Ecoengineers 2005a, b, c, 2006a, b and 2007);
- groundwater hydrogeological and surface water studies conducted at the former Tower Colliery since 2006 by Geoterra Pty Ltd (e.g. Geoterra, 2006a, b); and
- water-related End of Panel reports prepared by usd for each of the Area 7 Longwalls 701 through 703 mined thus far, following their completions (Ecoengineers 2008b, 2009, 2011).

The proposed mining of Appin Area 9 is part of the Bulli Seam Operations (BSO) Project being undertaken by BHP Billiton Illawarra Coal Holdings Pty Ltd. As such, the mining operations proposed for Appin Area 9 are regulated by the *BSO Project Approval (MP 08_0150) Schedule 3 under 75J of the Environmental Planning and Assessment Act 1979*.

Likely and possible surface water quality and hydrological effects associated with proposed Longwalls 901 to 904 have been assessed herein in accord with the Minister's requirements in the BSO Approval, particularly in respect of:

- the requirement set out under Schedule 3 of the Approval to ensure that the project does not cause any exceedances of the performance measures for Nepean River above negligible environmental consequences (i.e. negligible diversion of flows, negligible change in the natural drainage behaviour of pools, minimal iron staining and minimal gas releases); and taking into account
- matters related to surface water covered by the prior assessment conducted by Gilbert and Associates in later 2009, presented as Appendix C of the

Environmental Assessment prepared for BHP Billiton Illawarra Coal's Bulli Seam Operations at Appin and West Cliff Collieries.

This report seeks to provide reasonable assessments of all relevant surface water related mining-induced phenomena and classes or rates their projected impacts using the following terms as defined in the text of the Minister's Approval:

- Adaptive management;
- Environmental consequences;
- Feasible;
- Incident;
- Material harm to the environment;
- Minor;
- Mitigation;
- Negligible;
- Rehabilitation;
- Reasonable; and
- Remediation.

Monitoring of surface water flow and water quality within the Nepean River system will be performed to ensure that impacts associated with longwall mining in Area 9 comply with the predicted impacts detailed in the *BSO Project (MP 08_0150)* and the *BSO Environmental Assessment: Appendix C* (Gilbert & Associates 2009).

Our investigation of possible mechanisms inducing water quality effects have largely been restricted to the identification, classification and quantification of effects caused within the Longwalls 901 through 904 General Study Area i.e. in Nepean River and its major tributary Harris Creek as shown in **Figure 1.1** above.

We also consider potential down-river and far field effects in Nepean River east of the General Study Area in accord with the BSO Approval in particular the extension of dissolved oxygen (DO) depletion effects which may extend down river also known as 'DO sagging'.

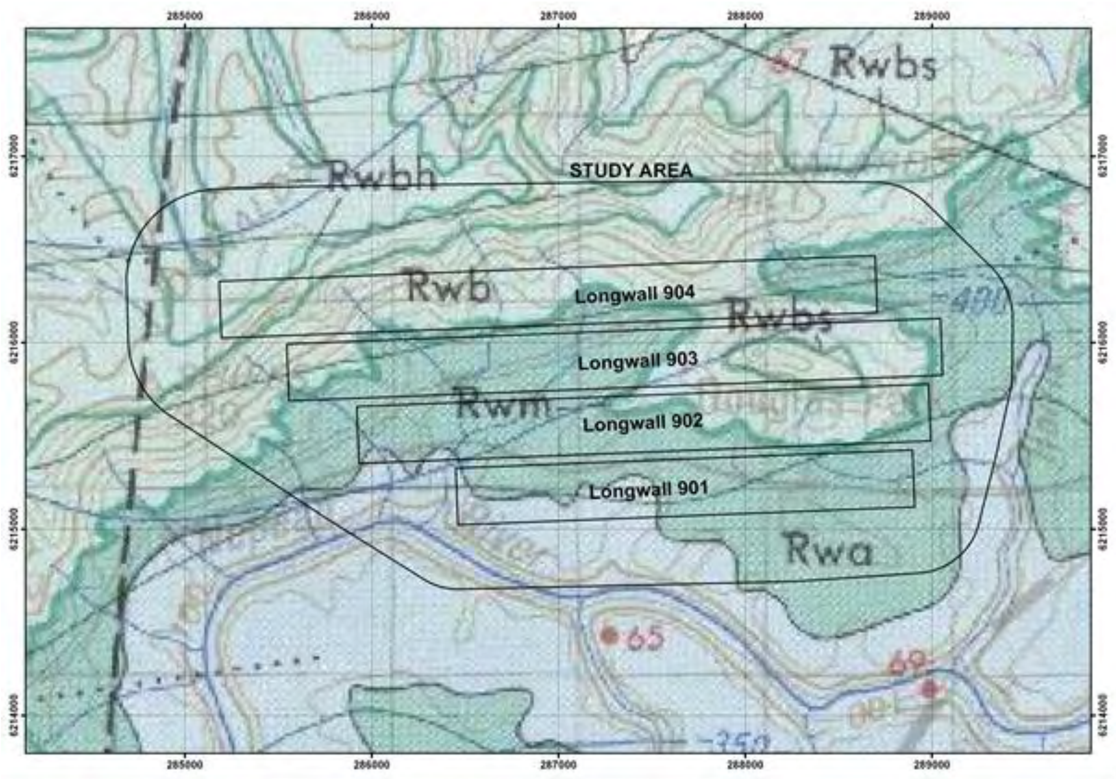
2. BACKGROUND

2.1 NEAR-SURFACE GEOLOGY, GEOMORPHOLOGY AND SOILS

Figure 2.1 below shows the mapped general extents of Hawkesbury Sandstone (Rh) and Wianamatta Shale (RWa, Rwm, Rwb, RWbs) surface outcropping in the local area.

It is noted that Wianamatta Shale outcrops almost uniformly, on the northern side of Nepean River near the margins of Nepean River gorge. The exposure of the Hawkesbury Sandstone (Rh) is limited to the Nepean River valley, Harris Creek valley and the lower sections of the tributaries in the southern part of the Study Area.

Figure 2.1 Surface Geology Within and Adjacent to the General Study Area.

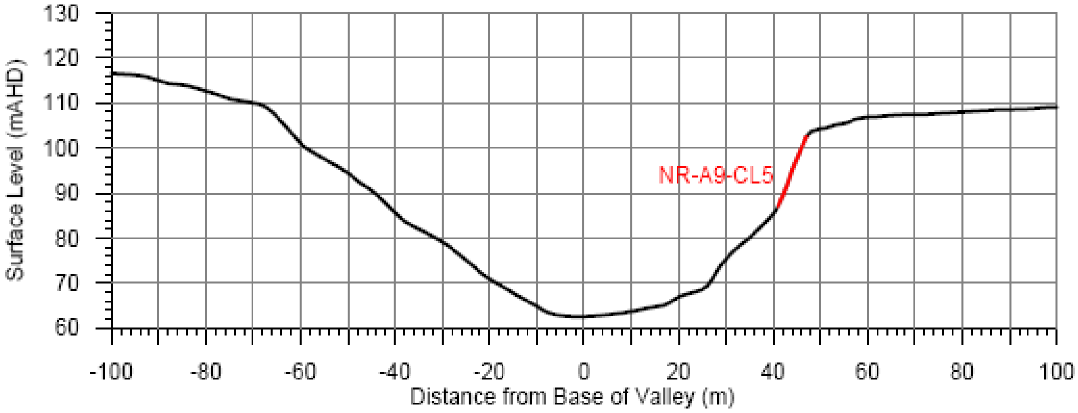


The land within the General Study Area drains freely into the Nepean River and the associated drainage lines, and no areas are considered flood prone. The banks of the River and narrow river flats and islands in the bottom of the Nepean River gorge, are however, susceptible to inundation during major flood events.

Figure 2.2 below shows a typical cross-section of Nepean River within the General Study Area.

The ephemeral creek, Harris Creek, is the closest major tributary of Nepean River on the northern side of the River. It lies at a distance of 375 metres east of Longwall 903 at its closest point along the eastern margin of the General Study Area. The natural grade of the upper creek within the General Study Area varies between a minimum of 5 mm/m and a maximum of 250 mm/m, with an average grade of approximately 25 mm/m.

Figure 2.2 Typical Cross Section of Nepean River Valley Within the General Study Area



A number of areas containing steep slopes have been identified within the General Study Area (MSEC, 2012). An example is shown in **Figure 2.2** above. Their reason for identifying steep slopes is to highlight areas in which existing ground slopes may be marginally stable and subject to erosive transport of fines into major creeks or into Nepean River.

Areas of steep slopes were identified from the 1 m surface level contours which were generated from an aerial laser scan of the area, and the locations are shown in **Figure 2.3** below.

The slopes have natural gradients varying between 1 in 3 and 1 in 1.5, with isolated areas having natural gradients of up to 1 in 1. Some cliffs along the Nepean River valley and within the General Study Area have been identified.

A steep slope has been defined as an area of land having a natural gradient between 1 in 3 and 2 in 1. The maximum slope of 2 to 1 represents the threshold adopted for defining a cliff. The minimum slope of 1 to 3 represents a slope that would generally be considered stable for slopes consisting of rocky soils or loose rock fragments. The stability of natural slopes varies depending on their soil or rock types, and in many cases, natural slopes are stable at much higher gradients than 1 to 3, for example talus slopes in Hawkesbury Sandstone.

The surface within the General Study Area generally consists of soils derived from Hawkesbury Sandstone and Wianamatta Shale, as can be inferred from **Figure 2.1** above. The majority of the slopes are stabilised, to some extent, by natural vegetation.

If the data analysis indicates the performance indicator has been exceeded, an assessment should be made against the performance measure.

If required, the data analyses may be revised in consultation with the DoP, NOW, DTRIS and OEH following revisions to the groundwater model.

11.1.2 Seepage Water Quality

The water quality performance indicator should be considered to have been exceeded if data analysis indicates a statistically significant change in the quality of groundwater in a private bore or the two proposed open standpipe piezometers after completion of mining Longwall 901, and to a lesser degree, Longwalls 902, 903 or 904. Specifically if:

- any water quality parameter exceeds the baseline mean plus two standard deviations for two consecutive months; or
- the sliding 12 month mean for any water quality parameter exceeds the baseline mean plus one standard deviation; and
- there was not a similar increase in the same measure at a control site outside of the 20mm subsidence envelope of Longwalls 901 to 904.

The data analyses may be revised in consultation with DoP, NOW, DTRIS and OEH following analysis of natural variability within the pre-mining baseline data.

The performance measure, *negligible reduction to the quality of water seepage into the Nepean River*, should be assessed to determine if the change in water quality is not negligible (i.e. small and unimportant, so as to be not worth considering).

The performance measure should be deemed to be exceeded if analysis of the monitoring results confirms the Project has resulted in a greater than negligible reduction in the quality of water resources reaching the Nepean River.

11.1.3 Potential Connective Cracking and Mine Inflows

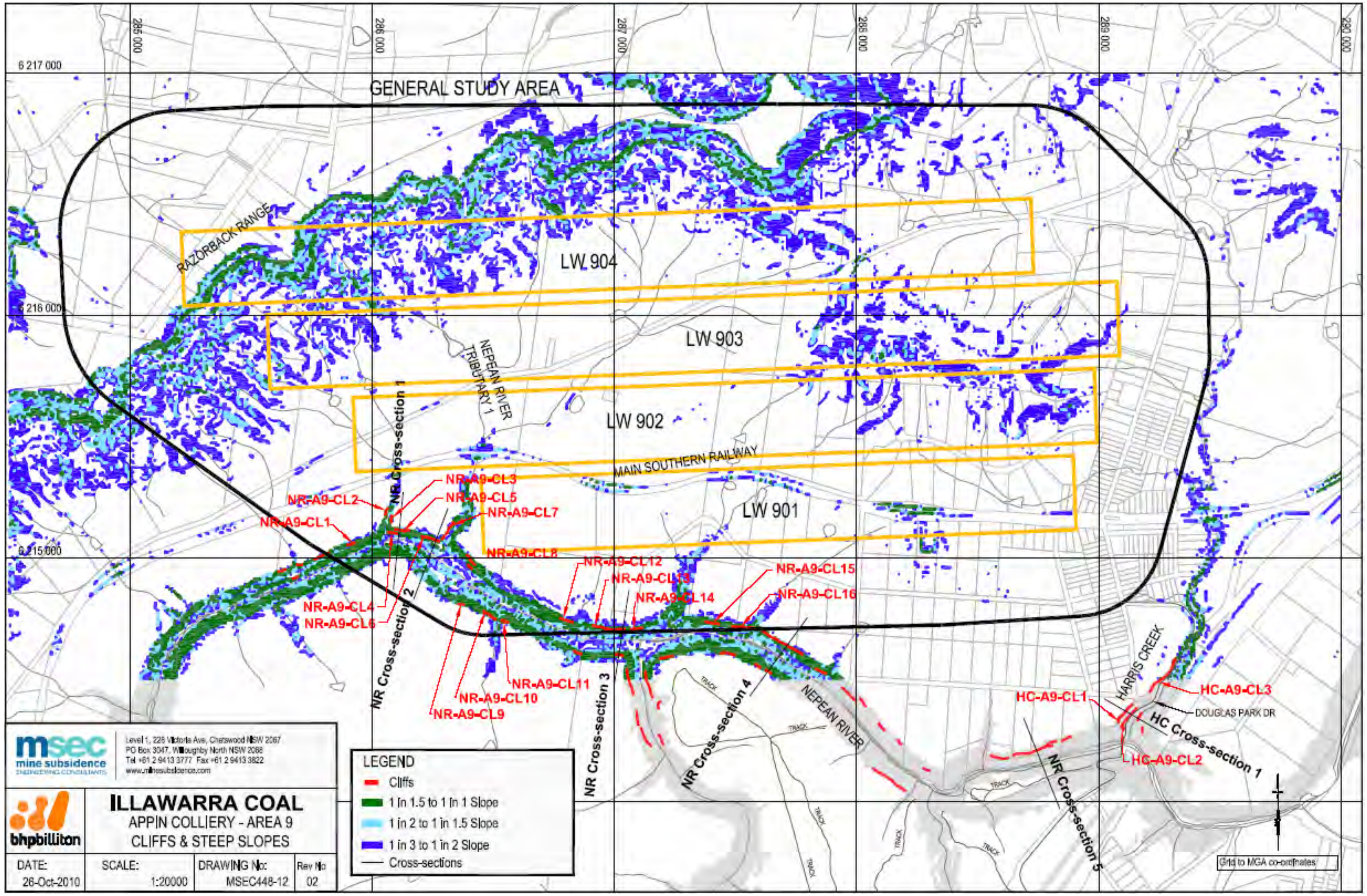
Statutory visual inspections and the mine water balance should be used to assess the potential for connective cracking between the surface and the mine. The monitoring components should include:

- statutory visual inspections for abnormal water inflow; and
- mine water balance monitoring (metered mine water reticulation, measured moisture content of mine ventilation, measured in-situ coal moisture content and measured moisture content of ROM coal).

The monitoring data should be used to assess the performance indicators and performance measures detailed in **Table 11**.

Log transformations (i.e. base 10 logs of the water quality concentrations) may be used to calculate the arithmetic means and standard deviations. Metal concentrations in water quality are measured as a positive value and therefore have a positively skewed distribution, whereas log transformations can be used to standardise the variance of a sample.

Figure 2.3 – Cliffs and Steep Slopes in the General Study Area



Landscapes within the General Study Area are known as Cumberland Plains Lowlands and Hawkesbury-Nepean River Valley.

Soils within the General Study Area have been mapped by the Soil Conservation Service of NSW and are described by Hazelton and Tille (1990) to be of five soil landscape types. Soils within the Study Area were described in the Bulli Seam Environmental Assessment (Appendix E).

No swamps or wetlands have been identified within the General Study Area. There are, however, water-related ecosystems within the General Study Area, in particular, along the Nepean River and in pool ecosystems of the larger, ephemeral drainage lines, principally in Harris Creek. These have been investigated and are comprehensively described in reports by Biosis (2010a) and Cardno Ecology Lab (2010).

No lands within the General Study Area have been declared as critical habitat under the *Threatened Species Conservation Act 1995*. There are, however, threatened and protected species within the General Study Area as described in reports by Biosis (2010a) and Cardno Ecology Lab (2010).

2.2 LOCAL HYDROLOGY

Water flows in the Nepean River are derived from a number of sources and include flows from catchment areas, licensed discharges, including Appin and Tahmoor Collieries, and runoff from agricultural and urban areas. Flows from catchment areas contribute the majority of base water flows into the river.

Some natural catchment flows are retained by large storage dams upstream of the General Study Area for the purposes of the Sydney water supply system. Water is also retained by numerous farm dams within the local part of the Nepean River catchment in particular with the General Study Area.

Water flows vary within Nepean River and are largely dependent on rainfall events within the catchment. Regular flow monitoring has not been undertaken within the General Study Area as there are no areas of restricted flow and it is very difficult to measure flow across flooded channels.

The closest river flow monitoring station upstream of the General Study Area is at Maldon Weir, which is located approximately 4.8 km south-west of the General Study Area. The closest monitoring station downstream of the General Study Area is at Menangle Weir, which is located approximately 6.3 km north of the General Study Area.

Two licensed extraction pumps which draw water from the Nepean River have been identified upstream of the Douglas Park Causeway, only one of which only one is located within the General Study Area. This single licensed extraction pump within the General Study Area would not extract significant daily volumes in terms of River flows equivalent to at least a 5 percentile flow or more in the River.

Measured daily mean water flows at Maldon Weir were provided by Sydney Catchment Authority SCA for the period between 10 June 1975 and 9 January 2011. The Maldon record had almost no gaps, and as such covers a total of 9502 days (26.0 years).

Measured daily mean water flows at Menangle Weir were provided by the SCA for the period between 3 July 1990 and 30 December 2009 at which time gauging of the weir terminated for an extended period due to construction of a fish ladder. There are some gaps in this record, which covers 6698 days (18.4 years) out of a total of now 7384 days (20.2 years).

Much of the data at both weirs has a poor quality HYDSTRA rating. Measured flow data with an acceptable quality has been ranked for these entire periods for both sets of data and the results are summarised in **Table 2.1.**

Table 2.1 Percentiles for Sydney Catchment Authority long term flow frequency records for Maldon and Menangle Weirs

Percentile	Maldon Weir flow record (ML/day)	Menangle Weir flow record (ML/day)
60	21.5	43.6
50	16.5	34.7
40	12.8	26.0
30	9.8	18.6
20	7.2	10.9
10	4.5	5.5
Total Days Flow Recorded	9502	6698

Maldon Weir has a nominal catchment of 865 km^2 which includes some 333 km^2 below Pheasants Nest Weir, the Bargo River (approx. 181 km^2), Stony Quarry Creek, Picton (approx. 120 km^2) and Allens Creek catchment (approx. 32 km^2).

Maldon Weir catchment comprises some 181 km^2 below Pheasants Nest Weir for the 50 percentile (median) flows when SCA is generally not spilling over Pheasants Nest Weir, but does not take into account outflows from the catchments of Stony Quarry Creek, Picton (approx. 120 km^2) and Allens Creek (approx. 32 km^2).

Flows at Maldon Weir underestimate flows in the Nepean River adjacent to Area 9 by at least 80% at low percentile flows, by at least 85% above about 10 percentile flows, and above 100% above the 50 percentile situation when Pheasants Nest Weir is generally spilling.

Relatively consistent discharges to the Nepean River below Maldon Weir come from Stony Quarry Creek, Picton and Allens Creek, Wilton, together with an approximate 1 ML/day from Allens Creek via the Appin Mine licensed discharge, as well as irregular flow inputs from ephemeral creeks such as Harris Creek, (Geoterra, 2006).

The most significant flows in terms of low percentile flows in the River enter from Allens Creek, which drains a large subcatchment south of the river with a total area of approximately 32 km^2.

It is not practical to measure River flows adjacent to Longwalls 901 to 904. Median flow rates in the Nepean River adjacent to the proposed Longwalls are likely to be much more than the median flow rate at Maldon Weir, which is 16.5 ML/day, and a little less than the median flow rate at Menangle Weir, which is 34.7 ML/day, by about 15%. Therefore median (50 percentile) flow rate adjacent to the General Study Area is about 30 ML/day. The water level in 'Section 2' of the Nepean River General Study Area is controlled by the Douglas Park Weir which ensures that Section 2 of the river remains fully charged at all times.

Some cessations of flow events have been recorded by SCA, which reflect periods where more water is extracted from the River than that which flows in from upstream, with maximum falls below the weir spill point of 36 mm at Maldon Weir and 295 mm at Menangle Weir. Subtraction of daily Maldon Weir flows from Menangle Weir flows occasionally gives negative values either because of flow gauging errors or the effect of licensed extractions. Such negative values became rare following local cessation of the 2000 – 2006 Millenium Drought in about mid-September 2006.

In summary, water flows in the Nepean River:

- vary greatly and are highly responsive to rain events due to the significant areas of catchment involved;
- reach very high levels during sustained storm events, while minimum flow is rarely likely to be less than 1.5 ML/day (approx. 5 percentile flow);
- cease on a small number of occasions, usually only when the rate of pumping out of the River exceeds the rate of inflow under prolonged low flow or drought conditions; and
- interpolation between the Maldon and Menangle Weir long term flow records basis suggests a median (50 percentile) flow past the proposed longwalls of approximately 25 - 30 ML/day.

2.3 NEAR-SURFACE HYDROGEOLOGY SUMMARY

It is well known that water levels in the Nepean River lie at the lowest point in the hydrological catchment and therefore has no deeper stream or groundwater system to which it can flow, except for downstream along the gorge towards Menangle Weir.

Salinities of regional Hawkesbury Sandstone ground waters presented at a University of Technology Sydney and University of New South Wales sponsored symposium on the hydrogeology of the Sydney Basin in 2007 (proceedings unpublished) suggest that deeper groundwaters in the area meander north along the Nepean River valley as shown in **Figure 2.4**.

Air-lift yields are low in the area; typically <1 L/s in the vicinity of Appin Area 9 as shown in **Figure 2.5** below, although they rise into the range 1 – 5 L/s further to the west under the Razorback Range.

Miall and Jones (2003) inferred that seeps observed through remnant iron staining on cliffs along river gorges indicated the presence of a vertical permeability barrier, such as a mudstone or claystone denoted the L-MS facies.

Liu et al*.* (1996) observed that permeability was more variable vertically than horizontally and that permeability in the Hawkesbury Sandstone is extremely variable and primarily relates to sedimentary structures, such as types of cross-bedding, along with variations in grain size and sorting.

The local hydrogeology and potential impacts of mining Longwalls 901 - 904 have been further investigated and assessed by Geoterra (2010). Potential water migration zones were assessed through interpretation of the drilling, packer testing and cliff inspection data. This data indicated generally low permeability with no discrete continuous permeable zones that can be extrapolated over the General Study Area.

FIGURE 2.4: HAWKESBURY SANDSTONE MAJOR REGIONAL GROUNDWATER SALINITY ZONATION

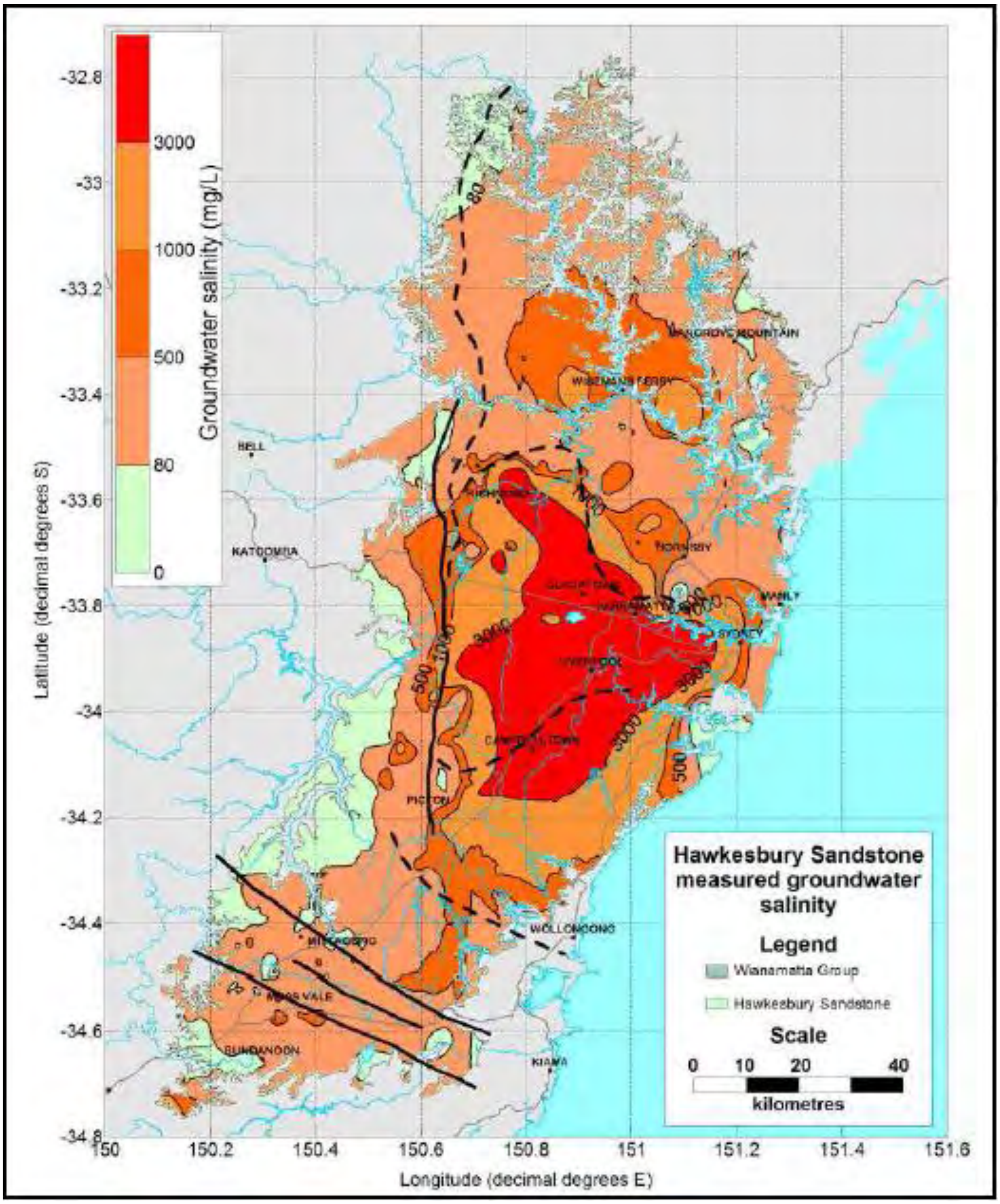
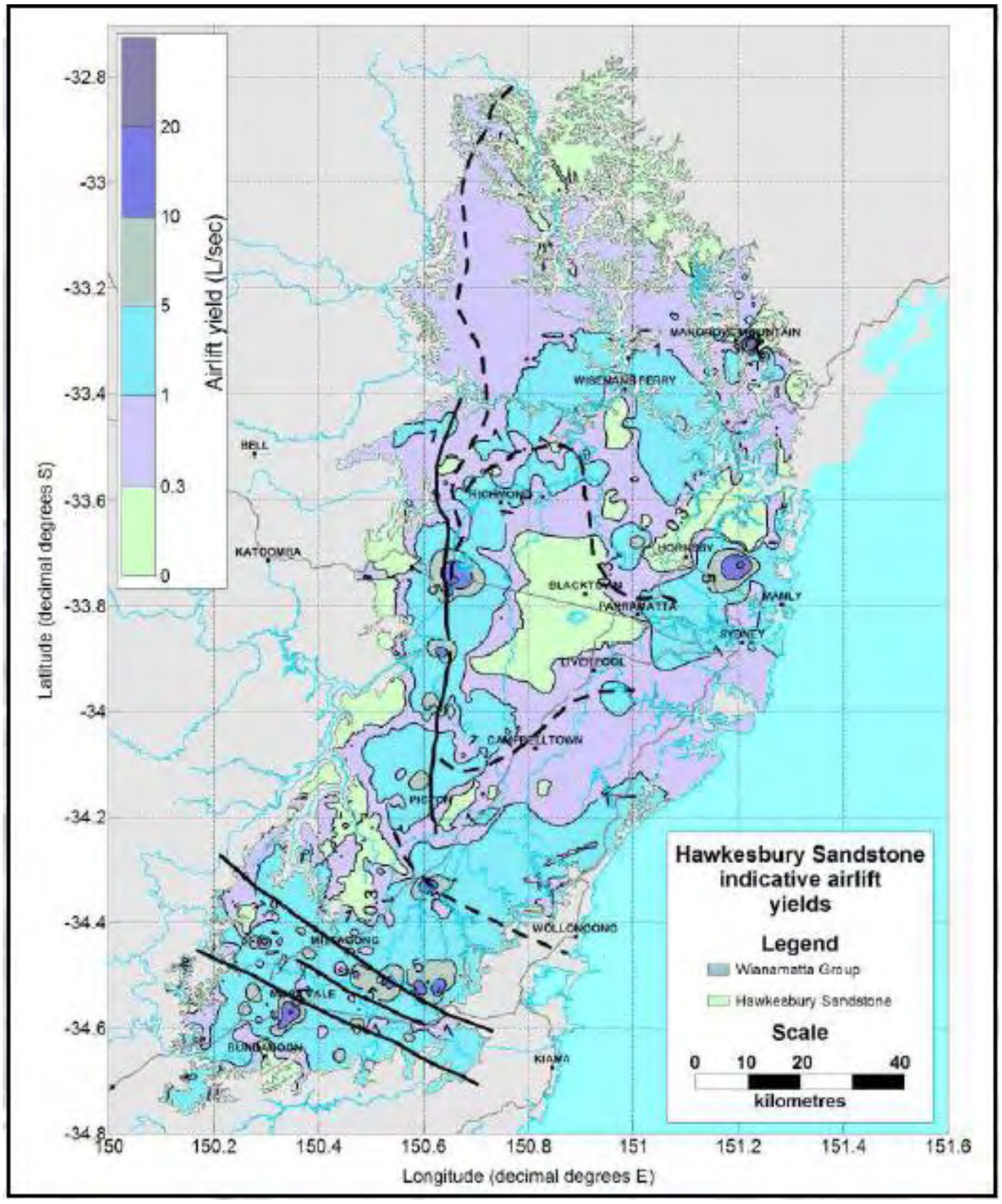


Figure 2.5 Typical Hawkesbury Sandstone Airlift Yields in the Sydney Basin and Southern Coalfield.



Water injection testing injected volumes below the pervasive claystone/mudstone L-MS facies were generally low, with migration along joint planes restricted to strata above the River and in close proximity to the cliffs where lack of horizontal confinement enables seeps to develop (Geoterra, 2010).

Bore yields in the general area obtained from the DNR database indicate the local Hawkesbury Sandstone in the General Study Area is generally low yielding, with flows of only up to 1.8L/s reported (Geoterra, 2010).

2.4 PREDICTED WATER-RELATED SUBSIDENCE IMPACTS

Predicted subsidence movements and effects resulting from the mining of Longwalls 901 - 904 on Nepean River and its tributary Harris Creek are presented in **Sections 5.2 and 5.3**, respectively, in the MSEC (2012) report.

2.4.1 Potential Changes to River Water Levels

Section 1 of the Nepean River (upstream of Allens Creek) and upriver of Longwalls 901 – 904 as defined by MSEC (2012) is a free flowing river system. Surface water flow and depth in this section of the river is controlled by flow restricting features including boulder fields, a rock bar and a small weir. It should be noted that the water level is not considered to be regulated by the submerged rock bar identified in this stretch of the river.

The water level in Section 2 of the Nepean is controlled by the Douglas Park Weir. Douglas Park Weir is located approximately 900 m south of the proposed Longwalls 901 to 904, and therefore the predicted systematic subsidence and valley related movements at the weir are negligible (MSEC 2012). It is highly unlikely that the extraction of the proposed longwalls would result in any significant impacts on Douglas Park Weir or the water level in Nepean River Section 2.

It is expected that the water level along the Nepean River within the General Study Area will remain essentially unchanged after mining, whilst it is expected that the riverbed would uplift slightly as a result of the extraction of the proposed longwalls. This is because the upsidence (110 mm max.) is expected to exceed the subsidence (30 mm max.) along the river (MSEC, 2012). Based on the conservative predictions of upsidence and relatively small amounts of predicted subsidence, the maximum uplift along the River is expected to be 110 mm.

Measurable changes in water level relative to the banks of the river were observed as a result of the past mining of Tower Longwall 17. Based on observations of water levels at Morrison's Pump and ground monitoring along the TK Line, it was estimated that the banks of the River rose by less than 50 mm following the completion of mining, though the banks had risen by up to 200 mm as the longwall progressed past the monitoring sites (MSEC, 2006). Subsidence and upsidence movements observed during the mining of Longwall 17 were substantially greater than those predicted for Longwalls 901 - 904 and those observed during the more recent mining of Longwalls 701 and 702 (MSEC, 2012).

Should upsidence exceed subsidence along sections of the Nepean River, these sections would experience a slight change in the frequency of water inundation that occurs. This may be more noticeable where the banks of the river are shallow. Field investigations of the banks of the Nepean River have been conducted by Geoterra (2010) for the purposes of ascertaining the potential extent of desiccation.

The predicted maximum 110 mm (MSEC, 2012) uplift of the banks is of a similar order of magnitude to the changes in water level associated with fluctuations in flow rates in the Nepean River in response to changes in flow from the catchment (monitoring indicates a range of 150 mm).

It has also been observed that water levels rise by at least 600 mm when flows reach a peak of approximately 730 ML/day at Maldon Weir, which is an event that occurs approximately 6% of the time. These flows are significantly greater than any predicted upsidence. Furthermore, the extent of maximum predicted upsidence (110 mm) is small in relation to the overall fall of the River over Section 1 (1 m) and

Section 2 (4 m) (MSEC, 2012). Flow changes due to upsidence are therefore expected to be insignificant.

2.4.2 Potential for Surface Fracturing in Nepean River

Longwall mining can result in the development of surface fractures in stream beds. Surface fractures have been observed in almost all incised and rock bedded streams that have been directly mined beneath.

In this case, the proposed Longwalls 901 to 904 do not mine directly beneath the Nepean River. As previously noted, the proposed longwalls are set back at least 130 m from the centreline of the Nepean River (MSEC, 2012). Observations indicate that under such circumstances only isolated and minor fracturing may occur in the bed of the River as a result of the extraction of the proposed longwalls (MSEC 2012).

The furthest distance of an observed fracture from a goaf edge is approximately 415 m from Longwall 401 at the base of Broughtons Pass Weir (Cataract River). Any fracturing that does occur at this distance is expected to be minor in nature. Fractures may be visible within the base of the river valley in exposed areas such as river banks and alluvial flats, or be inferred from the emission of gas bubbles in the river.

The likelihood of fracturing is very low for bedrock that is located beyond the predicted limit of subsidence, although some minor fracturing may occur up to approximately 400 m from the proposed longwalls. Mining-induced fracturing at these remote distances is unlikely to result in surface flow diversions or reduction in water quality, as discussed in the following sections.

2.4.3 Potential for Loss or Diversion of River Water

There has been no reported or observed loss of surface water as a result of previous mining directly beneath or near the Nepean River by Tower Longwalls 15 to 20. This included observations at a monitoring site that was located directly above Tower Longwall 17, which directly mined beneath the river for a length of approximately 800 m.

There has also been no reported or observed loss of surface water from the river more recently as a result of mining Appin Longwalls 701, 702 and 703.

MSEC (2012) assessed the potential for surface water flow diversion to occur as a result of the extraction of the proposed Longwalls 901 – 904 to be negligible.

The potential for infiltration of water into the groundwater system is also very low as the Nepean River represents the regional low point in the water table. The potential for loss of surface water into the mine is also negligible due to the depth of cover, offset of the longwalls in relation to the river, and presence of the Bald Hill Claystone which acts as an aquiclude between the River and the mine.

Further detailed discussions on the potential for this form of flow diversion are provided in the report by Geoterra (2010).

2.4.4 Potential for Shallow Ground Water Inflows to River

Although the proposed longwalls do not mine directly beneath the Nepean River or Harris Creek, it is conceivable that mining-induced springs may develop following the extraction of the proposed longwalls.

However, the mining of Longwalls 702 and 703 which approached Harris Creek from the east to a comparable extent to the proposed approach of Area 9 longwalls to the creek from the west did not lead to induction of any ferruginous springs in Harris Creek.

Furthermore, no pre-existing natural springs have been unambiguously detected along the Nepean River within the General Study Area, although it is possible that some discrete seepage already occurs into the River. This is discussed in further detail by Geoterra (2010).

Maximum predicted systematic tilts, which can cause dilation, within the General Study Area, resulting from the extraction of the proposed longwalls, are 1 mm/m in tributaries, 3.5 mm/m in the Nepean River, and 6.5 mm/m in the Razorback Range (MSEC, 2012).

Vertical dilation between Wianamatta Shale and Hawkesbury Sandstone is therefore possible, especially along Harris Creek. This could occur particularly if the thickness of the shale is less than 10 m, as field studies suggest that vertical dilation in creeks and rivers extend, as a maximum, to these depths (Mills and Huuskes, 2004). Where these tributaries flow into the Nepean River, however, the vertical dilation is expected to be small as they are invariably located at the ends of the proposed longwalls.

It has previously been observed that perched water storage occurs in the base of the Wianamatta Shale (Hazelton and Tille, 1990). The chemical characteristics of local springs suggest that the water passes through, and accumulates immediately beneath upland Wianamatta Shale to then permeate through natural or mining-induced fractures in the Hawkesbury Sandstone before emerging in draining streams or the river.

Chemical characteristics and geochemical modeling of previous mining-induced springs confirms that the source water has passed through upland Wianamatta Shale and/or been in contact with shale for extended periods. This water then permeates down through natural or mining-induced fractures in the Hawkesbury Sandstone before emerging in the valley wall.

We have comprehensively discussed the mine subsidence-related mechanisms driving the induction and maintenance of such ferruginous springs in a large number of previous reports (Ecoengineers Pty Ltd., 2005b, 2005c, 2006a, 2006b and 2007).

Vertical dilation between Wianamatta Shale and Hawkesbury Sandstone is possible along the tributaries to the Nepean River, particularly if the thickness of the shale is less than 10 to 15 m.

Saline, ferruginous springs induced by longwall mining has been observed in the Southern Coalfield in sub-catchments of the Cataract and Georges Rivers, most notably:

1. the very large, and long-lived (ongoing) ‘SW2 Spring’ in Cataract River just west of Back Gully Creek induced by Appin Longwall 21 B in 1996; and
2. the moderately large and moderately long-lived ‘Pool 11 Spring’ in Upper Georges River induced by West Cliff Longwall 5A2.

Other springs have either been induced or, if pre-existing, been increased in flow rate following longwall mining in the catchments of Ousedale and Mallaty Creeks, tributaries of Nepean River.

Induction or exacerbation of such springs is believed to result from strata dilation and bed separation leading to increased storage of perched groundwater, especially at and near to the interface between Wianamatta Shale and underlying Hawkesbury Sandstone. The experience in the Southern Coalfield is that such springs do not occur in terrain where Wianamatta Shale and shale-derived soils do not outcrop.

The interface between the Hawkesbury Sandstone and the Wianamatta Shale sequences appears likely to undergo a mine subsidence-induced permeability enhancement along the sub-horizontal interface between these units due to dilation and bed separation induced by subsidence.

The shale, being marine sediment, continues to contain traces of connate water with an elevated (seawater composition) salt load and a significant load of major cations on cation exchange sites in ratios that are still relatively similar to that of seawater. These are displaced by protons in weakly acidic infiltrating meteoric water, so increases in salinity are predicted to occur from the subcrop of the basal interface between the shale and the underlying Hawkesbury Sandstone.

The shale also contains a high concentration of finely disseminated crystalline iron (Fe) and manganese (Mn) oxides (after siderite and rhodocrosite). An elevated dissolved Fe and Mn load, largely due to microbiologically-mediated reductive dissolution of Fe and Mn oxides and oxyhydroxides within the base of the weathered shale during saturation (Lovley and Phillips, 1986), is expected from waters that become stored in the catchment of any spring.

It is also possible that strata out-gassing (a known effect of mine subsidence) from the Hawkesbury and/or Bulgo Sandstone may lead to accumulations of dissolved methane in perched water at this dilated Hawkesbury Sandstone/Wianamatta Shale interface. This effect, if it does occur, is also likely to provide a food source for, and increase the activity of iron dissimilatory bacteria driven reduction and dissolution of Fe and Mn oxyhydroxides and siderite/ankerite etc., from the base of the shale and upper, weathered intervals of the Hawkesbury Sandstone or Mittagong Formation (Lovley and Phillips, 1986).

Enhancement of vertical percolation of this more saline, iron-rich water into the upper Hawkesbury Sandstone strata (or at least a surficial Mittagong Formation) due to subsidence-induced dilation and valley closure effects is also conceivable. This appears to be what has also happened with the SW2 spring in Cataract Gorge.

Harris Creek, while not directly mined beneath by the proposed Area 9 longwalls could be subject to some dilation (MSEC, 2012) and hence also be subject to this ‘springs effect’ particularly in the slopes above the creek bed where shale outcropping finishes and Hawkesbury Sandstone outcrop remains (Ecoengineers, 2005a, b, 2006a, b, and 2007b).

2.4.5 Potential for Gas Emissions in the river

Mining can result in fracturing of the strata above the extracted area and/or relative movement of strata along pre-existing joint planes. This may result in the liberation of methane and other gases from the strata to the surface. Gas emissions have typically occurred within deep river valleys, although some gas emissions have also been observed in creeks and water bores.

Substantial studies have been undertaken into the properties of gas within rock strata. Gas is found in most rocks, and can exist in three different states – free gas, dissolved gas in water and absorbed gas. Analyses of gas compositions indicate that the near-surface strata are the direct and major source of the gas rather than the extracted coal resource. The most likely source of strata gas is the Hawkesbury Sandstone (APCRC, 1997). As rocks in the near-surface strata experience compression in response to valley closure movements, free or absorbed gas can be released, typically exiting the stream bed through existing or new fractures and joints (Geoterra, 2008).

Gas emissions typically occur in isolated locations and are most vigorous when an area is directly mined beneath. However, gas emissions do occur in areas that have not been directly mined beneath.

Gas emissions have previously been observed in the Nepean River during the mining of Tower Longwalls 17, 20 and most recently Appin Longwalls 701 - 703. In the case of the Nepean River, the bedrock is submerged and covered by alluvial deposits. It is therefore not always possible to visually identify the exact location of the gas release and the extent of any fractures associated with the gas release.

Baseline monitoring undertaken by BHPBIC has shown that low dissolved oxygen (DO) conditions often apply in the Nepean River upstream of the Menangle Weir particularly during low flow conditions (less than 50 percentile or around 34.7 ML/day).

Careful inspection of all data accumulated by BHPBIC since 2003, both before and during the mining of Longwalls 701 and 702 shows that DO concentrations regionally within the Nepean River can be influenced by numerous factors and can be caused by a number of factors including;

- oxidation of inputs of high levels of dissolved iron – particularly from Cataract River;
- periodic algal blooms during periods of low flow in spring and summer;
- excessive growth of aerobic bacteria – particularly as a result of input of agricultural runoff; and
- consumption of hydrocarbons (i.e. methane) in gas seeps by aerobic bacteria.

BHPBIC water quality monitoring of the Nepean River for Appin Area 7 commenced in July 2002. Since then, surface water quality has continued to be monitored weekly and laboratory analysis samples collected monthly.

Field inspections carried out by representatives of the BHPBIC Environmental Field Team included monitoring of iron stain zones and gas release zones. Eight gas zones and one iron stain zone were identified during the mining of Longwalls 701 and 702 and four new gas zones were identified in the period of mining Longwall 703. Four gas zones, first identified during the mining of Longwall 701 and 702, were reactivated during the period of mining Longwall 703.

Following completion of Longwall 703, gas releases ceased in all these gas zones, except for Gas Zone 5 situated in Elladale Creek on the southern side of the river (i.e. the opposite side to Longwall 703). Gas Zone 5 has continued to release minor, slow, intermittent gas releases.

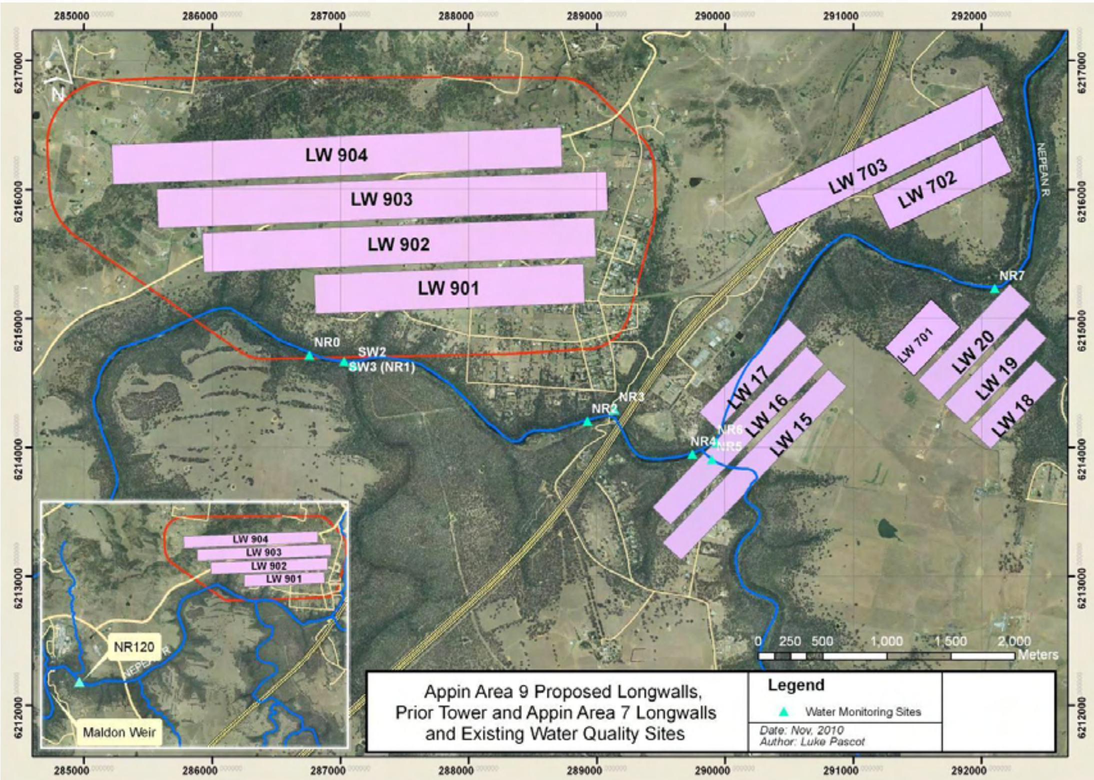
No clear correlation between the observation of gas bubbling in the river and reductions in DO in the river due to microbiological consumption of dissolved methane by natural aerobic bacteria (i.e. ‘obligate aerobes’) within the water column could be detected during the period of mining of Longwall 702. No iron staining has been observed in the river following the completion of Longwall 703.

2.5 BASELINE WATER QUALITY AND LOCAL WATER QUALITY ISSUES

We have assessed BHPBIC surface water monitoring data (refer **Figure 1.2** above for their sampling sites) for an Area 9 baseline period from October 2008 to September 2012. This and future data will form a more comprehensive baseline data set prior to the future commencement of Longwall 901.

Figure 2.6 below shows the locations of the previously mined Appin Longwalls 701 and 702, Tower Longwalls 15 – 20, the currently mined Longwall 703 and the locations of the proposed Longwalls 901 to 904. Water quality monitoring sites relevant to this study report are also shown.

Figure 2.6 Disposition of proposed Area 9 and previous longwalls and locations of existing water quality monitoring sites.



Average (mean) water qualities to date, i.e. over the entire baseline monitoring period at the existing water quality monitoring sites shown in **Figure 2.6** above are summarized in **Table 2.6** below together with the standard deviations on those means. Note 'St. Dev.' denotes the magnitude of the one standard deviation variation on these means.

Figures 2.7 to 2.16 below show the average magnitudes of major water quality parameters within the river and at the lower ends of the major tributaries for the river from the upriver site NR120. **Figures 2.7 to 2.11** show, respectively, the average pHs, salinity (EC), DO, Total Iron (Fe), and Total Manganese (Mn) in the river and in the lower ends of major tributaries for a baseline period from October 2008 to September 2010. **Figures 2.12 to 2.16** show, respectively the same parameters in the river and in the lower ends of major tributaries for a typical low flow situation during the baseline period. The chosen low flow situation was the period 12 – 20 January 2009 when flow in the river averaged 16.6 ML/day at Menangle Weir – about a 27 percentile flow. Error bars are set at ± one standard deviation level from the mean for each individual site.

Note in **Table 2.6 and Figures 2.7 to 2.16** below the following (labelled) sites are not located along the River but within the lower part of tributaries of the river as follows:

- SW2 is within the lower reaches of Allens Creek, just upstream of the confluence and the Nepean River; and
- NR3 is within the lower reaches of Harris Creek.

Table 2.7 Baseline Water Quality Data Nepean River and Lower Tributaries October 2008 – February 2012

Site	EC (µS/cm)	St. Dev.	pH	St. Dev.	DO (%)	St. Dev.	Total Fe (mg/L)	St. Dev.	Total Mn (mg/L)	St. Dev.	Ni Filt (mg/L)	St. Dev.	Zn Filt (mg/L)	St. Dev.
NR120	333.7	175.1	7.94	0.56	81.3	17.6	0.20	0.11	0.031	0.017	0.004	0.002	0.011	0.010
NR0	295.4	109.7	7.61	0.38	92.4	15.0	0.23	0.20	0.0115	0.0064	0.0044	0.0021	0.0144	0.0145
SW3 (NR1)	296.6	109.7	7.75	0.36	88.3	16.9	0.19	0.15	0.0317	0.0318	0.0049	0.0021	0.0099	0.0111
SW2(1)	1734.6	1054.5	8.56	0.34	97.5	14.3	0.82	0.81	0.0496	0.0353	0.0710	0.0483	0.0101	0.0111
NR2	319.5	136.2	7.93	0.44	91.5	18.8	0.36	0.41	0.0368	0.0343	0.0055	0.0032	0.0100	0.0131
NR3	1359.9	647.6	7.77	0.38	92.3	31.9	0.79	0.48	0.1681	0.2750	0.0010	0.0005	0.0124	0.0152
NR4	334.8	140.5	7.64	0.49	88.6	15.9	0.29	0.20	0.0362	0.0307	0.0058	0.0029	0.0124	0.0140
NR5	170.0	87.9	7.34	0.40	65.7	33.5	0.71	0.57	0.0864	0.1193	0.0005	0.0000	0.0090	0.0122
NR6	284.8	152.4	7.47	0.76	86.9	18.4	0.40	0.40	0.0524	0.0690	0.0038	0.0031	0.0086	0.0096
NR7	286.4	153.2	7.57	0.44	84.7	17.5	0.30	0.13	0.0324	0.0239	0.0038	0.0029	0.0099	0.0104

(1) Note within Lower Allens Creek.

In the subsequent figures, the respective concentration parameter values for the sites SW2, NR3, and NR5 in the lower parts of the above tributaries are shown not plotted on the river transect trend line so that the magnitude of that parameter near the lower end of the tributary in relation to its magnitude upriver and downriver of each respective confluence is clearly indicated. The geographic position of the lower tributary site is simply projected to the nearby confluence.

Figure 2.7 Average pH versus Distance Down River of NR120 for October 2008 – February 2012

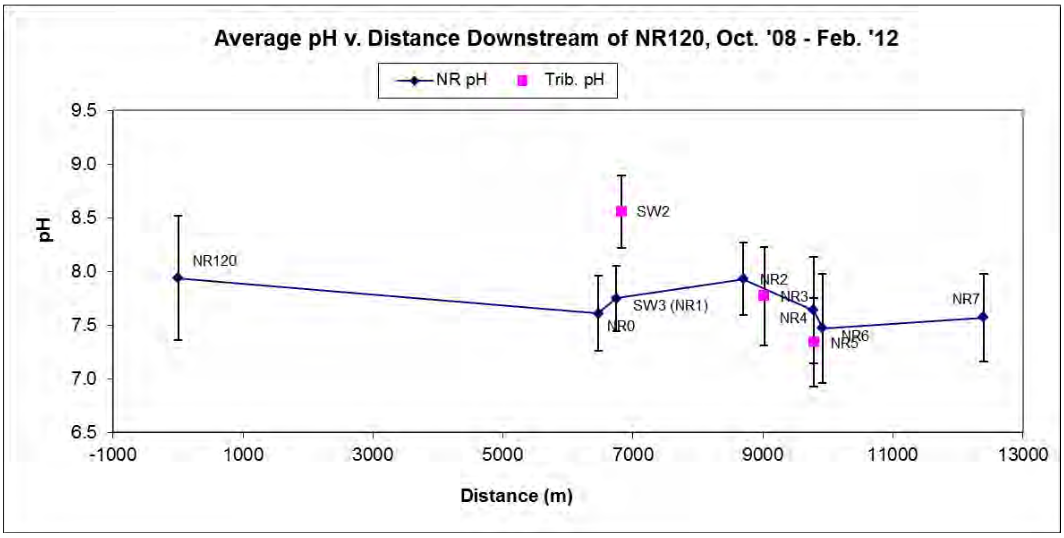


Figure 2.8 Average Salinity (EC) versus Distance Down River of NR120 for October 2008 – February 2012

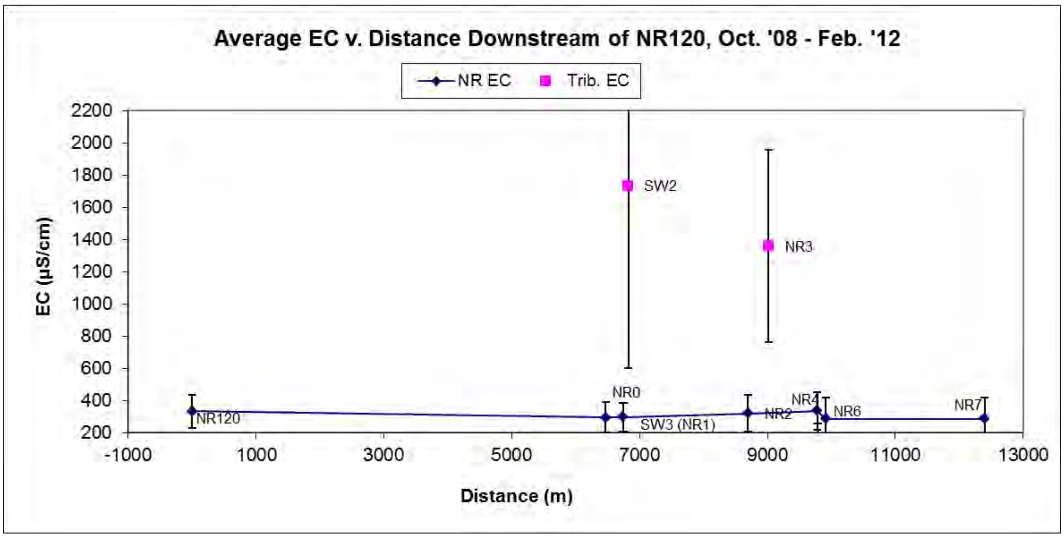


Figure 2.9 Average Dissolved Oxygen (DO) versus Distance Down River of NR120 for October 2008 – February 2012

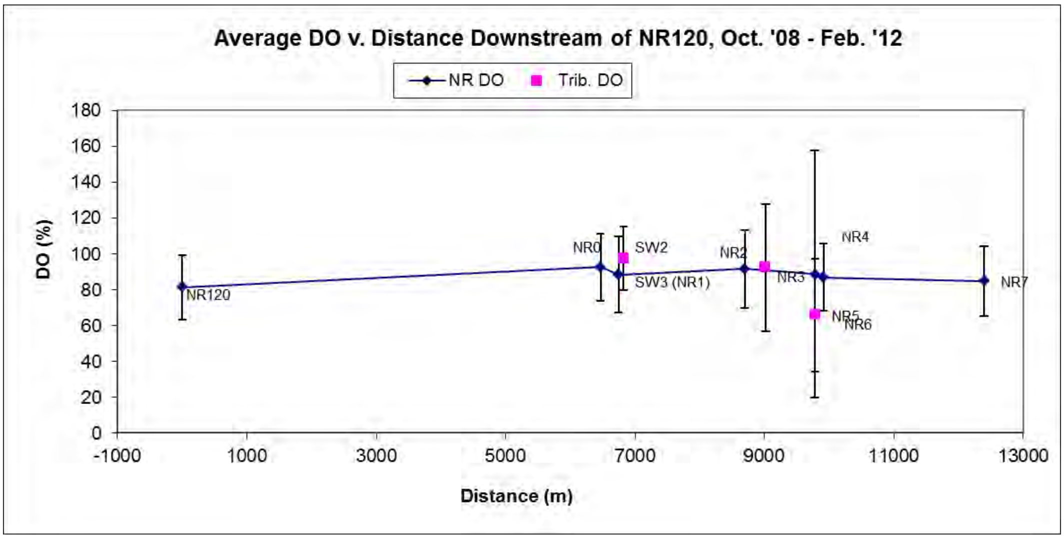


Figure 2.10 Average Total Iron (Tot. Fe) versus Distance Down River of NR120 for October 2008 – February 2012

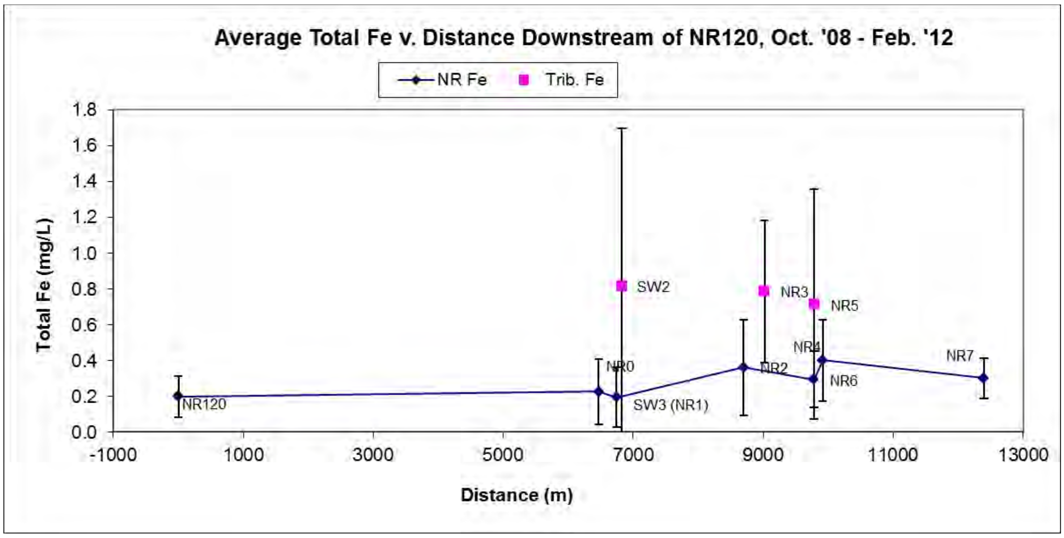


Figure 2.11 Average Total Manganese (Tot. Mn) versus Distance Down River of NR120 for October 2008 – February 2012

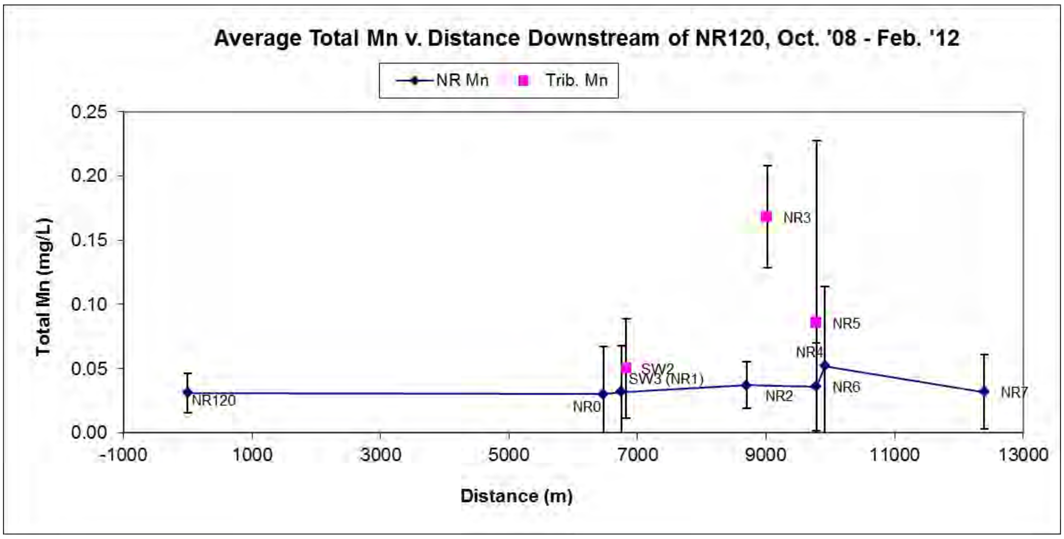


Figure 2.12 pH versus Distance Down River of NR120 for a Typical Low Flow Situation during the Baseline Period October 2008 – February 2012

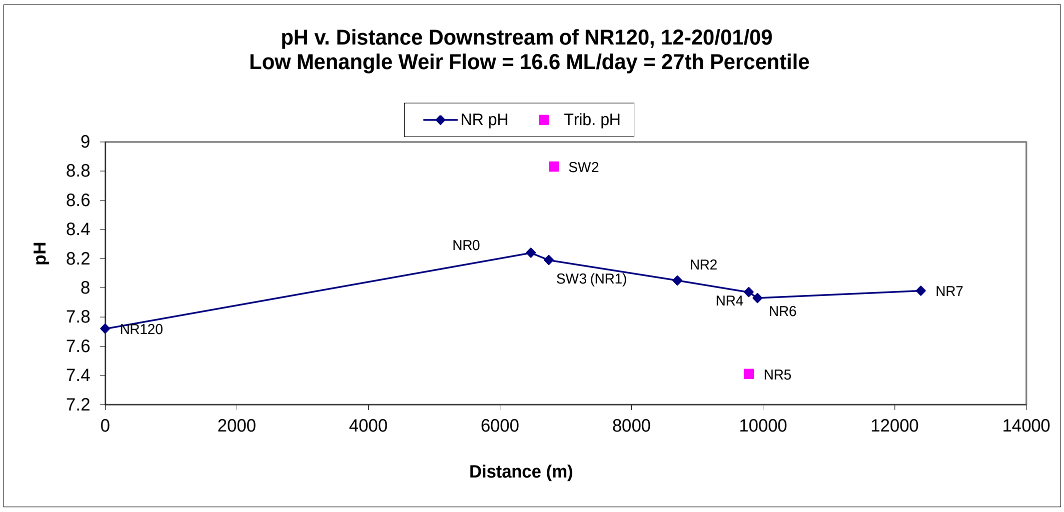
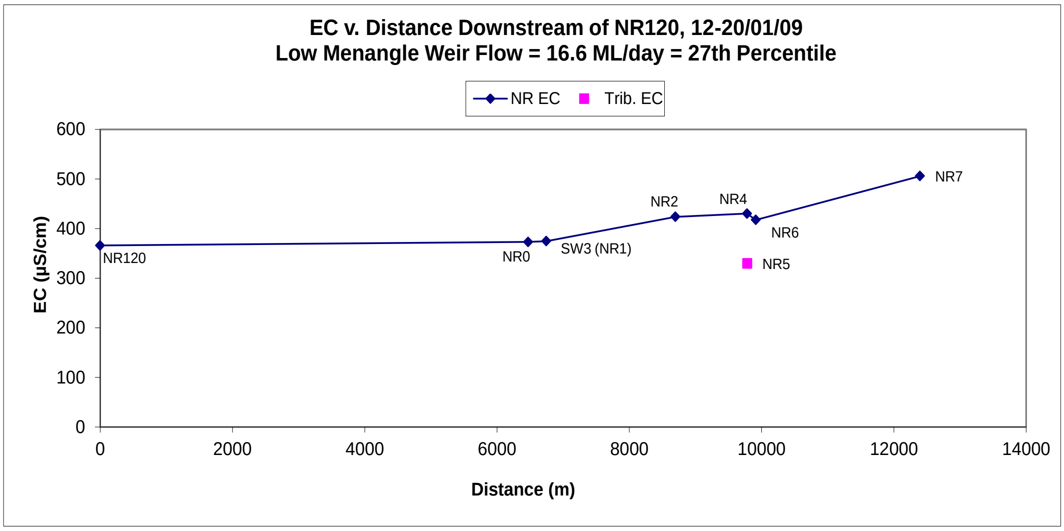


Figure 2.13 Salinity (EC) versus Distance Down River of NR120 for a Typical Low Flow Situation during the Baseline Period October 2008 – February 2012



Note in **Figure 2.13** above that EC data for site SW2 has been omitted as it grossly off scale (much higher).

Figure 2.14 Dissolved Oxygen (DO) versus Distance Down River of NR120 for a Typical Low Flow Situation during the Baseline Period October 2008 – February 2012

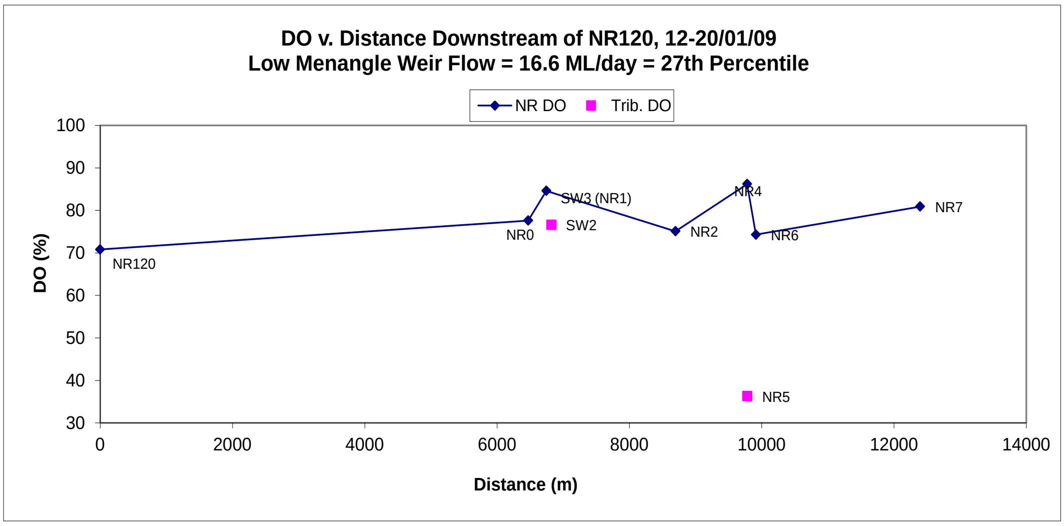


Figure 2.15 Total Fe versus Distance Down River of NR120 for a Typical Low Flow Situation during the Baseline Period October 2008 – February 2012

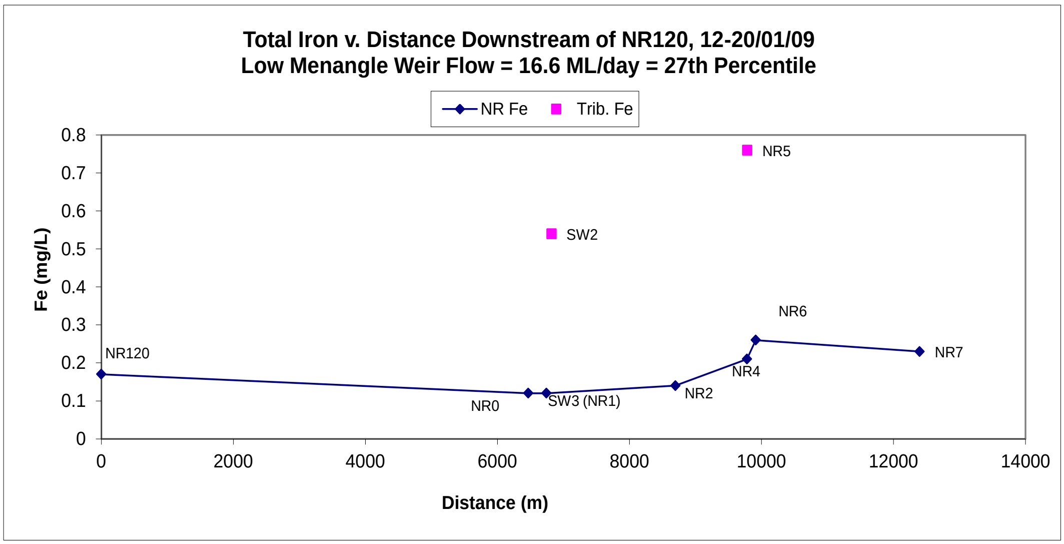
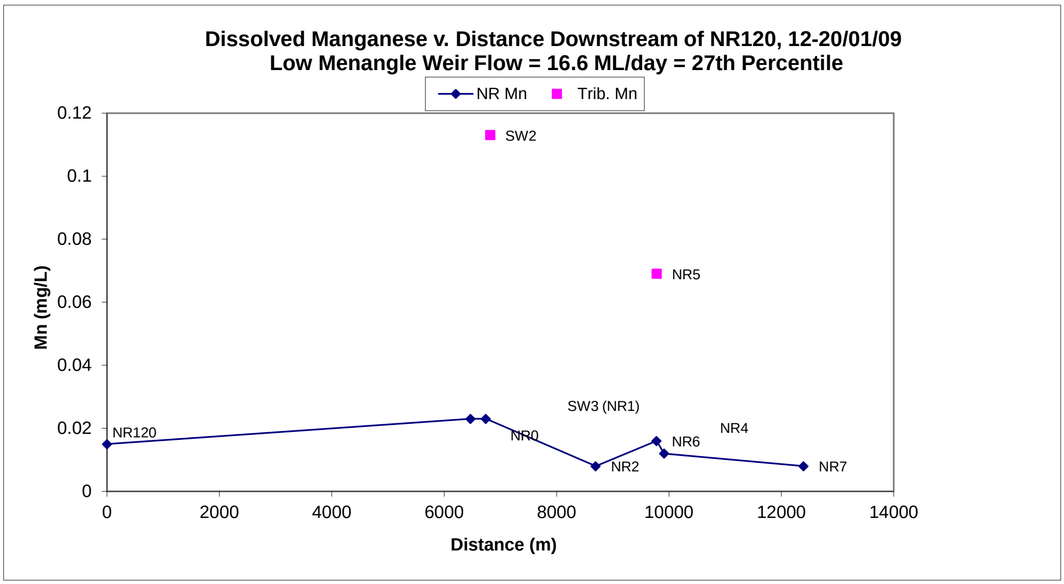


Figure 2.16 Total Mn versus Distance Down River of NR120 for a Typical Low Flow Situation during the Baseline Period October 2008 – February 2012



Earlier, analysis of the baseline period to September 2010, including water quality analyses at depth, showed the river, especially well down river of Area 9 near the confluence and downstream of Cataract River typically exhibits distinctive temperature/ dissolved oxygen (DO) and to a lesser degree salinity stratification between surface and deeper waters. Oxygen stratification is most apparent, with deeper stretches showing low to very low DO, particularly in summer months or during low flow periods where limited turbulent mixing occurs.

Inspection also shows that when flows in the Nepean River remain relatively constant due to controlled or no release from Maldon Weir and concurrent dry weather, with conditions being generally warm and sunny, then naturally occurring pH values in the river may occasionally be found in the 8.25 – 9.00 pH unit (high) range. This especially applies where Nepean River passes through any area dominated by farmland and can be expected to apply in the Area 9 General Study Area, due to pre-existing nutrient total phosphorus (TP) and total nitrogen (TN) inputs from the effects of fertilization and live stock waste pollution of catchments draining into the river.

It is likely that Allens Creek will be the major contributor of nutrients in the Longwalls 901 – 904 General Study Area. Such nutrient inputs have been detected in a large number of sampling campaigns conducted since July 2002 and are especially evident from sites NR11 and others further downriver of Area 7, especially following antecedent rain (which washes solids containing phosphorus off improved pastures).

It is clear that algal primary productivity in river pools maximizes under those circumstances. Algae absorb dissolved CO_2 and bicarbonate ions from water and produce oxygen – thereby driving pH up when CO_2 and bicarbonate ion concentrations decrease. It is common to observe pHs in the river rising to maximal levels as high as 9 or more during warm, sunny conditions. For this reason it would be unrealistic to expect the pH of water in the river to lie below 8.5 at all times and it is very likely that local aquatic biota are acclimatized to pHs as high as 9.5

As can be seen in the above figures,, to date there is very little difference in mean river baseline water quality immediately upriver, adjacent to and immediately downriver of the General Study Area. Baseline water qualities, especially under the ecologically more critical low flow conditions, are clearly dominated by input of more saline water from Allens Creek, particularly on some occasions but these have negligible bulk effect on overall river salinity due to the Allens Creek oputflows being very much less than flows in the River above the Allens Creek confluence.

The issue of salinity is relevant to the assessment of potential impacts on aquatic ecology for Longwalls 901 - 904 because mine subsidence-related effects can potentially affect two chemically very different classes of aquatic ecosystem, namely the following:

1. The low salinity (lowland river) context of Nepean River, where runoff into the river is dominated by a Cumberland Plain (Lowlands) landscape dominated by Hawkesbury Sandstone outcrop and sandstone derived soils, salinity of the river water (expressed in Electrical Conductivity (EC) units) even taking into account the Appin Colliery discharge to Allens Creek is unlikely to ever exceed 1000 µS/cm. Chloride and sulfate ion concentrations are unlikely to frequently exceed about 20 and 100 mg/L, respectively.
2. The water quality context of Allens Creek, which arises almost exclusively in Cumberland Plain (Lowlands) landscape dominated by Wianamatta Shale outcrop and shale-derived soils are such that salinities in the middle and lower sections of this creek frequently exceed 2000 µS/cm, and chloride and sulfate ion concentrations are likely to frequently exceed 500 mg/L and 30 mg/L, respectively.

The salinity of waters discharged from these shale catchment creeks into Nepean River is principally based upon the cation sodium (Na^+) and the anion bicarbonate (HCO_3^-).

It is now established that:

1. the anion bicarbonate is well known to be the principal and most variable driver of salinity-based ecotoxicity in such waters (e.g. Cowgill and Milazzo,1991; Hart, 1992; Hoke et al., 1992; Williams et al. 1993; Mount et al., 1997); and this means that
2. as pH is lowered the proportion of total alkalinity in the water comprised of bicarbonate ion increases and the proportion comprised of carbonate and hydroxide decreases (e.g. Stumm and Morgan, 1996), hence the ecotoxicity due to salinity alone by definition increases (per unit of salinity).

It is important to note that as the pH of the river water is lowered (e.g. here due principally to input of Fe and Mn and their oxidation and precipitation as hydrous oxides, and/or the addition of dissolved CO_2 from exogenous sources e.g. CO_2 in decomposition of natural organic matter) the ratio of bicarbonate to carbonate ion concentrations (i.e. $[HCO_3^-] / [CO_3^{2-}]$) rises (e.g. Toran and Saunders, 1995).

As noted in **Section 1.2**, there are no Water Quality Objectives regarding salinity arising from the Independent Inquiry into the Hawkesbury Nepean River System by the Healthy Rivers Commission and the Commission recommended using the trigger values in the national water quality guidelines (ANZECC&ARMCANZ, 2000).

We are of the view that Nepean River should be regarded as a lowland river where the default EC trigger value in the national water quality guidelines is 2200 µS/cm (ANZECC/ARMCANZ, 2000). This conclusion is based on:

1. studies which have shown that below Bargo the Nepean River has long been affected not only by discharges from Bargo River, the township of Picton and from Appin West Colliery but also by agricultural land uses; and the fact that
2. large areas of the river catchment are dominated throughout by Wianamatta Shale-derived soils, the shale being marine sediment (Hazelton and Tille, 1990). These marine sediments continue to provide salinity to runoff and groundwater seepages (interflow, throughflow etc) to the present day.

2.6 BASELINE AQUATIC ECOLOGY

Cardno Ecology Lab (CEL) (2010) has comprehensively reported on the aquatic ecology of the General Study Area and any ecological impacts associated with this proposal.

2.7 POTENTIAL EFFECTS

2.7.1 Effects of Riverbed and Rockbar Fracturing

Strains due to subsidence, leading to 'upsidence' and 'valley closure' beneath incised creeks and riverbeds can produce a complex suite of physico-chemical effects. Hydrological measurements, visual observations and water quality monitoring over recent years in the Southern Coalfield indicate these effects are:

1. Compressive or tensile (strain) failure fracturing of the Hawkesbury Sandstone bedrock leading to increased permeability and storage, possibly reduced surface flows, especially at the low end of the flow rate regime and

more rapid draining of defined rock bar controlled pools in no and low flow situations.

2. Diversion of stream flows through the fractured bedrock leading to loss of surface flows and potential loss of catchment yield to deep aquifer storage. This effect has been described in our previous reports as 'sub-bed diversion' (Ecoengineers, 2005b, c; 2006b).
3. Dispersion of small quantities of kaolinite from freshly fractured unweathered sandstone in the bedrock and its re-emergence from the bedrock immediately downstream of upsidence-affected areas. This effect has only been detected visually, occurs very early in the fracturing sequence, does not significantly affect downstream turbidities at anywhere near the levels that natural rainfall/runoff events cause and decays very rapidly.
4. Dissolution and oxidation of accessory siderite/rhodocrosite (ferrous/ manganous carbonate; $Fe/MnCO_3$) and marcasite (a form of pyrite, FeS_2) within freshly fractured or dilated groundwater pathways in the Sandstone, leading to release of sulfuric acid (H_2SO_4), dissolved iron (Fe), manganese (Mn), nickel (Ni) and zinc (Zn) and re-emergence of more acidic waters of lower pH, lower redox potential (Eh) and dissolved oxygen (DO) concentrations and higher concentrations of the above metals from bedrock immediately downstream of upsidence-affected areas.
5. Increased concentrations of dissolved aluminium (Al) in water emerging immediately downstream of fracturing-affected areas due to the dissolution of aluminium from kaolinite in the walls of flow paths conducting acidic water through the fractured bedrock.

Numerous studies and water quality monitoring undertaken in the Southern Coalfield have concluded that the estimated <u>maximum</u> daily rate of acid generation in any discrete sub-bed flow diversion/marcasite oxidation zone is currently believed to be of the order of 100 mole H_2SO_4/day which is equivalent to 100 mole $CaCO_3$/day to completely neutralize it, and that this maximum possible rate is <u>not sustained</u> for any more than a few months.

A critical characteristic of Hawkesbury Sandstone in the context of upsidence induced acid generation is that the sandstone has almost no neutralizing capacity and in most cases there is generally also very little neutralizing capacity in the chemistry of local natural stream and river waters. However, naturally occurring carbonate inputs from Wianamatta Shale-derived soil mantled catchments provide increased acid buffering potential in the Nepean River.

Any acid released by oxidation of marcasite in the sandstone is generally largely attenuated naturally downstream principally by dilution and by reaction with carbonate alkalinity in the passing creek or river water in which the acid dissolves. Given the flow rates and carbonate concentrations that occur in Nepean River water, it is unlikely that low pH conditions in the Nepean River would eventuate from the oxidation of pyrite type minerals in sandstone caused by valley related subsidence movements.

2.7.2 Strata Gas Emissions

Southern Coalfield strata gases are known to be high in methane – typically >90% by volume. They invariably also contain some carbon dioxide, nitrogen and small amounts of ethane – typically no more than 1% of the proportion of methane. Strata gases may also contain a low level of hydrogen sulfide and their emissions may or may not be accompanied by a small proportion of produced water also containing dissolved sulfide (e.g. Ecoengineers, 1998).

Possible ecological risks arising from emissions of strata gases are:

- The capacity of the gas to induce production of aerobic bacterial biomass 'feeding' on the methane,
- the consumption of DO within a water body into which the gas may be emitted,
- the production of low trace levels of potentially ecotoxic dissolved hydrogen sulfide and the production of potentially ecotoxic phenols – principally 4–methylphenol (para-cresol) as a known metabolic byproduct of the aerobic bacterial biomass which 'feeds' on the methane (e.g. Ecoengineers, 1998).

If substantial gas emissions occur at the surface, these could cause localized aquatic and terrestrial vegetation dieback. Such vegetation dieback is rare and has only been recorded in one location in the Southern Coalfield. Vegetation dieback has not been observed in areas that have not been directly mined beneath.

Further assessment of the potential impact of strata gas emissions of flora and fauna in the river gorge are provided in the report by Biosis (2010).

2.7.3 Strata Dilation Effects

The effect of induction of ferruginous springs as a consequence of mine subsidence has been observed before in the Southern Coalfield in sub-catchments of the Nepean, Cataract and Upper Georges River, most notably by producing:

- the large and long-lived 'SW2 Spring' in Cataract River just west of Back Gully Creek; and
- the long lived 'Pool 11 Spring' in Upper Georges River.

Other considerably smaller and shorter lived springs have been observed and monitored in association with mining operations within the Southern Coalfield.

On the basis of experience in the Southern Coalfield, it is inferred that such springs, if they do arise:

- may be generated by a catchment of as little as approximately 0.2 km^2;
- are likely to have a lifetime of at least 4 years with or without significant diminution in intensity; and
- may be relatively permanent once instigated, depending upon the size of the dilated catchment area providing their water supply.

The experience of the Cataract Gorge SW2 Springs suggests that a catchment size of the order of only 1 km^2 appears to be sufficient to confer a lifetime in excess of 10 years.

It is known that mining subsidence can have the effect of delaminating and dilating erosion surfaces and bedding planes within and between strata. These effects are predicted to occur preferentially along the interfaces between materials with different elastic properties.

In terms of the likely mechanism giving rise to such springs, it is now known that where broad scale upland subsidence occurs as a consequence of mining, delamination, dilation and hence permeability enhancement is likely along the sub-horizontal interface between the sub-cropping Hawkesbury Sandstone, perhaps an interfacial Mittagong Formation (thin intercalated lenses of sandstone and shale) and outcropping Wianamatta Shale and shale-derived soils (Hazelton and Tille, 1990).

This in turn apparently facilitates the increased detention and storage of infiltrating meteoric waters within the shale and close to the shale/sandstone interface. The water stored at the shale/sandstone interface subsequently drains down gradient in the direction of the local creek or river. In some cases it can then travel down natural or induced vertical cracks and along widened bedding planes in the sandstone and subsequently appear as well-defined springs.

That significant water storage at the Wianamatta/Hawkesbury interface occurs and is pronounced has been indicated by:

1. water yields recovered from various shallow boreholes drilled over the last 15 years in the Southern Coalfield on plateaux mantled with shale (i.e. those drilled just into the upper layers of the Hawkesbury);
2. periodic longwall mining-induced seepages into the Cataract Tunnel; and by
3. the emergence of highly visible ferruginous springs in the Upper Georges and Cataract Rivers.

It has been estimated that longwall mining-induced subsidence effects on shale-mantled upland catchments in the Southern Coalfield might generate ferruginous springs from upland catchments at a maximum recharge/discharge rate of about 0.8 mm/day and a mean recharge/discharge rate of about 0.2 mm/day for the source catchment. This would generate average flows of the order of 0.2 ML/day and maximum flows of the order of 0.4 ML/day per km^2 of catchment (Ecoengineers, 2005a).

Detailed geochemical investigation has shown such waters have the following pronounced geochemical characteristics:

1. A very distinctive geochemical signature characteristic of leaching of salts stored in (marine-derived) Wianamatta Shale clay soils. Specifically, the following is observed: very high magnesium/calcium (Mg/Ca) mole ratios between +3.6 and +5.0 (noting it is +5.2 in seawater), very low strontium/calcium mole ratios (Sr/Ca) between 0.004 and 0.009 (noting it is 0.009 in seawater), narrow log bromide/chloride (log(Br/Cl)) mole ratios between -2.85 and -2.95 (noting it is -2.81 in seawater), narrow log boron/chloride (log(B/Cl)) mole ratios between -11 and -18 (noting it is -12 in seawater), and narrow log sulfate/chloride (log(SO_4/Cl)) mole ratios typically between -1.3 and 2.0 (noting it is -1.3 in seawater). In other words, these waters have the signature of a marine shale soil profile, subsequently modified only by cation exchange processes on clays (for Na, K, Ca, Mg and Sr), clay adsorption (for B), and Fe and Mn oxide dissolution effects during percolation (e.g. Appelo and Postma, 1993).
2. Depending upon the depth of shale infiltrated, such waters often exhibit characteristically elevated levels of dissolved iron (Fe) and manganese (Mn) typically ranging from 0.2 – 40 mg/L and 0.1 – 2 mg/L respectively. Due to the well known high concentrations of disseminated Fe and Mn oxides (after siderite and rhodocrosite) in weathered Wianamatta Shales (which gives them their distinctive brick red through dark maroon colours), reductive dissolution of those oxides ('bleaching') has occurred in the subsoil storage

under the influence of so-called Fe and Mn dissimilatory bacteria (typically *Geobacter* species) that are well known to oxidize percolating dissolved organic matter (DOM) and, in that same biogeochemical process, use such oxides as their terminal electron acceptors (TEAs; Lovley and Phillips, 1986).

3. As distinct from the oxidative dissolution of marcasite that can occur in freshly fractured Hawkesbury Sandstone, the reductive dissolution (bleaching) of disseminated Fe and Mn oxides in the Wianamatta Shales does not increase SO_4 concentrations and does not produce acidity and hence lowering of pH *in situ* (although this will be created at emergence into the open air of such waters - see below). Hence these waters generally maintain constant SO_4 concentrations (albeit higher the greater the depth of shale and extent of salts leaching involved) and generally have near neutral to only weakly acidic pHs when properly sampled *in situ* or immediately upon emergence and if not subsequently passed through bulk fractured sandstone.

When a spring of this 'Wianamatta Shale-type water' emerges into the open air it tends to immediately react with the oxygen in the air or dissolved in the water of the creek or river it may flow into. This results in the precipitation of Fe and Mn hydrous oxides, generating acidity and consuming oxygen.

Fe and Mn oxidation and precipitation of hydrous oxides creates acidity principally through the following reactions:

$$2Fe^{2+} + 0.5O_2 + 5H_2O \Rightarrow 2Fe(OH)_3 + 4H^+$$

$$Mn^{2+} + 0.5O_2 + H_2O \Rightarrow MnOOH + 2H^+$$

Where such springs flow directly into ephemeral or low flow creeks, the bicarbonate/carbonate alkalinity of the water should generally be sufficient to ensure that the generation of acidity through the oxidation of the dissolved Fe and Mn is insufficient to produce pHs low enough to cause any ecotoxic effects.

The only situation where this could potentially not apply is where such a spring flowed into a large stream or river where the existing water was very fresh i.e. of very low salinity and hence of low alkalinity (Appelo and Postma, 1996). However, ecological stresses may also be caused by the low DO levels induced where such springs enter a permanent watercourse.

In summary:

1. Saline and/or ferruginous springs referred-to can be highly visible due to the voluminous precipitation of oxidised ferruginous material.
2. Increased inflows of saline waters into local creeks as a consequence of increasing infiltration into, and interflow through local Wianamatta Shale soils and outcrops due to mine subsidence-related effects (e.g. shearing/dilation) are a potential aquatic ecological stressor on local aquatic ecosystems (ANZECC/ARMCANZ, 2000), unless the waters in these creeks can be demonstrated to already receive Wianamatta Shale-derived waters of a similar salinity level and Fe and Mn concentrations.
3. As the reduced Fe and Mn load in the spring water is oxidised, and if it discharges to a creek, it consumes dissolved oxygen (DO) in the creek water at and immediately downstream of the point of entry to the creek. This could have ecotoxic effects both due to the reduction in DO and a smothering effect in the creek bed (ANZECC/ARMCANZ, 2000).

4. If the magnitude of such a spring was sufficiently large waters containing significant concentrations of dissolved Fe and Mn could also pass either indirectly or directly into the Nepean River this in turn would consume dissolved oxygen at the point of entry.

3. ASSESSMENT OF WATER-RELATED EFFECTS

3.1 FERRUGINOUS SPRINGS

On the basis of field observation, it is considered that ferruginous springs would be more prone to arise or be enhanced in tributary streams i.e. Harris Creek, rather than in Nepean River. This increased probability is suggested by the following:

1. the drilling of Tower Colliery borehole 22 in August 2001 in which a flow of a classic Wianamatta Shale water with high dissolved Fe and Mn concentrations was encountered in the low part of a westward draining catchment flowing towards Nepean River;
2. detection of a spring in Ingham's Tributary of Ousedale Creek at site IT30 which was detected after completion of West Cliff Longwall 30 and possibly induced or enhanced by mining of that longwall; and
3. detection of a pre-existing spring in Mallaty Creek between existing BHPBIC water quality sites MC05 and MC130.

Should the following occur:

1. discharge of ferruginous springs into tributary creeks such as Harris Creek, which typically has very low flows; or
2. discharge of ferruginous springs into farm dams sited along drainage lines,

within the General Study Area, they possess the potential capacity to drive down pH, consume DO and deposit ferruginous precipitates.

The tributary streams and farm water storages are impacted by current land uses and therefore contain minimal aquatic ecology. In addition, they are located in a Wianamatta Shale-derived region and may already be receptors for ferruginous springs which have arisen naturally. In this regard the effects described above are predicted to not be significant and may not be able to be identified.

The upland valleys on the western side of the Nepean River are shallow but substantial in area. Consequently the area of potential subsidence and dilation of near surface strata is expected to be comparable with the ~1.00 km^2 (100 ha) that was mined under by Appin longwalls to create the Cataract River SW2 spring.

Based on studies of previous springs we conclude that longwall mining induced subsidence effects on upland catchments in the General Study Area could generate individual ferruginous springs from upland catchments discharging to the river up to a maximum recharge/discharge rate of about 0.2 ML/day.

We modelled the effects of the mixing of 0.2, 0.1 and 0.05 ML/day of spring waters emanating from catchments over Longwalls 901 - 904 with 0.4 and 4.0 ML/day of river water i.e. River base flows equivalent to the 3.5 and 10 percentile flows using PHREEQC (Parkhurst and Appelo, 1999). This was done in order to obtain probabilistic information regarding the impact of any such spring discharging directly to Nepean River.

We assumed, by analogy with the IT30 spring sampled in Ingham's Tributary of Ousedale Creek (Ecoengineers, 2005a) that any upland subsidence induced springs over Longwalls 901 - 904 would have a maximum total Fe concentration of the order of 3.2 mg/L, and a maximum total Mn concentration of 1.2 mg/L (being the long term mean plus one standard deviation as established by BHPBIC's monitoring program). We have also assumed that for river flows up to 4.0 ML/day the river water would have a composition closely similar to the average for BHPBIC water quality monitoring site NR7.

Table 3.1 below shows the outcomes of that modelling, giving the estimated DO levels in the river at the point of mixing of spring and river waters.

TABLE 3.1: Modelled dissolved oxygen saturation at points of mixing of a ferruginous spring discharging directly to the river under 3.2 and 7.7 percentile river flow conditions as measured at Menangle Weir

Spring Flow Rate (ML/day)	Estimated DO (% saturation)	Estimated pH	Estimated DO (% saturation)	Estimated pH
	Mixing for 3.2 percentile river flow (0.4 ML/day)		Mixing for 7.7 percentile river flow (4.0 ML/day)	
0.20	53	6.83	83	7.36
0.1	67	6.96		
0.05	75	7.12		
0.00	87	7.69		
National Water Quality Guide-lines (NSW lowland rivers)	>85	6.5	>85	6.5

From the above **Table 3.1** the following may be inferred:

1. for discrete spring flows into Nepean River above 0.05 ML/day and very low river flows below about 0.4 ML/day as measured at Menangle Weir i.e. below 3.2 percentile river flows, the default guideline for DO in the national water quality guidelines would not be met at the spring emergence point, however this cannot by definition occur more than 3.2% of the time, based on the river flow magnitude and would invariably have an even lower duration (and hence frequency) because average spring flow rates of 0.05 ML/day and above have been found to be very rare.
2. for all discrete spring flows into Nepean River below ~0.2 ML/day and river flows above ~4.0 ML/day as measured at Menangle Weir i.e. above 7.7 percentile flows, the default guideline for DO in the national water quality guidelines would be met in all circumstances.
3. For all discrete spring flows into Nepean River below ~0.2 ML/day and river flows above 0.4 ML/day at Menangle Weir i.e. above 3.2 percentile flows, the default guideline for pH in the national water quality guidelines of 6.5 would be met in all circumstances.

3.2 STRATA GAS EMISSIONS INTO NEPEAN RIVER

As the most recent example, selected DO versus distance downriver of NR0 (the upriver site for the Appin Area 7 Longwalls) plots are shown in **Figures 3.1 to 3.6** below for the mining and post-mining period of Area 7 Longwall 702 from September 2008 to late-May 2009.

During this period, strata gas emissions were observed at eight sites along the river as described in **Section 2.4** above.

In **Figures 3.1 – 3.6** below, graphs of water quality down the river for days of less than 50 percentile flows (<34.7 ML/day) as measured at Menangle Weir are presented, as during such flows the potential effect of gas emissions has greater ecological significance (Ecoengineers, 2008)

Total Phosphorus (TP) and Total Nitrogen (TN) have also been plotted on the same graphs to give the concurrent TP and TN surface profiles down the river, as TP and TN are invariably the primary and secondary nutrient parameters (respectively) controlling algal and/or bacterial growth (alternatively generating or removing DO) in freshwater ecosystems.

These graphs are examples of what has long been commonly known as 'DO sags' i.e. pronounced declines in DO over a discrete stretch of the watercourse due to discrete inputs of readily aerobically available organic carbon (such as methane).

The principles and mechanisms of 'DO sagging' in a stream or river due to the input of an aerobically biodegradable organic material which is consumed by aerobic bacteria in the water column, thereby consuming DO and producing CO_2 have been very well established over approximately 50 years of environmental studies (e.g. Thomann and Mueller, 1987; Novotny and Olem, 1994).

Figure 3.1 Dissolved Oxygen, Total Nitrogen and Total Phosphorus in Surface Waters of Nepean River in October 2008 during Extraction of Longwall 702

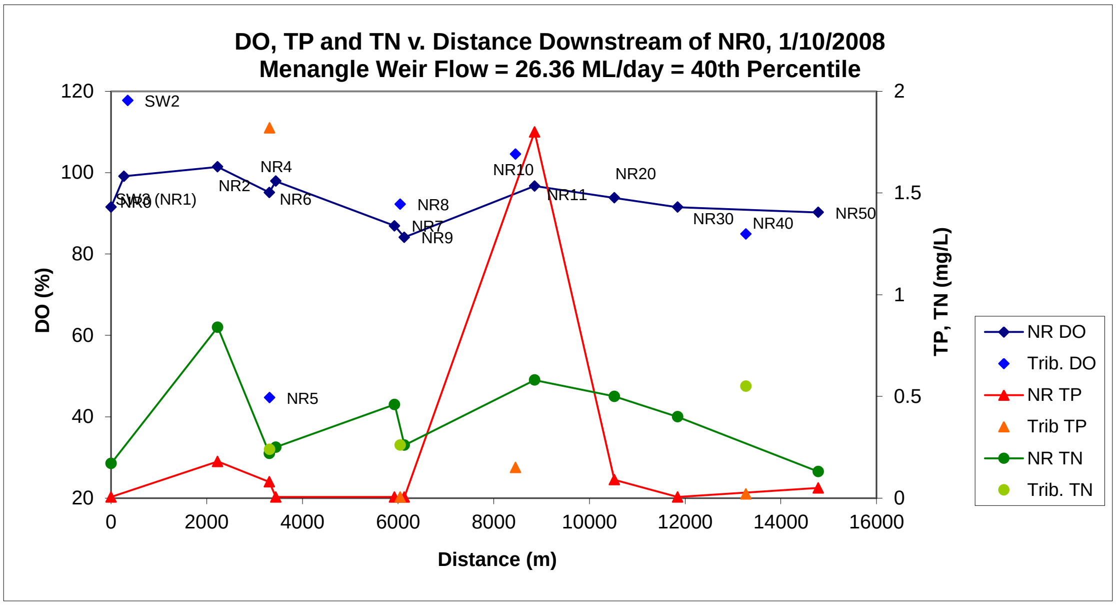


Figure 3.2 Dissolved Oxygen, Total Nitrogen and Total Phosphorus in Surface Waters of Nepean River in December 2008 during Extraction of Longwall 702

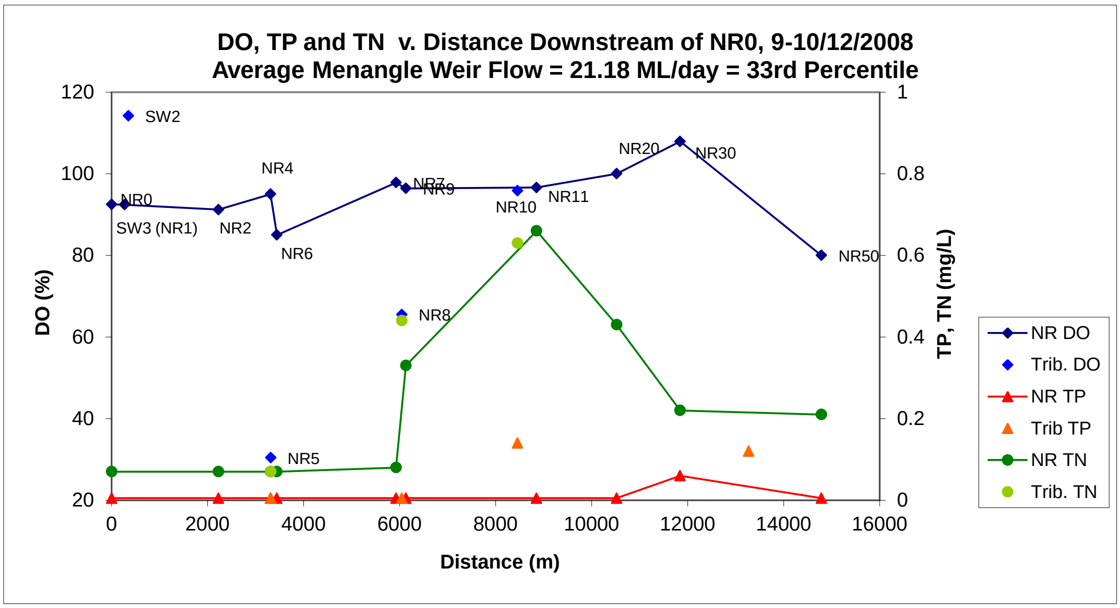


Figure 3.3 Dissolved Oxygen, Total Nitrogen and Total Phosphorus in Surface Waters of Nepean River in January 2009 during Extraction of Longwall 702

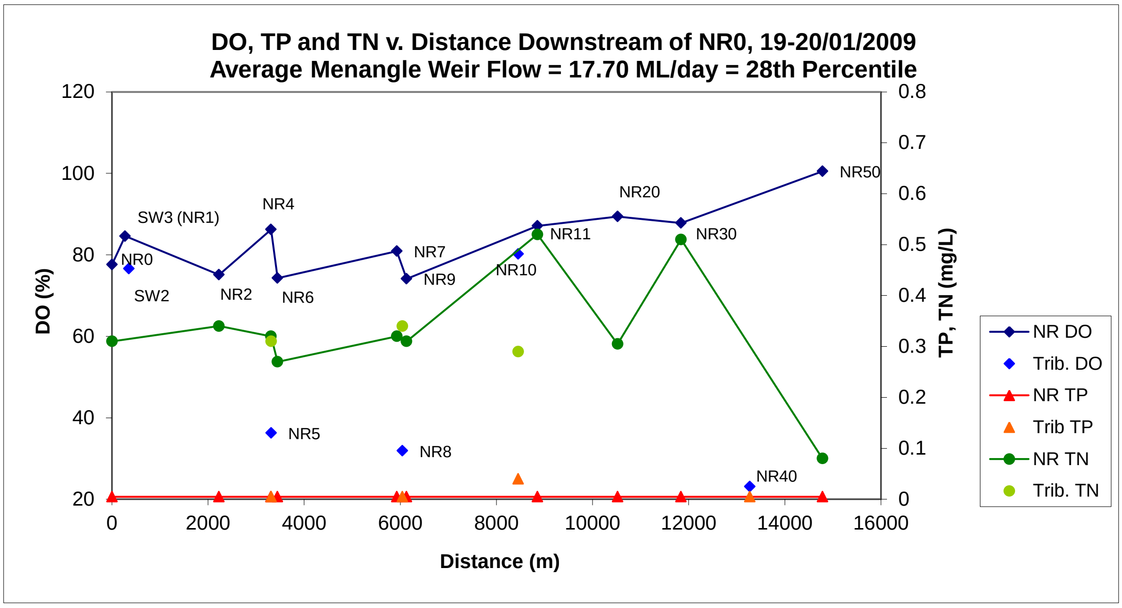


Figure 3.4 Dissolved Oxygen, Total Nitrogen and Total Phosphorus in Surface Waters of Nepean River in February 2009 during Extraction of Longwall 702

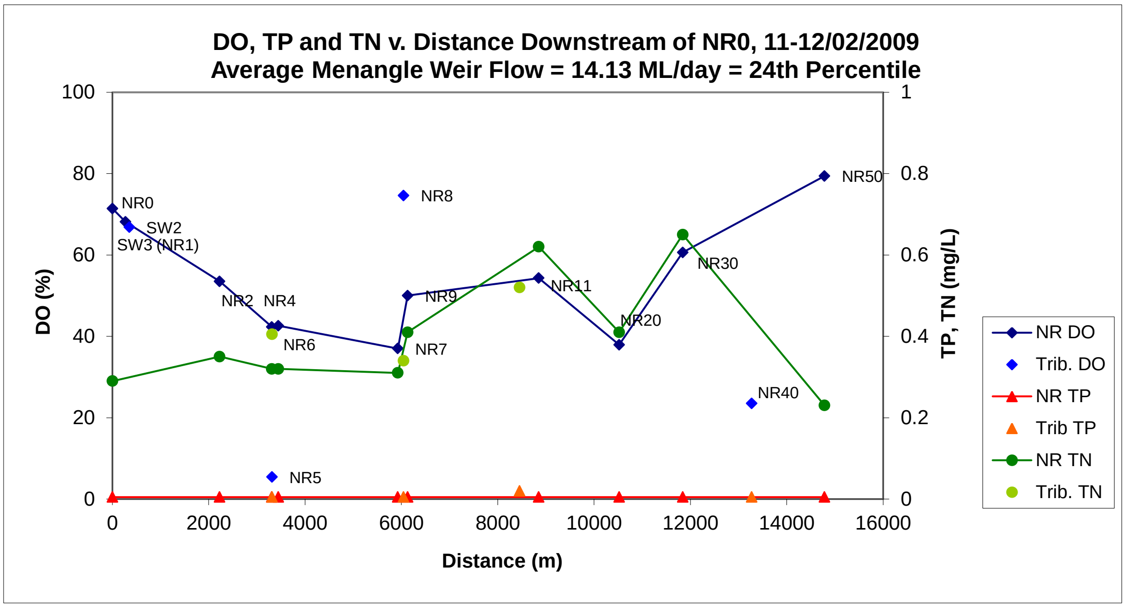


Figure 3.5 Dissolved Oxygen, Total Nitrogen and Total Phosphorus in Surface Waters of Nepean River in March 2009 during Extraction of Longwall 702

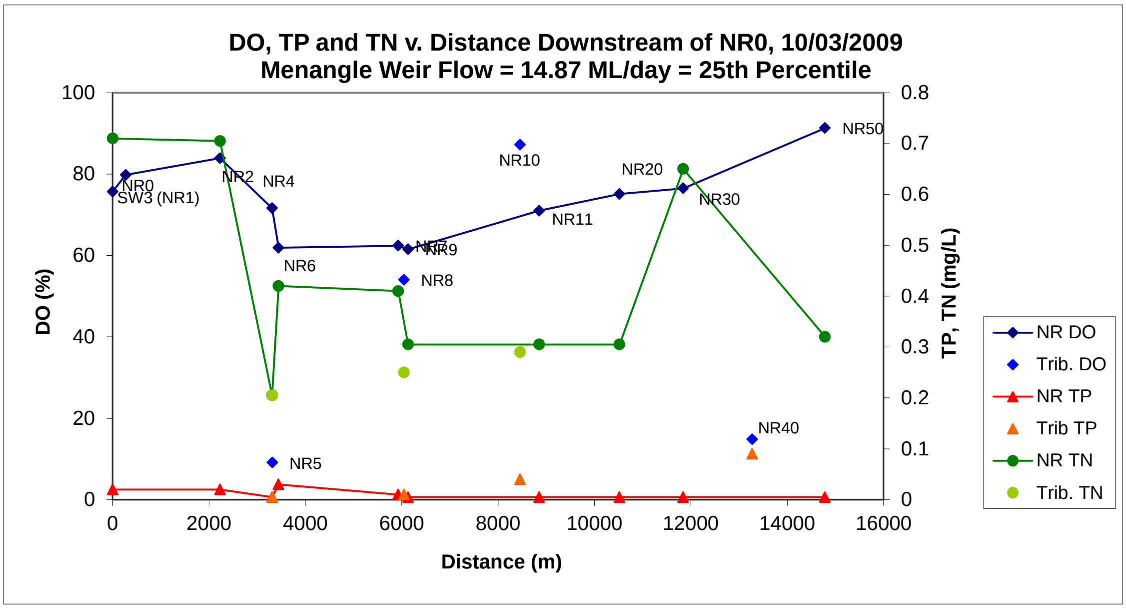
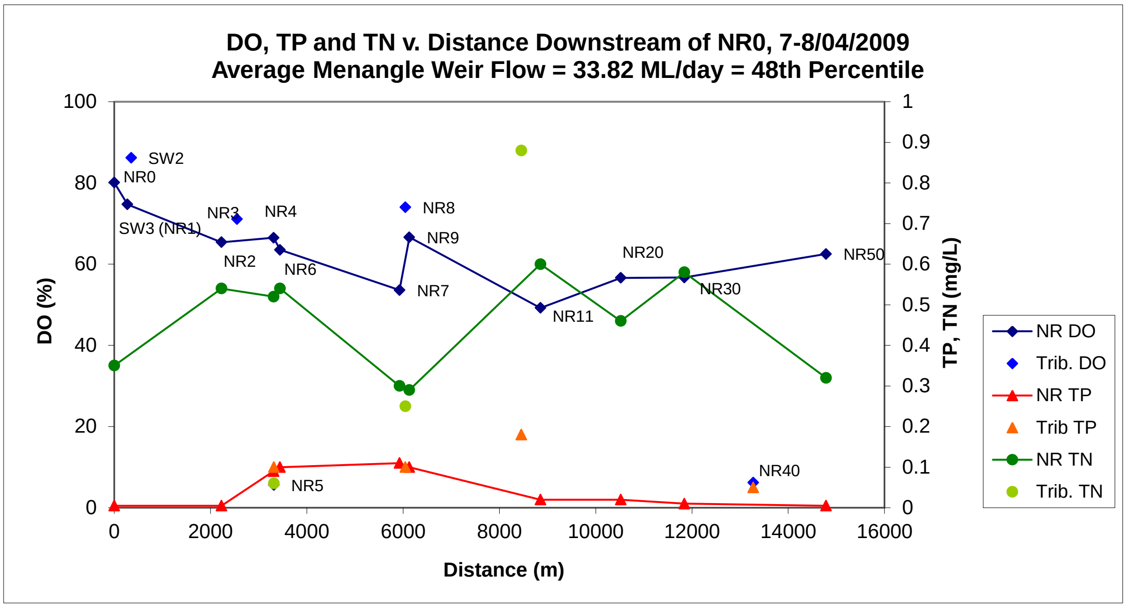


Figure 3.6 Dissolved Oxygen, Total Nitrogen and Total Phosphorus in Surface Waters of Nepean River in April 2009 during Extraction of Longwall 702



Examination of **Figures 3.1 to 3.6** above shows that, during the above described periods, Nepean River surface water qualities, especially under the ecologically more critical low flow conditions <50 percentile, were dominated by the following processes:

1. There was a consistent input of low DO water from Cataract River (site NR5) under all flow conditions and the Cataract River input is inferred to be the primary driver of DO sagging immediately downstream of the Cataract River confluence.
2. The river appeared to have a relatively low degree of re-aeration down river of this point i.e. the (flooded) geomorphology of the river is such that it has a low Re-aeration Coefficient (RAC).
3. Beyond site NR7, under low flow conditions DO reductions could be attributed to inputs of water from small tributaries carrying agricultural and industrial pollution as indicated by low DO and high TP (and TN) levels. Menangle Creek (site NR40) would be an example.

However **Figures 3.1 to 3.6** above do indicate that it is possible that emission of strata gas into the Nepean River which gave rise to further minor reductions in DO in the river between sites NR6, NR7 and NR9 adjacent to Area 7 was due to microbiological consumption of dissolved methane through growths of natural methanotrophic bacteria ('obligate aerobes') within the water column.

Of particular significance in the current context is that strata gas emission-induced reduction DO sagging may well become contiguous with the observed, pre-existing agricultural land-use induced DO sagging which the BHPBIC water quality monitoring data indicates is pronounced under most seasonal conditions except during a few warm summer months when algae are clearly blooming in the river and contributing oxygen into the water column.

Regardless, strata gas emissions into Nepean River and their potential biogeochemical impact at low river flow rates therefore has the potential to impact aquatic ecology. The significance of this impact is further assessed by Cardno Ecology Lab (2011).

3.3 RIVER FLOW DIVERSIONS AND THEIR GEOCHEMICAL EFFECTS

No field evidence for sub-bed diversion of Nepean River flows or un-natural rates of drainage of pools induced by coal mining 'upsidence' has previously been detected in Nepean River, including during and following the most recent mining of Longwalls 701 – 703. Valley closure predictions by MSEC (2012) for Longwall 901 are similar the confirmed closures produced by Area 7 longwalls 701 and 702 and less for Longwalls 902 through 904.

We previously quantitatively examined a series of low flow (i.e. <50 percentile flows at Menangle Weir = 34.7 ML/day) recession examples where we have subtracted the flows at Maldon Weir from the concurrent flows at Menangle Weir to get a measure of the flow through the river (Ecoengineers, 2008a, 2009, 2011).

Seventeen low flow, natural log-linear recession curves of this type could be identified and constructed <u>from the difference in flow rates between these two weirs from the period</u> between 1990 and 2009. Key data from analysis of these recessions have been consolidated and are presented below in **Table 3.2.**

For the 17 cases of low flow recession identified below in the period November 1990 through October 2007, the average slope of the log-linear recession curve (for the difference between gauged flows at Menangle and Maldon Weirs) is -10.55 ± 2.16 at the one standard deviation level (n=17).

Regardless of the known presence of licensed extractions between these weirs, none of these recession curves showed any non-linear steepening of their slopes as the difference in flows between Maldon and Menangle Weirs declined to zero, <u>such as would be created by an increasing non-recoverable loss of water into the river bed</u>.

Table 3.2 Menangle minus Maldon Low Flow Baseline Natural Log-Linear Recession Curves.

Date Range	Menangle minus Maldon Flow Maxima (ML/day)	Menangle minus Maldon Flow Minima (ML/day)	Slope	Good-ness of Fit R^2 value	Total Rainfall During Recession Period (mm)
24/11 – 6/12/1990	32.346	1.742	-10.4940	0.9634	6.6
11 – 24/12/1990	30.262	1.844	-9.4897	0.9241	17.5
13 – 23/09/1991	34.883	0.038	-12.9050	0.9030	0.0
19 – 27/02/1994	27.411	2.457	-12.8410	0.9419	0.0
20 – 30/04/1994	25.823	4.495	-9.4847	0.9573	0.0
14 – 23/04/1996	26.258	1.363	-11.9390	0.9471	1.4
11 – 19/11/1996	22.689	3.524	-8.8580	0.8486	20.0
3 – 14/12/1998	24.385	4.402	-7.4976	0.8870	12.4
16 – 26/02/2000	28.820	2.817	-10.8170	0.9399	0.0
20 – 28/12/2001	24.782	0.996	-12.5150	0.8989	3.4
6 – 14/01/2002	28.747	2.649	-11.4160	0.8605	12.2
31/07 – 9/08/2002	25.545	8.351	-6.7930	0.8569	1.0
20 – 28/09/2002	27.656	6.743	-8.4000	0.8559	0.0
26/03 – 3/04/2004	32.719	3.137	-14.7520	0.9497	0.0
11 – 19/04/2004	25.637	3.123	-10.5750	0.9533	0.0
12 – 18/12/2005	26.866	1.735	-12.0080	0.9512	0.0
27/09 – 7/10/2007	24.746	1.057	-8.5376	0.8215	0.0
Average	27.621	2.969	-10.5484	0.9094	4.4
Standard Deviation (n = 17)	3.315	2.112	2.1567	0.0462	6.8
Period of LW701 mining					
13 – 22/11/2007	25.179	3.775	-9.4984	0.9289	4.0
19 – 26/12/2007	24.489	1.579	-9.5349	0.8465	9.0
22 – 31/01/2008	30.561	4.46	-9.2562	0.7787	0.0
27/04 – 08/05/2008	32.360	4.448	-9.3892	0.8187	0.0
Period of LW702 mining					
20/02 – 28/02/2009	25.081	1.891	-10.5930	0.8825	0.0

These data show that over the period November 1990 through October 2007, during which period Tower Longwalls 15 – 20 were mined, that there was no detectable loss of water from the stretch of the Nepean River between Maldon and Menangle Weirs. It is noted this observation applies despite the fact that during this period Tower Longwall 17 directly undermined the river and the adjacent longwalls mined close to the banks of the Nepean River.

Maximum predicted upsidence and valley closure movements for Tower Longwall 17 were 600 mm and 750 mm respectively (MSEC, 2009). It is reported that pool water levels in the Nepean River were unaffected – being controlled by Menangle Weir downstream (BHP Billiton, 2007). Whilst it is considered likely that the River bed would have experienced fracturing and uplift, the effects were not seen in the submerged section of the Nepean River.

Table 3.2 above also shows a lack of statistically significant change in the log-linear slopes of the most sensitive low flow recessions computed for the difference between river flows at Maldon and Menangle Weirs between this pre-mining baseline period with respect to Longwalls 701 and 702 and the period of mining of Longwalls 701 and 702. A similar exercise could not be conducted for Longwall 703 due to a lack of river flow gauging at Menangle Weir for almost the entire duration of mining of Longwall 703. The likelihood of any Nepean River upsidence-induced bedrock fracturing causing sufficient sub-bed flow to lead to detectable temporary flow loss under low flow recession is therefore also considered to be negligible.

The Nepean River contains significant bicarbonate alkalinity – typically in the range 138 ± 59 mg/L expressed as calcium carbonate ($CaCO_3$). This alkalinity is available to neutralize any H_2SO_4 acidity released by weathering of marcasite in fractures of unweathered sandstone exposed through the cracking of river bed and/or rock bars. For the 10 percentile baseflow in the river adjacent to the General Study Area of around 4.7 ML/day (i.e. about 85% of the 10 percentile flow at Menangle Weir which is 5.5 ML/day), this means that, each day the total alkalinity passing down the river is equivalent to approximately 6486 ± 2773 moles of calcium carbonate per day. Thus, even allowing for the unlikely event of an unusually low total alkalinity in the water of 6486 – 2 x 2773 = 940 moles of calcium carbonate, there is still adequate alkalinity in the water to completely neutralize any water quality effect arising from a significant number of discrete zones of sub-bed fracturing in the river.

The upper stretch of the Nepean River from Maldon Weir to Allens Creek in the General Study Area for Longwalls 901 – 904 designated by MSEC (2012) as 'Section 1' is free flowing and contains a number of boulder fields, a rock bar and a small weir (refer MSEC, 2012 Table 5.2). As a result, Section 1 is likely to have a high Re-Aeration Coefficient (USEPA, 1985).

The lower stretch of the Nepean River in the General Study Area for Longwalls 901 – 904 designated by MSEC (2012) as 'Section 2' is flooded, but it is narrow in parts and also contains some emergent boulders and two submerged rock bars. It is also likely to have a lower (than Section 1), but still adequate Re-Aeration Coefficient.

Geochemical modelling for the Nepean River using the USGS model PHREEQC (Parkhurst and Appelo, 1999) based on observed past magnitudes of maximum discrete zones of acid production in other rivers and streams subject to mining-induced bedrock fracturing shows that:

1. low pHs could not be induced in the river;

2. any dissolved iron and/or manganese would generally be oxidized and precipitated;
3. carbonate-related aqueous speciation of any trace nickel or zinc released, producing predominantly neutral or negatively charged species, would ensure that ecological effects would also be negligible.

In this sense, the situation in Nepean River differs fundamentally from that in other rivers such as Cataract and Bargo Rivers (which contain water of much lower total alkalinity) where mining-induced sub-bed diversions and consequently episodes of marcasite dissolution and acidity generation have occurred.

Consequently, manifestation of adverse geochemical effects on river water quality from sub-bed flow diversions even in the unlikely event that one or more occurred is considered highly unlikely.

3.4 EFFECTS OF SUBSIDENCE ON SMALL CREEKS AND FARM DAMS

Nepean River Tributary 1 (refer **Figure 2.1**) is located directly above the proposed Longwalls 902 to 904. The lower reaches of the tributary is located directly above Longwall 902, with the remainder located south of the proposed longwalls. Two, third order branches of the tributary are located above the proposed Longwalls 902 and 903

Harris Creek is a third order tributary of the Nepean River located east of the proposed Longwalls 901-904 (400 m from Longwall 903 at its closest point) and just outside the General Study Area. It has been identified, however, as potentially being impacted by mining in Appin Area 9 and as a result was included in the assessment of impacts on the local watercourses (MSEC 2012). Subsidence, upsidence and valley closure occurring in Harris Creek is expected to be negligible, with <20 mm of movement predicted for each parameter (MSEC 2012).

Table 3.3 Predicted impacts of longwall mining on drainage lines General Study Area (adapted from Gilbert & Associates Pty Ltd., 2009 and MSEC, 2012).

Name of creek or gully	Impacting longwalls	Maximum predicted valley closure	Impacts
Nepean Tributary 1	LW901 – LW904	625 mm	- Localised areas with minor increases in ponding and flooding - Potential fracturing of exposed bedrock causing negligible diversion of surface water
Harris Creek	LW901 – LW904	< 20 mm	

A large number of farms dams have been monitored by BHPBIC Environmental Field Team during and following the mining of Longwalls 701, 702 and 703. In all but one of the cases impacts on farms dams from the mining (beneath them) of those three longwalls were found to be undetectable to very minor, not triggering a requirement for remedial works. Mining impacts were observed at one shallow dam.

It is therefore inferred that a similar outcome will occur with Longwalls 901 through 904 i.e. impact on farms dams will be unlikely and if impacts do occur they will be repaired as required under the Mine Subsidence Compensation Act.

The northern parts of Appin Area 9 are overlain by the upper reaches of Racecourse Creek (including Apps Gully), Matahill Creek and the headwaters of Navigation Creek. These are not mined under, however, by Longwalls 901 – 904. Gilbert & Associates (2009) have found that mining Longwalls 901 - 904 will not cause significant subsidence related impacts to these watercourses.

4. ASSESSMENTS

4.1 ASSESSMENT OF EFFECTS ON NEPEAN RIVER

Gas Emissions into the river

Minor emissions of methane-rich strata gas into the Nepean River are inferred to be a possible consequence of the mining of proposed Longwalls 901 to 904.

Dissolved oxygen 'sags' of various magnitudes were observed in Nepean River attributable to both natural and mining-related causes during the extended pre-mining baseline period for Appin Area 7 and during the mining of Longwalls 701, 702 and 703. Those dissolved oxygen sags could be principally attributed to inputs of dissolved iron from Cataract River in Nepean River and/or pulses of available nutrients in stormwater runoff from agricultural land on both sides of Nepean River. However, some minor sagging attributable to reduction in dissolved oxygen in the river due to microbiological consumption of dissolved methane around gas releases by natural aerobic methanotrophic bacteria ('obligate aerobes') could not be ruled out.

On the basis of the information presented in previous sections of this report and above we conclude that emissions of strata gas into the Nepean River might give rise to some temporary dissolved oxygen sagging during the mining of Longwalls 901 through 904, but that the impacts of such sags would be negligible.

Ferruginous Springs

Extraction of Appin Longwall 702, which did not mine under the river or any tributary, did not lead to the creation of any new ferruginous springs. It might be inferred that Harris Creek and the small stretch of the Nepean River within the General Study Area are at a similarly low probability of impact from this phenomenon.

Whilst the induction of ferruginous springs is considered unlikely, if it should occur, then only for all discrete spring flows into the river above 0.1 ML/day and only for river flows below about 0.3 ML/day i.e. below 3.5 percentile flows would the default lower limit for DO in the national water quality guidelines not be met, but only at the point of spring flow emergence into the river.

Such springs do not contain sufficient dissolved Fe and Mn to cause a significant depression of river pHs through the oxidation and precipitation of hydrous Fe and Mn oxides because the river water contains significant bicarbonate/carbonate alkalinity.

On the basis of the information presented in previous sections of this report we conclude there is only a low likelihood of ferruginous springs being induced in the walls of the river gorge adjacent to Longwalls 901 through 904 and should any occur the high inherent alkalinity and re-aeration capacity of the river would render their ecological impact to negligible.

River Sub-Bed Flow Diversions

It is highly unlikely there could be any significant effect on river water level or pH, total Fe, Mn, Ni or Zn concentrations from any sub-bed diversion effects resulting from the extraction of the proposed longwalls, even in the unlikely event of an upsidence induced fracturing of a rock bar or zone of river bedrock.

The likelihood of such an event has already been rendered extremely low due to:

1. the offset of the longwalls from the River as described by MSEC (2012); and
2. the significant capacity for neutralization of acidifying point source effects provided the moderately high total alkalinity of River waters.

Concentrations of ecotoxic Ni and Zn species in the Nepean River derived from any sub-bed flow diversions would not exceed their default national water quality guidelines limits (0.011 and 0.008 mg/L respectively for nickel and zinc; ANZECC/ARMCANZ, 2000) for river flows of 1.0 ML/day and above because of the considerable carbonate alkalinity in the river water. Modelling using PHREEQC shows that both trace nickel and nickel are overwhelmingly speciated into the non-ecotoxic neutral and anionic carbonate-complexed species.

On the basis of the information presented in previous sections of this report and above we conclude that total alkalinity of the river water is more than adequate to neutralize any acid produced from increases in dissolution of siderite and trace accessory sulfide minerals in the sandstone of the river bed, ensuring negligible reduction in river water pH.

Modeling also shows that precipitation of any iron and manganese released, and carbonate alkalinity-related aqueous speciation of any trace nickel or zinc released would ensure any riverine ecological effects would also be negligible.

4.2 ASSESSMENT OF EFFECTS ON HARRIS CREEK AND CATCHMENT

No pre-existing ferruginous and/or saline springs have been identified in Harris Creek. Given that the gradients in Harris Creek are similar to, and greater than those in Elladale Creek, the so-called Ingham's Tributary of Ousedale Creek and Mallaty Creek, there would appear to be a low probability of induction of one or more ferruginous springs in Harris Creek as a consequence of the mining of Longwalls 901 - 904.

However, the mining of Longwalls 702 and 703 just to the east of Harris Creek has not led to the induction of any detectable ferruginous and/or saline springs.

Nevertheless, on the basis of past experience, it is possible that ferruginous and/or saline springs might be enhanced or induced in Harris Creek. Harris Creek is ephemeral in nature with an agricultural land use.

It is unlikely that there would be any significant impact to creek water quality resulting from the formation of springs in these streams over and above current agriculture-related effects (The Ecology Lab, 2008).

Examination of existing baseline water quality data for the creek (BHPBIC site NR3) and for the upriver and downriver sites (BHPBIC sites NR2/NR2a and NR4/NR4a) shows that there is no significant input from Harris Creek to River flows below the confluence of the River and the creek – as would be expected for the sporadic nature of Harris Creek flows.

On the basis of this information we conclude there will be negligible environmental impacts on the creek and on Nepean River from the mining of Longwalls 901 through 904.

4.3 ASSESSMENT OF EFFECTS ON FARM DAMS

Based on experience from recent mining history in Appin Area 7 (i.e. Longwalls 701 – 703), it is considered unlikely that farm dams situated within the General Study Area and elsewhere in the catchment of Harris Creek will be subject to any significant damaging effects arising from the mining of Longwalls 901 – 904. In the unlikely event that farm dams are impacted they will be repaired using standard dam building techniques.

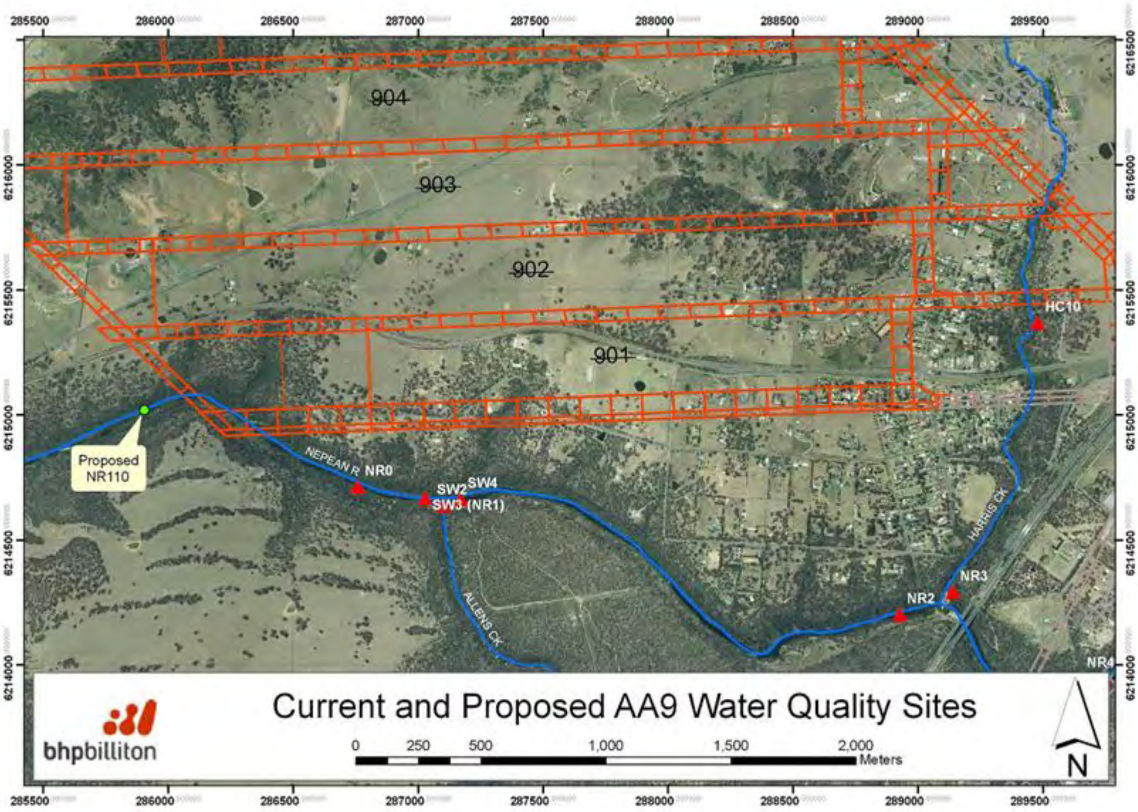
5 RECOMMENDATIONS

5.1 WATER QUALITY MONITORING AND PROPOSED WATER QUALITY TARPS

Baseline surface flow and water quality monitoring occurring in Nepean River upriver and adjacent to proposed Longwalls 901 - 904 and in lower Allens and Harris Creeks should continue up until the commencement of Longwall 901.

We propose the early implementation of an additional site in the Nepean River (to be designated NR110) between the current sites NR120 and NR0 but situated downstream of Byrnes Creek at or about the location shown below in **Figure 5.1** below.

Figure 5.1 Location of proposed additional sampling site NR110



This would allow for a more quantitative understanding of any effects in the River which are unrelated to the longwall mining of Area 9, particularly with respect to any impact of discharges from Byrnes Creek immediately upriver of the General Study Area and provide a means of ensuring that the TARPs to be established for site NR0 adjacent to the upriver 'Section 1' part of Area 9 were not triggered by upriver effects unrelated to the mining of Area 9, e.g. agricultural activities.

Analogously, it is proposed that River sites SW3 and SW4 respectively upriver and downriver of the confidence with Allens Creek and the lower Allens Creek site SW2 (refer **Figure 5.1** above) be used to ensure TARPs to be established for site NR2 adjacent-to the downriver 'Section 2' part of Area 9 site NR2 were not triggered by effects in Allens Creek unrelated to the mining of Area 9 e.g. agricultural or other activities.

It is recommended that, following commencement of Longwall 901, riverine water quality TARPs for pH, EC, DO, Total Fe and Total Mn be implemented for the adjacent Area 9 Nepean River monitoring sites NR0 and 2 based on the following principles:

1. Within Prediction Level 1 pH, EC, DO, Total Fe and Total Mn TARPs for sites NR0 and NR2 any surface water monitoring station should be based on greater than one and less than two standard deviations respectively below, above, below, above and above long term baseline mean levels for these effects monitoring sites.
2. Within Prediction Level 2 pH, DO, Total Fe and Total Mn TARPs for sites NR0 and NR2 should be based on a level greater than two standard deviations respectively below, above, below, above and above long term baseline mean levels for these effects monitoring sites.
3. Exceeding Prediction Level 2 pH, DO, Total Fe and Total Mn TARPs for sites NR0 and NR2 should be based on greater than two standard deviations respectively below, above, below, above and above long term baseline mean levels resulting from the mining which are sustained for more than 6 consecutive months.

A TARP at River site NR0 should only be considered to have been triggered whenever a two standard deviation change (from the long term mean) is not exhibited for the same parameter at the upstream site NR110.

A TARP at River site NR2 should only be considered to have been triggered when an equivalent change (from the long term mean) in excess of two standard deviations is not exhibited for the same water quality analyte at the upriver site SW3 (below the Allens Creek confluence.)

The TARPs described above and the appropriate triggered Actions which are proposed to be adopted for each level are listed in **Table 5.1** below.

It is also recommended that the water quality TARPs for pH, EC, DO, Total Fe and Total Mn as described above be applied to any detected site(s) of any significant, identified strata gas plumes greater than (say) 3000 L/min. Note these values will be refined by further field data collection as listed below and gas solubility modelling:

1. Detected gas emission flow rates should be estimated and then re-estimated whenever a significant increase is observed.
2. Detected gas emission of greater than 3000L/min should be sampled for chemical composition.
3. Samples for dissolved methane should be collected both exactly over any gas plumes and at the regular down river monitoring sites. Analysis should be made by a method with a limit of resolution (LOR) of no more than 1 µg/L.
4. Samples for total dissolved sulfide and total phenols in surface waters should be collected both exactly over the gas plume and at the closest down river monitoring sites. Analysis should be by sensitive methods which provide the lowest possible LOR.

Table 5.1 – Appin Area 9 Trigger Action Response Plan (TARP)

Monitoring	Trigger	Action
Surface Water		
- Baseline upriver sites for cross-checking for upriver perturbations impacting Area 9 monitoring sites: (1) New site NR110 - upstream perturbations (>2 stdev) (2) NR120 - upstream perturbations (>2 stdev) (3) SW3 – perturbations from Allens Creek (>2 stdev) - Impact monitoring sites adjacent longwall 901: (4) NR0 (5) SW2 (6) SW3 (7) NR2 (8) NR3 (Harris Creek)	***Within Prediction (Level 1)**** Impact monitoring sites: - pH reduction greater than 1 stdev but less than 2 stdev from pre-mining mean - DO reduction greater than 1 stdev but less than 2 stdev from pre-mining mean - Identification of strata gas plume of flow rate < 3000 L/min** **Current example values:** **NR0** - pH>6.85;<7.23 - DO>62.4%;<77.4% - EC>405 uS/cm;<515 uS/cm - Total Fe>0.424;<0.623mg/L - Total Mn>0.018;<0.024 mg/L **NR2** - pH>7.04;<7.49 - DO>54.0%;<72.8% - EC>456 uS/cm;<592 uS/cm - Total Fe>0.769;<1.176 mg/L - Total Mn>0.071;<0.105 mg/L **NR3 (Harris Creek)** - pH>7.00;<7.38 - DO>28.5%;<60.4% - EC>2007 uS/cm;<2655 uS/cm - Total Fe>1.269;<1.744mg/L - Total Mn>0.443;<0.718 mg/L **NR120 upstream normality checks** - pH>6.81;<7.37 - DO>46.1%;<63.7% - EC>509 uS/cm;<684 uS/cm - Total Fe>0.311;<0.424mg/L - Total Mn>0.047;<0.064 mg/L	- Continue monitoring program - Report other WQ-related impacts to key stakeholders - Summarise impacts and record
	Within Prediction (Level 2)* Impact monitoring sites: - pH reduction greater than 2 stdev from pre-mining mean - DO reduction greater than 2 stdev from pre-mining mean - EC, total Fe and total Mn increases greater than 2 stdev from pre-mining mean	- Actions as stated for Level 1 plus: - Review monitoring program - Notify relevant specialists (BHPBIC) and develop and implement remedial action if necessary *Strata Gas Emission Plume:* - Estimate gas emission flow rates. Re-estimate should significant change be observed - Take sample of plume for chemical composition - Take sample for dissolved methane from exactly above gas plume and at established downriver monitoring sites

Monitoring	Trigger	Action
	Current example values: **NR0** - pH<6.85 - DO<62.4% - EC>515 uS/cm - Total Fe>0.623mg/L - Total Mn>0.024 mg/L **NR2** - pH<7.04 - DO<54.0% - EC>592 uS/cm - Total Fe>1.176 mg/L - Total Mn>0.105 mg/L **NR3 (Harris Creek)** - pH<7.00 - DO<28.5% - EC>2655 uS/cm - Total Fe>1.744mg/L - Total Mn>0.718 mg/L **NR120 upstream normality checks** - pH<6.81 - DO<46.1% - EC>684 uS/cm - Total Fe>0.424mg/L - Total Mn>0.064 mg/L - Identification of strata gas plume of flow rate >3000 L/min**	- Take sample for dissolved sulfide and total phenols from exactly above gas plume and at nearest downriver monitoring site(s)
	Level 3 Impacts Impact monitoring sites: - Level 2-type reduction in water quality resulting from the mining observed for more than 6 consecutive months	- Actions as stated for Level 2 plus: - Immediately notify OEH, D&PI, NoW & DRE and any other relevant specialist. - Consultation with stakeholders. - Collect laboratory samples and analyse for: o pH, EC, Total Fe and Mn o Suite of Filterable metals. o Dissolved methane, sulfide and total phenols (if relevant). - Develop site management measures as soon as practically possible (pending stakeholder availability) and seek any approvals required to implement

5.2 MANAGEMENT AND MITIGATION

In the unlikely event that future water monitoring shows that there have been significant hydrologic or aquatic ecotoxic effects within the General Study Area or immediately downstream in Nepean River then management and mitigation measures may be required.

The estimated 'cut off' river flow rate above which any 'worst case' effects possibly induced by mining Longwalls 901 to 904 are considered to be comparable with effects deriving from natural variations in flow rate, water temperature, water quality, etc. in the river lies in the range of about 0 - 10 ML/day.

Where low DO concentration in the Nepean River can be attributable to mining induced gas emissions by this means, it is proposed that exceedance (i.e. falling below the DO level) of the Level 1 TARPs would result in a higher degree and frequency of monitoring and input from relevant stakeholders.

The triggering of the Level 2 TARPs, would result in the requirement for consultation regarding development and possible implementation of remedial action(s) in association with relevant stakeholders.

Internationally, remediation of persistent low riverine DO typically takes the form of air curtains, sometimes laid across the river bed or attached against the upstream sides of weirs.

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